Enhancing Mobility as a Service –
Sustainability, Willingness to Pay and Profitability Aspects

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Abstract

The mobility industry must be transformed to comply with demands concerning reduced emissions and a societal shift from ownership to access. This transformation is addressed by Mobility as a Service (MaaS), a concept consisting of a budget available for integrated mobility packages organised by the platform intermediary. Recently, however, researchers have begun to doubt its ability to transform the industry, as no existing service has yet achieved a breakthrough. Reasons are the missing evidence that MaaS is a sustainable transport alternative, the missing understanding of customer utility, and the missing proof of its economic viability. Therefore, the aim of this work is to find out how MaaS can be enhanced – in terms of its sustainability, customer-orientation and profitability.

Consequently, the first study presents a new multi-method approach that combines multi-criteria decision analysis with an interpretative structural model to identify conflicting sustainability criteria. It is used to analyse the sustainability impacts of public transportation and sharing services commonly used in MaaS with 12 sustainability criteria. The second study is based on a conjoint analysis with 1,165 respondents to examine user preferences and willingness to pay for e-scooters, bike and car sharing and on-demand e-shuttles in integrated offers to identify benefit segments. In the final study, data from 1,668 survey respondents and real market data are used for market simulations on profitability of MaaS ecosystems under different orchestrator settings – public and private.

The results show that public transport is the most sustainable alternative, and its deficits in travel speed could be compensated by car sharing, demonstrating the potential of MaaS as a mediation solution for sustainability. Three benefit segments are identified with conjoint analysis: frugal bicycle users, car users and generous multimodal flexibility users, all with different willingness to pay. Market simulations were able to demonstrate the superiority of a private over a public orchestrator, although losses were incurred in all situations. The reasons are losses in the individual service providers' operations and too differentiated target customers. To conclude, enhancing MaaS should be achieved by a thorough selection of service providers, according to their sustainability performance, by segment-specific MaaS packages as a low, medium and premium offer, and by expanding the value proposition beyond mobility to generate additional value.

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List of Abbreviations

GAIA	Graphical Analysis for Interactive Aid
GHG	Greenhouse gas
ISM	Interpretive Structural Modelling
ISM-P	Interpretive Structural Modelling with Polarity
MaaS	Mobility as a Service
MCDA	Multi-criteria Decision Analysis
MICMAC	Matriced' Impacts Croise's Multiplication Appliquee a UN Classement
PAYG	Pay-as-you-go
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
RO	Research Objective
RQ	Research Question
GAIA	Willingness to Pay

Chapter A: Introduction

1. Motivation

Five major trends affect all industrial sectors, concerning ecology, policy, technology, society, and economy (Schikofsky et al., 2020; Sousa and Castañeda-Ayarza, 2022). These trends, which will be elaborated in the following, especially affect the automotive and mobility industry in recent times. For this industry, Mobility as a Service (MaaS) is promised to be a response for dealing with the effects of these trends (Smith et al., 2023).

The MaaS concept consists of a certain amount of money (budget) that is available for differently composed mobility packages (bundles) and of platform intermediaries (brokers) that organise the MaaS offer (Arias-Molinares et al., 2023; Hensher, 2017). MaaS is customer-oriented, technology-specific, and provides organisational and policy novelties such as the integration of transportation modes (Jittrapirom et al., 2017). Apart from the integration, the customer orientation, and the platform it is based on collaborative consumption as a societal phenomenon that is important for MaaS offers (Jovic and Baron, 2019). It is hence known as the Netflix of transportation (Ho, 2022).

The first trend is the ecological requirements: MaaS is a concept that is often mentioned in the context of sustainable mobility, especially in terms of its environmental benefits (European Commission, 2019a). Although omnipresent nowadays, it is not clear what the sustainability paradigm means (Kraus and Proff, 2021). Its origin dates back to the eighteenth century and originally meant not endangering the livelihood of future generations (Carlowitz, 1713). The first warnings that this could happen became evident over 50 years ago when the Club of Rome published the results of scenario simulations that showed that resource consumption would lead to a decline in industrial capacity as well as a continuing population decline if levels remained constant (Meadows et al., 1972). This report can be seen as a starting point for sustainability research as known today. In this context, Rockström et al. (2009) defined the planetary boundaries of growth and explicitly showed that the limit imposed by climate change has already been exceeded due to high energy consumption. It is widely accepted that humanity must drastically reduce its greenhouse gas (GHG) emissions by 2030 to keep global warming below two degrees Celsius (IPCC, 2023). As demonstrated, sustainability in a narrow sense is frequently equated with environmental protection in public debates.

Since limiting climate change can only be reached through global efforts, it is policy as a second trend that needs to react and provide a framework for society and industry to reach a sustainability shift. This is vital for MaaS since the EU transport law has been failing to secure passengers' rights and liability issues between all participating institutions (Murati, 2020). In addition, although technologically feasible (Handte et al., 2021), data analysis of mobility patterns to improve the MaaS offer is difficult from a policy perspective. This is mainly due to data protection laws. Hence, only early adopters in the technological industry could advance in data analysis so far (Fina et al., 2021). To design policies promoting sustainability, governments from around the world have reached historic agreements: first within the framework of the Brundtland Commission in 1987 (United Nations, 1987). This was followed by several international efforts to put sustainability on the political agenda. One example is the 1992 Earth Summit, which set out a blueprint for international environmental action (United Nations, 1992). Other key policies are the definition of Sustainable Development Goals and the Paris Agreement, in which nations declared a goal to keep global warming well below two degrees Celsius (United Nations, 2015). This was followed in 2019 by the European Green Deal, which describes binding targets to make the European Union carbon-neutral by 2050 (European Commission, 2019b). Targets were set for all industrial sectors to reduce GHG emissions, but the actions in the transport sector are essential to comply with the guidelines to limit global warming in Germany and the European Union. This sector accounts for a quarter of all GHG emissions in the European Union. The Green Deal sets the target of reducing these emissions by 55% by 2030 (European Union, 2020). In Germany, however, emissions in this critical sector continue to rise, requiring programmes to meet climate targets under the German Climate Action Law (Deutsche Welle, 2022). Car dependence is the main source of emissions in the sector, accounting for 11% of total GHG emissions in the European Union (European Commission, 2019c).

Another trend is technology, which is sometimes even seen as a complementary sustainability pillar (in a wider sense) (Liang et al., 2019). It is a driver for MaaS because this is based on platform technology to integrate a variety of mobility services (Jovic and Baron, 2019). Information and communication technologies have enabled digitalisation (Sommer et al., 2021). Digitalisation, in turn, is a driver for discontinuous changes in the automotive industry (Sommer and Proff, 2023). In this context, four major technological developments can be observed: Connectivity (and digitalisation), autonomous driving, shared services for flexible use, and electromobility, all of which aim to create a holistic mobility offer (Adler et al., 2019; Covarrubias, 2018). The so-called CASE technologies are expected to achieve market breakthrough by 2040 (Adler et al., 2019). They are thought to have the potential to disrupt the automotive and mobility industry as it has been known to date (Adler et al., 2019; Kraus and Proff, 2023a). Research is also emerging on the bundling or integration of the technologies (Habib and Lynn, 2020). Such integration is enabled by digital platform technology (Jovic and Baron, 2019). In the digital age, the rise of platform firms is emblematic across all sectors (Gawer, 2022). This has led to increased competition from new digital market entrants (Proff, 2019; Stopka, 2020). Platform-based business models have changed the competitive landscape around the world (Kumar et al., 2021). They contribute to the servitisation of the economy by enabling interaction-based customer solutions (Proff, 2019). The impact of this transformation on traditional automotive companies is still unclear but different paths are possible: In one scenario, platform firms become increasingly important because users interact with the vehicle primarily through them. For example, if ride sharing becomes the most used mobility solution, fewer vehicles need to be produced (Adner and Lieberman, 2021). In any case, resource reallocation of traditional car manufacturers is necessary to compete with new market entrants that are platform-based businesses taking advantage of CASE technologies. Disruptive technology thus affects both traditional firms and new market entrants (Covarrubias, 2018) and facilitates the creation of data-based business models (Sommer and Proff, 2023).

The shift towards more customer-centric solutions in businesses is accompanied by a disruptive societal phenomenon as a fourth trend driven by growing ecological and social concerns (Jovic and Baron, 2019). A shift from owning to merely using products, the so-called sharing economy, has been on the rise over the last decade (Eckhardt et al., 2019). In this regard, it is also often mentioned in terms of sustainability in a wider sense (Curtis and Lehner, 2019). The sharing economy is another crucial driver for MaaS because it implies a shift from car ownership to the usage of mobility options (Proff, 2019). Shared consumption involves used products, gifting, swapping, borrowing, or renting in consumer networks (Roos and Hahn, 2017). This socioeconomic system enabled by technology is expressed in many cases by firms such as Airbnb or eBay (Eckhardt et al., 2019). This new form of economy is changing business principles just as society (Rifkin, 2015). It is especially true for the "Generation Young", people between 18 and 25 years of age, where there is generally decreasing importance of status symbols and a higher acceptance of new technologies (Elder, 1994; Hunecke et al., 2020; Proff, 2019). As a result, adoption rates vary across society, but a paradigm shift from ownership to access is seen as the future norm. This trend goes along with collaborative consumption, as both phenomena are based on temporary access to services and products that are not owned as well as their dependence on the internet (Belk, 2014). Traditional sectors such as tourism, finance, and the food industry are already being disrupted by the sharing economy. The success of the sharing economy is determined by the design of the platforms: they need a transparent interface, control mechanisms for access to shared content, and a segment-specific offer (Akbari et al., 2022). Such offerings are of special importance as they often provide an economic advantage over purchasing products (Jovic, 2022). The sharing economy is increasingly present in the mobility industry, especially through app-based services such as ride hailing like Uber and ride pooling such as BlaBlaCar (Akbari et al., 2022). However, as mentioned earlier, acceptance is segment-specific and changing mobility behaviour is a difficult task for which there is little empirical evidence to date (Rahman, 2023). This is mainly due to the fact that the choice of mobility is a habitualised practice, i.e., individuals automatically choose a transportation mode mainly based on previous experience (Leontaris et al., 2024). Interventions are needed to incentivise an attitude switch (Rahman, 2023).

The economic advantage is becoming increasingly important given recent developments in the global economy. The economy as the fifth trend can hence be seen as a driver for MaaS since MaaS platforms usually show mobility options from which, e.g., the least costly ones can be selected (Kamargianni and Matyas, 2017). The economy has incurred the largest crisis in over a hundred years due to the COVID-19 pandemic (The World Bank, 2022). Moreover, economic growth is being outpaced by the war in Ukraine on a global scale, and inflation is rising faster (Kammer et al., 2022). In particular, energy prices have been affected globally by the war. Due to fossil fuel dependence and the associated rising transportation costs, supply chain costs for a variety of consumer goods have also increased. Because of economic developments, the cost of mobility, especially fuel, has risen (Hubacek et al., 2023). Furthermore, sustainable mobility solutions as alternatives to private cars are not yet affordable (Alyavina et al., 2020). Hence, supply-side profitability is more important than ever. In summary, the current economic pressure on households is a possible driver for the sharing economy, which is mainly enabled by digitalisation and platform technology and is discussed as a more ecological form of consumption, as required by climate legislation.

The described megatrends in ecology, policy, technology, society, and economy are of critical importance for the automotive and mobility industry for several reasons. These megatrends require a mobility shift that is desired by customers. Car manufacturers must subsequently also participate in the shift to be able to compete with digital market entrants. MaaS is discussed in terms of all five megatrends in transportation and mobility (Kostiainen and Tuominen, 2019). Figure A-1 condenses the influence of these trends on the automotive and mobility industry and the possible solution of MaaS. Flashes imply conflicts, particularly in policy, between compliance with sustainable mobility regulations and data protection laws. In society, the shift to sharing is hindered by habitualised, i.e. automated, mobility behaviour. In the economy, sustainable mobility solutions are not yet profitable, although they are necessary to thrive.

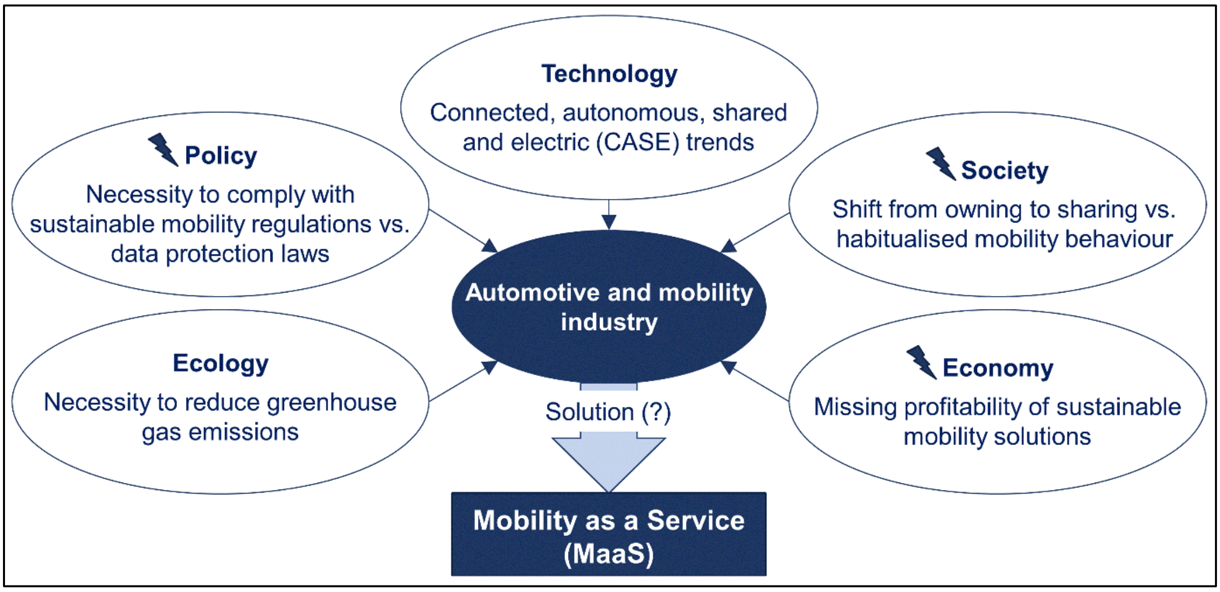


Figure A-1: Megatrends in ecology, policy, technology, society, and economy affecting the automotive and mobility industry (own elaboration)

2. Research questions and objectives

MaaS aims to propose added value to all stakeholders, which are the firms, the users, and the policy-makers. The participating firms are promised increased profits (Ho, 2022). Users are offered the proposition of the convenience of integrated user-centric mobility as an alternative to a private car (Maas, 2021). Policy-makers are promised an effective tool for a shift towards the desired sustainable mobility (Schikofsky et al., 2020).

However, recently, researchers have started questioning whether MaaS can deliver the proposed value (see e.g. Hensher and Hietanen, 2023; Ho, 2022; Jittrapirom et al., 2020; Orozco-Fontalvo and Moura, 2023; Smith and Hensher, 2020) and whether it has the potential to scale (Alyavina et al., 2020; Hensher et al., 2020; Lyons et al., 2019). So far, no breakthrough has been achieved by existing MaaS offers (Smith and Hensher, 2020). There are three areas that need to be addressed to enhance MaaS: analysing its sustainability (in a broad sense), a better understanding of the (potential) customers, and increasing its profitability.

First, whether MaaS is truly a sustainable alternative to private car use, as claimed in previous research (see e.g. Alyavina et al., 2020; Kamargianni and Matyas, 2017; Strömberg et al., 2018), is highly dependent on the mobility services integrated into the system (Smith et al., 2023; Utriainen and Pöllänen, 2018). So far, the high expectations announced praising MaaS as a revolution of the transportation system as a whole could not be reached (Smith et al., 2023). In order not to use the term “sustainable” in the context of MaaS as just another buzzword (Hensher et al., 2020), the literature suggests that the orchestrator (i.e. the MaaS integrator or broker, e.g. a public authority) selects and promotes more sustainable partners for bundling (Reck et al., 2020). Otherwise, MaaS might even promote unsustainable travel because car sharing services might be preferred due to higher profit derived from it compared to public transportation and subsequent modal shift from sustainable alternatives towards car usage (Krauss et al., 2022; Lyons et al., 2019).

This highlights the importance of objectively analysing different mobility service providers and their transportation services regarding their sustainability in a wider sense. Consequently, it can be decided whether it is desirable to include them in a MaaS bundle for a given region. Since the services offered and their quality depend heavily on regional (built) factors (Otsuka et al., 2021), for the sustainability assessment a specific region and its service offers must be chosen. For this study, the German Ruhr area was selected because of its relevance for transportation research due to its polycentric structure, the associated dispersed workplaces inducing commuting, and its large number of mobility services offered (see e.g. Adolphi et al., 2023; Goetz, 2018; Reggiani et al., 2011). The first research question (RQ1) is therefore formulated as follows:

RQ1: Which is the most sustainable transportation service in the Ruhr area?

However, sustainability itself is a vague and complex multi-criteria decision problem. Although many researchers agree on the tripartite division into economic, social, and environmental dimensions (sustainability in a wider sense; see e.g. Carter and Rogers, 2008; Sdoukopoulos et al., 2019), it is unclear how to measure the outcomes of each dimension (Kraus and Proff, 2021). The difficulty of measuring sustainability arises from three main issues:

1. Sustainability is a complex problem consisting of interrelated elements at different hierarchical levels (Kraus and Proff, 2021; Litman, 2021).
2. The elements or goals of sustainability are often contradictory which has not been considered in sustainability assessments so far (Haffar and Searcy, 2019; Nilsson et al., 2016).
3. Sustainability is not measured by a universally accepted solution, but by a plethora of multi-criteria decision analysis (MCDA) methods, none of which includes an objective weighting method (see e.g. Colapinto et al., 2019; Saaty, 2012; Vincke, 1986; Wallenius et al., 2008).

Therefore, an improved sustainability assessment is needed that allows for a comprehensive and transparent assessment of the sustainability performance of different transportation service providers in the Ruhr area. A comprehensive set of evaluation criteria for the MaaS offer is essential as a basis (Orozco-Fontalvo and Moura, 2023). Although sustainability and sustainable transportation are assessed in the literature using MCDA (see for instance Awasthi et al., 2018; Bandeira et al., 2018; Bojković et al., 2010), two research gaps exist in the methods concerning (1) the appropriate objective weighting of sustainability criteria (Cascetta, 2009; Cinelli et al., 2022; Nijkamp et al., 1990; Turcksin et al., 2011) and (2) the explicit inclusion of criteria conflicts in the decision-making process (Aarseth et al., 2017; van der Byl and Slawinski, 2015). These research gaps are considered when addressing the first research objective (RO1):

RO1: to evaluate mobility service providers according to their sustainability impact.

Second, it is important that users accept and choose the sustainable offers provided (Eckhardt et al., 2016; Sochor et al., 2018). So far, existing MaaS offers have not helped much in changing customer behaviour (Hensher and Hietanen, 2023). The choice process depends on various latent and manifest variables. In transportation, the proportion of money spent on mobility out of the total money available, i.e., affordability, is important. This has a direct impact on price sensitivity and demand elasticity (Pesendorfer et al., 2023). Price, in particular, is important in the purchase decision process for the customer due to its signalling function (Roy et al., 2016), but also for firms, as price determines profitability to a large extent (Ramirez and Goldsmith, 2009). An important research stream regarding the individual choice process assumes that a customer's willingness to pay (WTP), i.e. the maximum price the customer is inclined to pay in exchange for a certain good or service, depends directly on the utility, i.e. the value the customers derives from the characteristics of the good or service (Bowman and Ambrosini, 2000). This is corroborated by various algorithms that have been developed so far to describe utility as accurately as possible (Backhaus et al., 2016). Furthermore, the offer should be tailored to the customer's needs in order to increase utility, which is also one objective of MaaS. Since utility is highly individual, a personalised offer meets the varying customer needs best (Bornstedt, 2007; Krauss et al., 2022). Price discrimination is an important tool to apply to different customer segments (Rietveld and Schilling, 2021). The aim is to find segments that are as homogeneous as possible while also being heterogeneous concerning the other segments (DeSarbo et al., 2001).

The specific service characteristics from which utility is derived are jointly evaluated by an individual. In MaaS, these characteristics which are translated into WTP depend on the package composition consisting of the different mobility services and the extent to which a budget includes them (Jovic, 2022; Stopka, 2020). Multiple combinatorial options are possible, which quickly increase complexity and transaction costs (Polydoropoulou et al., 2020a). In line with the integration aspect of MaaS, to increase the overall WTP for a MaaS offering, it is important to find MaaS package compositions (or bundles) that are most attractive to customer segments and that reduce the number of combinatorial options to a feasible size.

Therefore, customers should be preselected for MaaS and transportation in general, which is a growing area of research (Nash and Mitra, 2019). Still only little is known about MaaS users and their motivation (Smith et al., 2023). University students represent a promising customer group because universities serve as places for experimentation of sustainable mobility options (Nelson et al., 2023). In general, university students have higher adoption rates for sustainable transportation modes and new mobility services compared to the general average (Zhou, 2012), and there is still potential to improve the sustainability of their mobility practices (Daisy et al., 2018; Hafezi et al., 2019). However, there is insufficient knowledge about university students as MaaS users and their preferences: Only one study has explicitly addressed MaaS for university students (Gandia et al., 2021a), but without focussing on customer segments and WTP. Therefore, the project InnaMoRuhr (integrated and sustainable mobility concept for the University Alliance Ruhr) is used as an example to analyse the mobility behaviour of students (and employees additionally) of three universities in the German Ruhr area and measures to change it (Handte et al., 2022, 2023). Consequently, RQ2 is formulated as follows:

RQ2: How should MaaS offers be designed for university students?

Yet, university students are not a homogeneous segment by themselves (Groth et al., 2021). In addition, young people generally have a smaller budget available (Günthner et al., 2021). This corroborates the need for a customer-centric approach to determine the maximum WTP for different segments of university students. This is considered in the formulation of RO2:

RO2: to develop a MaaS offer appealing to promising customer segments.

Third, to provide a persistent MaaS offer, the operation needs to be profitable, which is not yet the case for any of the existing MaaS offers (Hensher et al., 2020, 2023). One reason is the insufficient customer orientation of the offer (Ho, 2022). Another reason is the inclusion of transportation services, which are not economically viable (Krauss et al., 2022). Hence, the absence of a clear business case is also evident in several mobility services, as evidenced by the high market volatility, e.g. in e-scooter sharing (Carey and Cohn, 2021) or the fact that the largest ride hailing operator Uber has only recently started to generate profits (Nachiappan, 2023). However, the market for MaaS is expected to grow considerably over the next few years (Deloitte, 2021). The problem with such predictions is that the definition of MaaS is used by analysts as a vague concept with different partners included. In terms of business performance, a concept gaining importance is how partner networks simultaneously cooperate and compete to generate overarching value, so-called ecosystems (Dattée et al., 2018). MaaS is also frequently referred to as an ecosystem, although the definition is fuzzy (Hensher et al., 2023; Hietanen, 2014; Kamargianni and Matyas, 2017). Consequently, the inherent set of actors, i.e., the boundary between ecosystem actors and mere suppliers or second-order stakeholders, is not defined. Without a clear distinction between ecosystem actors and other stakeholders, it is not possible to define the value elements (regarding value outflow and inflow) necessary to estimate the potential value generated within the ecosystem. This depends on the value streams in the MaaS ecosystem and the value elements that are part of these streams (Lewrick et al., 2018; Polydoropoulou et al., 2020b).

The central role in any ecosystem is that of the platform orchestrator (Teece, 2019). This role is responsible for coordinating activities and providing resources and infrastructure (Lingens et al., 2021). It is the key decision-maker: the orchestrator sets the framework, rules, and principles for growth and is responsible for governance mechanisms (Lewrick, 2022). To increase the attractiveness of participation, the orchestrator must ensure that all partners benefit and appropriate value (Lang et al., 2020). One peculiarity of MaaS compared to other ecosystems is that the service providers are both private companies and public institutions (operating and/or regulating public transportation). Subsequently, it is discussed whether the orchestrator should be public or private (see e.g. Hensher et al., 2023; König et al., 2016; Mukhtar-Landgren and Smith, 2019). However, this discussion does not yet include a numerical comparison of the ecosystem outcomes with public versus private orchestrators, so the type of joint value created in the differently orchestrated MaaS ecosystems remains unclear (Liljamo et al., 2020). This elicits RQ3:

RQ3: How does the joint value created differ in private MaaS ecosystems from a public MaaS ecosystem?

By answering RQ3, a contribution is aimed at the topic that is most discussed in MaaS (see e.g. Karlsson et al., 2020; Liljamo et al., 2020) but hast the least evidence:

RO3: to discover how the MaaS ecosystem can be offered profitably.

Figure A-2 shows the three RQs and subsequent ROs derived from the status quo regarding sustainability, customer centricity, and supply-side profitability. A profound examination of the right composition of an offer that is also economically viable and scalable is necessary.

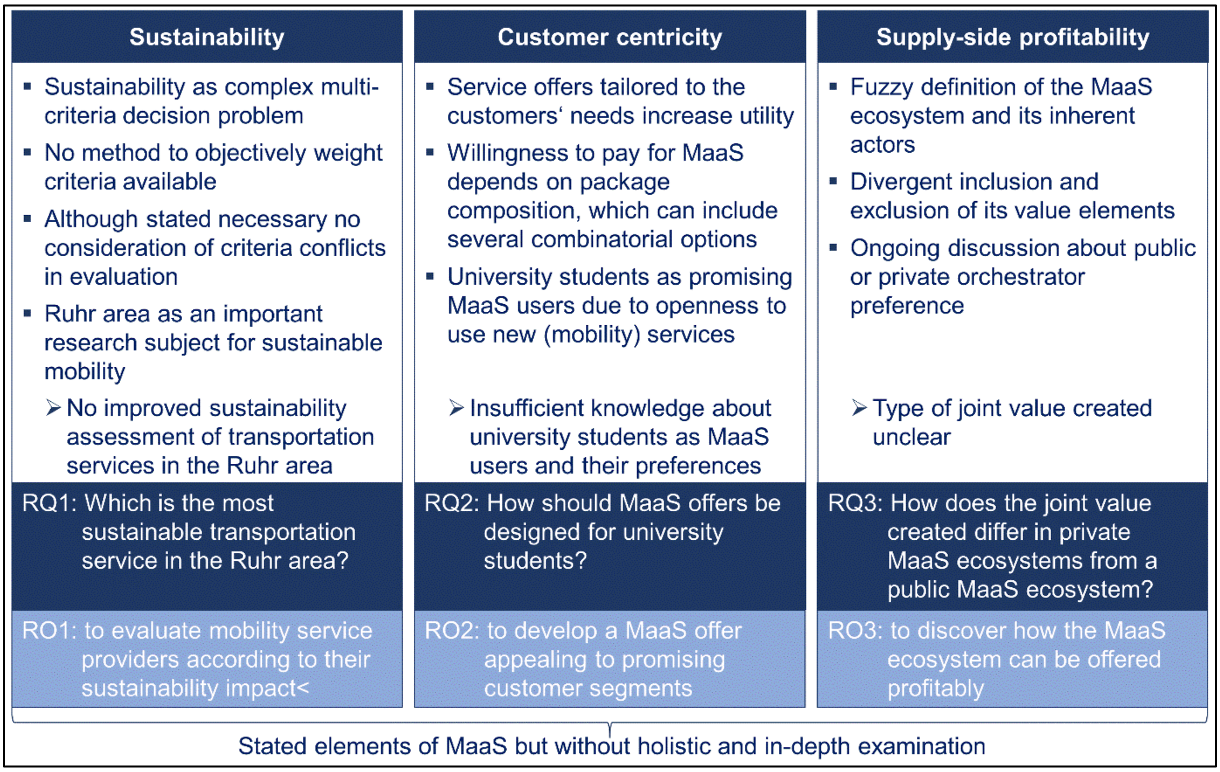


Figure A-2: Research questions and objectives concerning sustainability, customer centricity, and supply-side profitability (own elaboration)

3. Theoretical background

To provide a solid research foundation for the course of this work, it is important to provide explanations for the three themes of MaaS – sustainability, customer centricity, and supply-side profitability – and the links between them.

3.1. Sustainability

Sustainability is often treated as a decision problem to quantify the sustainability outcome of a particular course of action or object (Bogetoft and Pruzan, 1997; Macharis et al., 2008; Nechi et al., 2019). A decision problem is characterised by a decision-maker, two or more alternatives, decision variables, multiple criteria, the decision field, and limiting factors (French, 1995). It can be either static or dynamic (Götze, 2014). The corresponding decision theory is defined as the empirical analysis of rational decision behaviour (Bamberg et al., 2012). Rationality is the premise, i.e. the decision-maker wants to maximise goal fulfilment (Dinkelbach and Kleine, 1996). However, it is acknowledged that rationality is bounded (Raiffa, 1994). Therefore, the goal is to help decision-makers with bounded rationality to make the right choices through formal models (Bell et al., 1988).

Three theoretical streams can be distinguished: descriptive, prescriptive, and normative decision theory. The first analyses empirically why decision-makers reach certain conclusions for different classes of decisions based on behavioural decision theory (Morton and Fasolo, 2009). Prescriptive decision theory uses normative models and applies them to real-world decision problems to aid the decision-maker. It argues how decisions should be made rationally and provides aid for specific cases in practice based on normative theory (Dyer and Smith, 2020). Normative theory builds on the theory of rational choice and can be applied to all decisions by theoretical thinkers (see e.g. Neumann and Morgenstern, 2007; Savage, 1972). Some authors see descriptive and normative decision theory as the basis for prescriptive decision theory (Smith and Winterfeldt, 2004). Other authors debate whether normative and prescriptive decision theories are the same (Bell et al., 1988). A proposed distinction between normative, prescriptive, and descriptive decision theory is provided in Table A-1.

Table A-1: Distinction between descriptive, normative, and descriptive decision theory (own elaboration based on Keeney, 1992)

Theories	**Criterion**	**Problem focus**			**Judges of theories**
		All decisions	**Classes of decisions**	**Specific decisions**	
Descriptive	Empirical validity		x		Experimental researchers
Normative	Correctness	x			Theoretical thinkers
Prescriptive	Usefulness			x	Applied analysts

Since the most important part of management science is to support the decision-making process by systematising and formulating decision rules (Wallenius et al., 2008), prescriptive decision theory is of high relevance. For this theory, axioms, i.e. logical rules, have been formulated that are theoretically feasible and to which solutions must adhere. An important axiom is the transitivity axiom: For each pair of results x_i and x_j, the decision-maker must be able to choose between $x_i > x_j$ (preference of x_i), $x_i < x_j$ (preference of x_j) or $x_i \sim x_j$ (indifference). Transitivity means that for three results x_i, x_j and x_k, the following applies (Bell et al., 1988):

if $x_i > x_j$ and $x_j \sim x_k, then$ $x_i > x_k$,

if $x_i > x_j$ and $x_j > x_k, then$ $x_i > x_k$ and

if $x_i \sim x_j$ and $x_j \sim x_k, then$ $x_i \sim x_k$.

Other axioms are (Keeney, 1982):

- specification of two or more alternatives,
- identification of the possible consequences for each alternative,
- quantification of the probability for each consequence,
- quantification of the relative desirability for each consequence,
- comparability of alternatives with equal probability but different desirability of consequence, and
- substitution of alternatives with indifferent consequences leading to indifferent alternatives.

Prescriptive decision theory thus helps decision-makers to objectively choose certain actions or objects by evaluating their outcomes regarding the sustainability paradigm. It bears in mind that the decision-maker is not a fully rational individual (Bell et al., 1988).

3.2. Customer centricity

Continuing with explanations for customer centricity, two factors are important: explaining why customers choose certain products and services (internal view) and explaining how firms generate superior value when they explicitly involve the customer in the value creation process (external view).

As far as the **internal view** is concerned, the best-known explanation for individual customer choices is choice theory. Discrete choice theory assumes that there is a single utility function that varies from customer to customer (Ben-Akiva and Lerman, 1985). This theory stems from economic consumer theory, which explains alterations in individual behaviour and its modelling by transforming assumptions about needs into demand functions (Ben-Akiva and Lerman, 1985; McFadden, 2001). The theory of rational choice serves to model the consumer as a black box, mapping a flow from input to output.

The underlying hypothesis borrows information from utility theory: it assumes that customers are rational, i.e., they always choose the offer among alternatives that maximises utility, an index of attractiveness (Ben-Akiva and Lerman, 1985; McFadden, 1986). This index consists of objects from which customers derive their utility, i.e. product attributes (Lancaster, 1966). Therefore, consumer economics posits that consumers perceive products or services as bundles of characteristics and that the purchase decision for the preferred bundle is made depending on its price and the consumers' income (Fishburn, 1968). Information integration theory from psychology also states that customers perceive products or services as attributes composed of various separate stimuli, for which an integration process of overall utility is assessed (Anderson, 1981). The aim is to demonstrate how information processing works in reality (Perrey, 1998).

Nonetheless, research has found that individual perceptions and attitudes are unstable, leading to the likelihood of random components in preferences and the emergence of random utility theory (McFadden, 1986). This theoretic branch originates from psychology (Thurstone, 1927) and states that the modeller should consider utility as a random variable, maintaining the assumption that the choices made by customers are utility-maximising (Ben-Akiva and Lerman, 1985). Thus, it is a probabilistic choice theory that includes random errors resulting from (Manski, 1973, 1977):

- missing product information,
- flawed instrumental variables,
- measurement error,
- imperfect information,
- observational flaws related to taste variations, and
- missing attributes by the modeller.

Random errors help in modelling the deviation of the actual choice from the predicted one (Ben-Akiva and Lerman, 1985). Random utility theory is widely used because it incorporates heterogeneous unobserved characteristics as mechanisms for forming perception and taste (McFadden, 2001).

Choice theory, as defined by McFadden (1986), extends the random utility by not only assuming investigation errors as an explanation of derivation from predicted and actual choice behaviour but also actively incorporating psychological factors that explain why utility derived directly from product attributes is not the only factor explaining choice (Louviere et al., 2007). This way, the contemporary view can better explain the heterogeneity of customer choice (McFadden, 2001; Vij and Krueger, 2017). It shows that attitudes influence perceptions and hence utility maximization is one of many variables involved in decision-making. Attribute perceptions, such as mental accounting for cost and time, are important but less studied (McFadden, 2001). Product preferences, behavioural intentions, and decision protocols, as well as previous decisions, beliefs, perceptions, and taste, are psychological determinants of choice (McFadden, 1986, 2001). Therefore, the choice process is highly individual and the value perceived by each customer must be measured individually, according to subjective value theory (Heinrich, 2020).

Regarding the **external view**, the service-dominant logic is a commonly used explanation to provide insight into value creation through customer centricity. This logic explains how utility depends on context as the central object is value and its definition. This distinguished this logic from the traditional goods-dominant logic. Table A-2 systematises the differences in terms of the exchange unit, the role of goods and customers, the firm-customer interaction, and the determination and meaning of value. In the goods-dominant logic, people exchange for goods, which are adapted by marketers. The customer receives the goods and is addressed by the marketer to create transactions. The value of the goods is determined by the firm. The service-dominant logic uses a product as an intermediary to create value together with the customer, who defines the value. The customer is seen as an operant resource participating in the value creation process, contrary to the goods-dominant logic in which the customer is only addressed to buy a product already determined by the producer (as an operand resource).

Table A-2: Distinction between the goods- and the service-dominant logic based on operant and operand resources (own elaboration based on Vargo and Lusch, 2004a)

	Goods-dominant logic	Service-dominant logic
Exchange unit	People exchange for goods that serve primarily as operand resources	People exchange to acquire benefits of services or competences as operant resources
Role of goods	Goods as operand resources from which marketers take matter and transform it	Goods as transmitters of operant resources as intermediate products used by other operant resources (customers) in the value-creation process
Role of customers	Recipients of goods and operand resources to which marketers work on	Co-creators of services and operant resources interacting with marketers
Firm-customer interaction	Customers are acted on to create transactions with the resources, i.e. they are operand resources	Customers as interactive participants in cocreation and relational exchange, i.e. they are operant resources
Meaning and determination of value	Determination by the producer and definition as value-in-exchange	Determination by the customers and definition as value-in-use

The service-dominant logic considers five elements, which are described in more depth (Vargo and Lusch, 2016). First, according to this logic, the **exchange base** is **service**, as described in Table A-2. Second, this approach builds on **co-creation** together with the customer as an operant resource, i.e., a resource that can act on other resources through reciprocal service exchange (Lusch et al., 2007). Consequently, all involved parties, including the customer, are both value creators and value beneficiaries (Lusch and Vargo, 2006). Third, it explains the importance of service **integration** as part of the value proposition (Proff and Szybisty, 2018; Sawhney et al., 2006). Since customer value depends on the specific resource combination for a given service, standardised components are combined in a modular system for individual requirements to increase customer value (Davies et al., 2007; Vargo and Lusch, 2013). Subsequently, individualisation is another aspect of the value proposition, as customers' utility for a particular service varies through heterogeneous offers, pricing, and demand-responsive customised services (Danneels, 2003; DeSarbo et al., 2001; Vargo and Lusch, 2004b, 2016). Fourth, it states that the value can only be determined by the customer as **value-in-use**, depending on the customer's perceived value proposed by a firm (Vargo and Lusch, 2004a). Hence, firms can only make a value proposition to the customers (Lusch et al., 2007). The logic thus posits that value-in-exchange (revenue) can only be created if there is value-in-use (utility), and that value is determined by the customer, expressed as individual WTP (Grönroos, 2008). More effective pricing depends on how customers perceive value, helping firms generate economic rents (Dutta et al., 2003; Lusch et al., 2007). Subsequently, the value proposition is the promise of a link between value-in-exchange and value-in-use (Lusch et al., 2007). It cannot be defined objectively, as every customer evaluates certain offers differently. Therefore, **individualisation** is another important element of the value proposition (Vargo and Lusch, 2004a). Fifth, institutional arrangements assist in the **coordination** of the value cocreation process. This element is the last one added and acknowledges the fact that the resource integration process requires multiple parties, whose cooperation requires a coordinating institution (Vargo and Lusch, 2016).

Hence, the integration and individualisation value of MaaS as stated in Section A.2 can be explained through the service-dominant logic. The choice theory explains how individual utility determines transportation mode choices. Both explanations help in identifying utility-maximising aspects of MaaS packages.

3.3. Supply-side profitability

As for supply-side profitability, explanations are needed for value creation among several firms in ecosystems. The term ecosystem is relatively new: It is defined as a novel form of partnership network, in which firms collaborate and adapt their value streams to provide an overarching value proposition (Leclercq et al., 2016). Given the novelty of this research, there is no so-called ecosystem theory yet.

However, as ecosystem partners both cooperate to create joint value and compete to appropriate a reasonable share of it, game theory with a focus on hybrid games plays an important role in explaining value generation in ecosystems. In particular, biform games, which include non-cooperative games, serve as a basis (Brandenburger and Stuart, 1996, 2007). Based on the non-cooperative component, firms independently bring activities into value creation. They determine their strategic moves to increase their share of the total value. In the cooperative phase of the game, which models the emerging competitive environment and especially the total value created by all participants, firms negotiate the distribution of the value generated (Brandenburger and Stuart, 2007). In this two-stage game, the strategies to capture value for the firm itself (first phase) form the responses of the participants and hence the competitive environment (second phase). This in turn shapes the fortune of the individual firm, i.e., the value to be appropriated.

The amount of value appropriated by one firm is limited by the customers' WTP and the minimum amount a supplier will accept for the resources, i.e. the opportunity cost (Lusch et al., 2007; Tower et al., 2021). The value created in a vertical chain is distributed as follows: The supplier's share is the difference between cost and opportunity cost, the buyer's share is the value difference between WTP and price, and the firm's share is price minus the cost (Brandenburger and Stuart, 1996). In contrast to a vertical chain, superior value is created in an ecosystem. Firms need to change the perspective from an internal to an external one (Parker et al., 2016) Thus, added value is created through the integration of external competences by the firms (Hannah and Eisenhardt, 2018; Normann and Ramírez, 1993).

Further platform effects drive value in ecosystems: Economies of scope are achieved, i.e. the joint value proposition of all firms creates more value than the sum of individual value created through task sharing and transfer of competences (Dyer et al., 2018; Gawer, 2014) and through the co-creation with customers (Jacobides et al., 2018; Vargo and Lusch, 2004a). Network effects lead to economies of scale through scaling without additional costs (Rietveld and Schilling, 2021). Modularisation reinforces this by reducing transaction costs through standardised interfaces (Chen et al., 2022). Otherwise, increasing the number of partners in an ecosystem increases complexity and value destruction is likely to occur (Chen et al., 2022; Cusumano et al., 2019).

Figure A-3 illustrates the increased value created in an ecosystem with the orchestrator, a buyer, and one ecosystem partner compared to a vertical chain with the firm, the buyer, and the supplier. To simplify the figure, although an ecosystem consists of multilateral partnerships, only one ecosystem partner is included. Explanations for ecosystems and the joint value created in them serve to select value elements necessary to calculate the value generated in a MaaS ecosystem. This is also important to uniformly define who is an ecosystem partner and who is not, as stated in Section A.2.

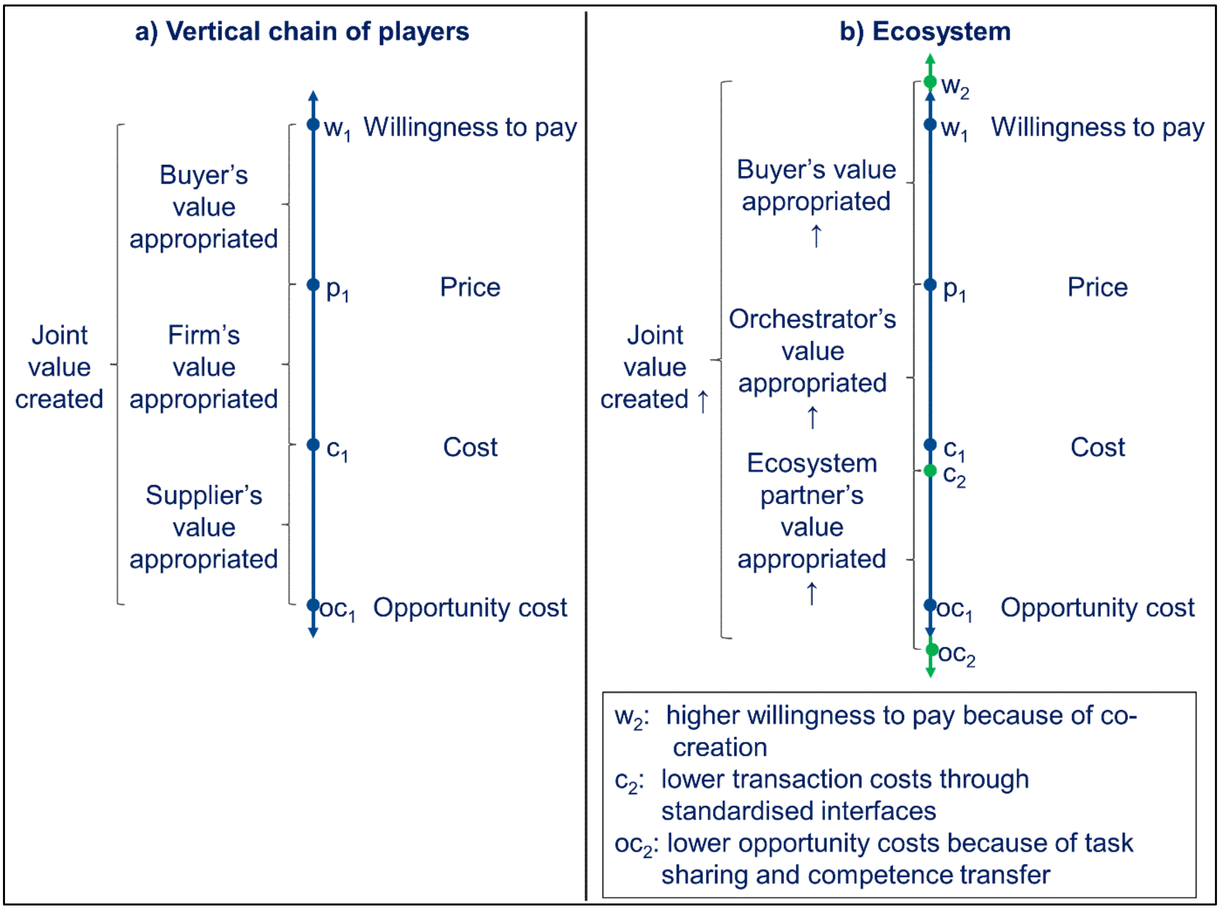


Figure A-3: Static comparison of value creation and value generation between a) a vertical chain of players and b) an ecosystem (own elaboration based on Brandenburger and Stuart, 1996)

3.4. Interaction of the explanations

Although each theory is different in its scope and content, the results of each theory are connected. First, prescriptive decision theory explains the importance of considering multiple criteria for sustainability, which is important for the selection of mobility offers that should be integrated into MaaS. Prescriptive decision theory is the most comprehensive of theories presented in this section. It forms the basis for various management research disciplines, as economic actions are characterised by choices between alternatives and is hence relevant for the macro-level (Stelling, 2009). Furthermore, it addresses decision-makers in general and helps them to make utility-maximising decisions considering their bounded rationality. It has a clear link to choice theory because a decision is defined as the choice of at least one possible alternative course of action (Laux et al., 2018).

The premises of choice theory, i.e. the definition of the decision-maker, alternatives and their attributes as well as a decision rule, overlap with the characterisation of decision problems addressed in decision theory (Ben-Akiva and Lerman, 1985; French, 1995; Keeney, 1992;

McFadden, 2001). Therefore, choice is a decision problem, just like a firm's choice of strategy in biform games that explain value creation in ecosystems (Brandenburger and Stuart, 2007). Moreover, prescriptive decision theory aims to maximise utility by making the right decisions and thus builds on utility theory, just like choice theory. Similarly, utility theory is applied in prescriptive decision theory to quantify the outcomes of the various alternatives being assessed (Keeney, 1992). The choice theory addresses any individual and is hence relevant for the micro-level.

The focus on increasing utility is also at the centre of the service-dominant logic. The focus is the customer as the decision-maker, who defines the value-in-use (Vargo and Lusch, 2004a). Thus, firm value is dependent on customer utility. The rationality assumptions are important: In prescriptive decision theory it is assumed that rationality is not always given and therefore help is provided to the decision-maker (Bell et al., 1988). In choice theory, a contribution is made by including further psychological variables that explain why rational choices maximising utility are not always made (McFadden, 2001).

Nowadays, both choice theory and decision theory themselves are theories that are more applied than developed. However, a major difference lies in the perspective of the two theories: While prescriptive decision theory helps to explain how decisions should be made *objectively* through models, choice theory tries to predict how an individual chooses *subjectively,* including psychological variables (Bell et al., 1988; McFadden, 2001). Furthermore, both the service-dominant logic and choice theory posit that the customers' choices are highly individual (Heinrich, 2020). The service-dominant logic complements choice theory as it extends the knowledge about individual customer choice to the firms providing a service and states that this service should be as individual as possible (Vargo and Lusch, 2004a). Furthermore, choice theory assumes that various factors are evaluated in the decision, which can be translated into the integration axiom of the service-dominant logic (Vij and Krueger, 2017).

The explanations for ecosystems and the service-dominant logic have emerged more recently and are still developing. Explanations for ecosystems state that firm value is dependent on co-opetition, i.e., the simultaneous cooperation and competition with other firms. The axiom of value co-creation of the service-dominant logic is also a value driver as a platform effect for ecosystem partners. The ecosystem perspective is strongly focussed on the customer and the delivery of an overarching value proposition (Jacobides et al., 2018; Vargo and Lusch, 2004a). A more recent extension of the service-dominant logic explicitly includes service ecosystems, emphasising the importance of cooperation and coordination (through an ecosystem orchestrator) of multiple actors in value co-creation (Vargo and Lusch, 2016). This is consistent with the cooperative stage of biform games and the creation of economies of scope (Brandenburger and Stuart, 2007; Jacobides et al., 2018).

Figure A-4 depicts the interplay of prescriptive decision theory, choice theory, and the service-dominant logic, as well as explanations for joint value creation in ecosystems as explanations for sustainability, customer centricity, and supply-side profitability.

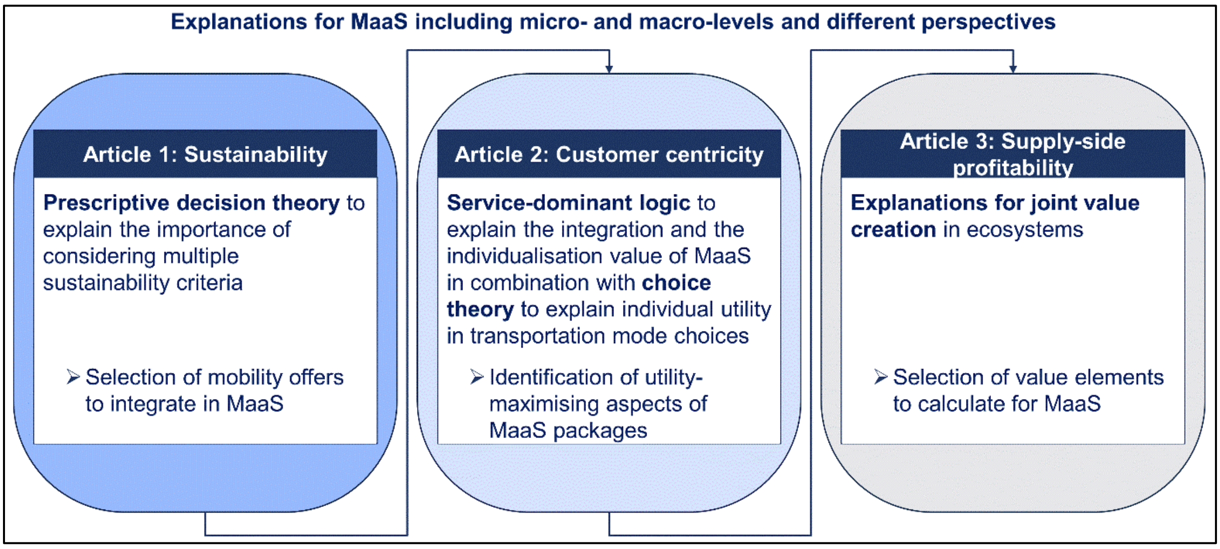


Figure A-4: Interplay between explanations for sustainability, customer centricity, and supply-side profitability (own elaboration)

The figure shows that the results of one theory serve as an input for another one. Ecosystem theory borrows from the result of the service-dominant logic to explain value co-creation with the customer and from choice theory, which focuses on the customer choosing the service offered. These two theories borrow from the results of prescriptive decision theory as they focus on utility and (bounded) rationality for multiple criteria in deciding either how much to pay (in the service-dominant logic) or which offer to choose (in choice theory). The methods used in combination with the explanations presented will be described in more detail in Section A.4.

As for the scope of the explanations, ecosystem explanations focus on specific ecosystems involving a limited number of partners, while decision theory is universally applicable to various economic problems. The explanations complement each other due to their different scope (micro- and macro-level) and research focus (perspectives).

4. Methodology

In line with the explanations in Section A.3, methods are explained for sustainability, customer centricity, and supply-side profitability, which in combination result in a multi-method approach (Johnson et al., 2007; Kuckartz, 2019) for a holistic analysis of MaaS.

4.1. Sustainability

Starting with a sustainability assessment methodology, classical analytical methods that only consider monetary values are not optimal for an assessment of sustainable mobility due to the tripartite nature of the concept (Macharis et al., 2012). Therefore, the three sustainability categories are assessed and aggregated together (de Almeida Guimarães and Leal Junior, 2017). Accordingly, several different objectives need to be considered when evaluating mobility projects (Macharis et al., 2010). However, due to the divergent nature of the sustainability dimensions, trade-offs are inevitable, preventing the objectives of all dimensions from being achieved simultaneously (Byggeth and Hochschorner, 2006; Haffar and Searcy, 2015; Huang et al., 2020; Nechi et al., 2019; Ozanne et al., 2016). Therefore, further research on transportation project evaluation should include the identification and resolution of conflicting goals in sustainable transportation, as a decision in transportation planning can only ever be a compromise (Litman, 2003; Nijkamp et al., 1990). Therefore, a multi-method analysis is proposed that includes a) the detection of goal relations, especially goal conflicts, and b) the sustainability assessment of alternative transportation modes based on several different criteria.

An established procedure for detecting relationships between criteria is Interpretive Structural Modelling (ISM) (Attri et al., 2013). It is particularly suitable for analysing dependencies concerning the sustainability dimensions through pairwise criteria comparisons using expert opinion and incorporating transitivity checks based on the prescriptive decision theory described in Section A.3.1 (Pathak et al., 2019; Sushil, 2018; Vishnu et al., 2019). As a result, a hierarchical model is created to determine the driving power and the dependence of each criterion on the other criteria with a method called Matriced' Impacts Croise's Multiplication Appliquee a UN Classement (MICMAC) (Hachicha and Elmsalmi, 2014). This can be presented in a matrix according to Duperrin and Godet (1973). The classical ISM method has been developed into an advanced Total ISM. This approach adds the interpretation of relationships between items (Menon and Suresh, 2020). Based on Total ISM, other modifications have been discussed. One of them is based on the belief that the assumption of binary relations (present or absent) between items in ISM excludes the nature of the relationships, as they can be negative, positive, or neutral (Chaib-draa et al., 1994).

Consequently, it is important to detect especially negative or positive relationships. Therefore, Sushil (2018) presented an approach to include the polarity of relations in ISM (ISM-P). A pairwise comparison with polar relationships was carried out by Ülengin et al. (2010), too. Thus, ISM and its further developments are used not only to identify criteria interrelationships and dependencies but also to classify these dependencies either as conflict or harmony.

The second method for sustainability assessment results from MCDA, which considers several criteria simultaneously. This is especially important for sustainability assessment (Zimmermann and Gutsche, 1991). In particular, decision aid can be provided by using approaches that avoid the assumption of compensation between criteria and require only partial information about pairs of decisions (Stewart, 1992; Vincke, 1986; Zhaoxu and Min, 2010). In terms of MCDA applications in sustainable transportation, Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) is increasingly used (Broniewicz and Ogrodnik, 2020; Cinelli et al., 2014). This transparent approach, developed by Brans et al. (1986), starts by establishing an outranking relationship between the alternatives, which is used to maximise the criteria for different actions (Brans et al., 1986). A preference function as well as criteria weights need to be selected to rank the alternatives according to their scores on the selected criteria, including their weight (Zimmermann and Gutsche, 1991). Another special feature of PROMETHEE is its transparency. For instance, there are unique visualisation tools that help to display the criteria score of each alternative as well as conflicting criteria, for instance the Graphical Analysis for Interactive Aid (GAIA) web (Brucker et al., 2004).

The link between both methods is established in two ways: First, the criteria interrelations from the driving and dependence power matrix enter the criteria weighting process in MCDA. Second, it is examined whether the criteria conflicts identified in ISM-P are also visible as a diverging performance of a (transportation) alternative. If the performance diverges, measures must be defined for the specific alternative to resolve the conflict. This approach is a novelty in (sustainability) research. The sustainability evaluation can be used to decide which mobility services should be integrated into a MaaS platform (usually an app) according to the sustainability evaluation.

4.2. Customer centricity

Since price is a determinant of demand according to consumer theory, the developed choice models can be used, among others, to detect price effects (McFadden, 1986, 2001). As preference is an indicator of the preferability of an individual's evaluation object, it forms the basis for such evaluations (Baier and Brusch, 2009). For preference measurement, products and services are presented as bundles of attributes, i.e., as a combination of different characteristics. The attributes are used to analyse the benefit of each component for the customer and to quantify it in the form of a utility function, through which purchase decisions are predicted, taking into account varying circumstances (Eggers and Sattler, 2011). The customer’s perceived utility (i.e. the subjective value) determines the WTP, i.e. the maximum price a buyer would accept for a given offer (Bowman and Ambrosini, 2000; Fojcik and Proff, 2014; Günthner et al., 2021; Wertenbroch and Skiera, 2002) as described in the service-dominant logic explained in Section A.3.2. Specifically for MaaS, the novelty of the concept lends itself to an analysis of price effects, namely conjoint analysis (Albers et al., 2007; Stopka, 2020). Concerning MaaS, it has already been used by Feneri et al. (2020) and Guidon et al. (2020). The conjoint analysis follows the random utility theory. Besides other variants such as rankings and ratings, choice-based conjoint analysis most realistically depicts an actual purchase decision (Eggers and Sattler, 2011; Souka et al., 2020). In conjoint analysis, indirect price queries are used to evaluate product alternatives that differ in individual product characteristics which are evaluated as a bundle of attributes (Eggers and Sattler, 2011). This method is used to convert subjective responses to product alternatives from a questionnaire into estimation parameters of part-worth utilities derived from probability models in a decompositional way (Green and Srinivasan, 1978; Hair et al., 2010). Attribute sensitivity analysis is a method for estimating relative demand curves. The WTP is therefore determined as the point at which the analysed product is no longer preferred in the event of a price increase (Eggers and Sattler, 2011).

Both the price importance and mode choice are heterogeneous (McFadden, 2001) and the variety of latent variables used also serves to find differences between heterogeneous consumer groups. Therefore, the market can be segmented according to the part-worth utilities or the relative importance of an attribute, which is determined by dividing the range of its levels by the sum of the ranges of all attributes, as benefit segmentation (Hair et al., 2010; Wind, 1973). This benefit segmentation is useful because it is based on data gathered from conjoint analysis rather than sociodemographic variables, which tend to be poor predictors of individual choice (DeSarbo et al., 1995; Haley, 1968). A common approach to benefit segmentation is cluster analysis (Hair et al., 2010) where the size and number of segments are determined only by the choice-based conjoint data (DeSarbo et al., 1995; Hair et al., 2010).

Consequently, for customer centricity in MaaS, two approaches are combined to reach more precise and individual results and to compose MaaS packages that maximise the utility of the potential customers: conjoint analysis and cluster analysis for benefit segmentation.

4.3. Supply-side profitability

Finally, to determine supply-side profitability, a method must be found that can forecast future demand for MaaS. This is important since data from real MaaS offers are sparse and methods for ecosystem value forecasts are absent. One advantage of conjoint analysis is that the part-worth utilities as outputs can be transformed into predicted market choices through market simulations (Orme, 2010). The utilities are used for forecasting because adoption behaviour and purchase probabilities can be estimated in prediction models using competitive market scenarios derived from market data (Eggers and Eggers, 2011; Jeon et al., 2010; Orme, 2010).

Therefore, different scenarios can be defined as predictions of the development of new technologies. For this purpose, key decision factors must be defined that represent the value elements for profitability estimations (Tseng et al., 2012). These are derived from a literature review. Based on this, different operating models and orchestrator settings are condensed, as these determine the value generated. A distinction was made between a public and a private entity as an ecosystem orchestrator. In the public orchestrator setting, no value is internalised and hence no profit is generated (Daymond et al., 2022). As for the private orchestrator setting, the agency operating model serves as the basis. In this model, the orchestrator receives volume discounts from the mobility service providers for purchasing a large amount of transportation capacity regularly (Kamargianni and Matyas, 2017). The price of the bundle offered to customers can either be lowered to increase demand or remain the same to increase the individual contribution margin. This model is used by the most integrated MaaS operators (Hager and Karl, 2021). Three different amounts are used as volume discounts in the operating model, as discussed in the literature (Hager and Karl, 2021; van den Berg et al., 2022; Zipper, 2020).

The composition of the offer and the price for the specific offer composition can be varied and the demand for them can be predicted (Orme and Chrzan, 2017). Hence, market share is predicted based on customer choice simulation to determine the best product composition (Jeon et al., 2010). By including real market data, especially for the costs of different services integrated into the MaaS ecosystem and for additional revenue streams besides the actual transportation service, the joint value created in the MaaS ecosystem can be estimated (Tseng et al., 2012).

4.4. Interaction of the methodologies

The results of the different methodologies are connected to serve the purpose of this research. The different methodologies presented above complement each other in several ways: First, each methodology enables an analysis on a different level. For instance, the sustainability assessment refers to the company level, as different mobility service providers can be compared. This is also an objective methodology, as the data used as input comes from different datasets. It uses expert opinions, but only at an aggregate level (Menon and Suresh, 2020). Hence, the sustainability assessment covers the composition of the MaaS ecosystem, as it determines which partners should be integrated into a MaaS platform from a sustainability perspective.

The services analysed for sustainability are entered as elements of MaaS services in the questionnaire (as attributes in the bundles of MaaS offers) for conjoint analysis. Conjoint analysis aims to capture the customers' choices and preferences, i.e., to include subjective, individual analysis of WTP and to find out how the MaaS bundles should be composed (Stopka, 2020). This complements the objective sustainability assessment.

Finally, building on the conjoint data and on the sustainability assessment of different services as input for profitability calculations as market simulations, joint value estimations are carried out at the ecosystem level, especially for the supply side. This level includes both the mobility service providers and the customers. Therefore, it provides a holistic assessment based on customers' WTP and the individual and ecosystem costs of the service providers, as well as further sources of value inflow. Hence, this method builds on the previous assessments and integrates objective firm and subjective customer data. The methodologies are inextricably linked as a multi-method approach to provide a holistic view of MaaS. Figure A-5 shows the specificities of each method and the links among them.

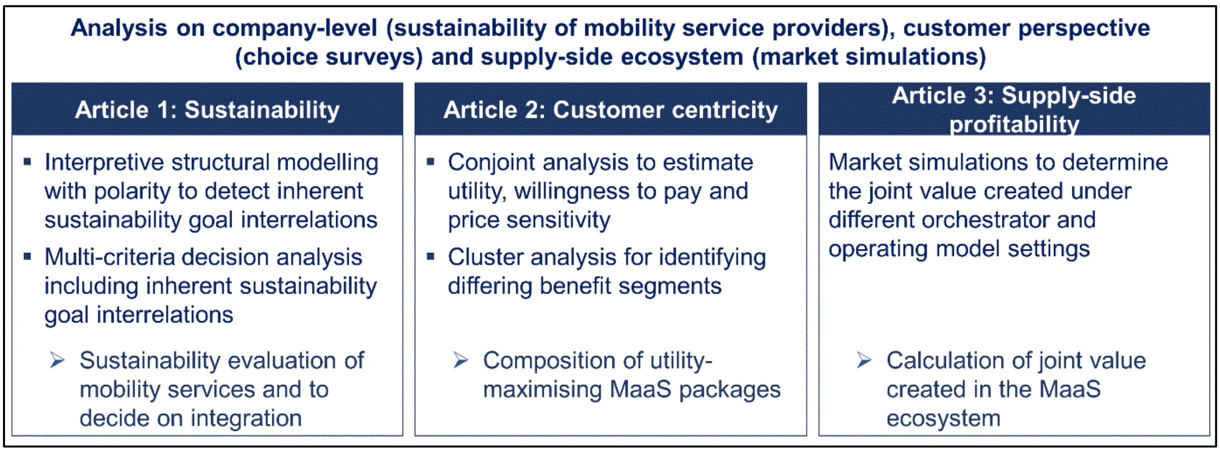


Figure A-5: Methodologies used and their linkages (own elaboration)

5. Structure of the thesis

To achieve the ROs by answering the respective RQs formulated in Section A.2, the following chapters are elaborated. Based on the introductory Chapter A, including the explanations given and the methodology presented, the main body of the thesis includes the three articles that were elaborated to achieve the ROs (see Table A-3).

Table A-3: Chapters of this thesis and the corresponding journal articles (own elaboration)

Chapter	Article	CRediT authorship contribution
B	Kraus, L., Wittowsky, D., Proff, H. (2023): Multi-method analysis to identify criteria interrelations for sustainability assessment of urban transportation services. In: *Journal of Cleaner Production,* 412, p. 137416. https://doi.org/10.1016/j.jclepro.2023.137416	**Kraus, L.**: Conceptualisation, Data curation, Formal analysis, Methodology, Writing – original draft, Data collection and assessment. **Wittowsky, D.**: Supervision, Validation, Writing – review & editing. **Proff, H.**: Supervision, Writing – review & editing.
C	Kraus, L., Proff, H., Giesing, C. (2023): Composition of a mobility as a service offer for university students based on willingness to pay and its determinants. In: *International Journal of Automotive Technology and Management*, 23 (2/3), pp. 227–256. https://doi.org/10.1504/IJATM.2023.133351	**Kraus, L.**: Conceptualisation, Data curation, Formal analysis, Methodology, Writing – original draft, Data collection and assessment. **Proff, H.**: Supervision, Validation, Writing – review & editing. **Giesing, C.**: Assistance in data curation, Writing – review & editing.
D	Kraus, L., Proff, H., Jeppe, A., 2023. Estimation of joint value in mobility as a service ecosystems under different orchestrator settings. In: *European Transport Research Review* 15 (25), pp. 1–15. https://doi.org/10.1186/s12544-023-00594-1	**Kraus, L.**: Conceptualisation, Methodology, Writing – original draft, Visualisation. **Proff, H.**: Writing – review & editing, Supervision. **Jeppe, A.**: Validation, Visualisation.

Each RQ and corresponding RO explained in Section A.2 is addressed in Chapters B, C and D. Thereby, the ROs are sub-objectives of this thesis. To reach them, the methodologies described in Sections A.4.1 to A.4.3 are applied.

To gain a comprehensive understanding of the current problems of MaaS and to propose solutions to enhance its uptake, it is important to focus on the characteristics that describe how MaaS works. Therefore, the critical aspects of sustainability of the offer, customer utility, and WTP as well as profitability, as described in Section A.2, must be included in the analysis.

The consecutive order is justified as follows. After the sustainability assessment of services (Chapter B), which is an essential part of the value proposition of MaaS, the question remains how a MaaS solution based on the sustainable services found should be designed to appeal to customers. This question is subsequently answered in Chapter C by analysing the (potential) customers and their utility. The open question of whether the customers' WTP for a MaaS offer calculated in Chapter C is high enough to cover the costs of MaaS to be able to offer it profitably is answered in Chapter D. In the final Chapter E, a conclusion is drawn. It summarises the results from Chapters B, C, and D and highlights the connections among the findings. It also discusses the limitations of this work and provides an outlook. An overview of the structure of the thesis is provided in Figure A-6.

Chapter A	**Introduction**	
Chapter B	**Article**	**Multi-method analysis to identify criteria interrelations for sustainability assessment of urban transportation services**
	RQ RO	Which is the most sustainable transportation service in the Ruhr area? to evaluate mobility service providers according to their sustainability impact
	Theory	Prescriptive decision theory
	Method	(1) Interpretive structural modelling with polarity to detect inherent sustainability goal interrelations (2) Multi-criteria decision analysis including inherent sustainability goal interrelations
⇒ Open question: How can an integrated mobility (MaaS) solution be organised that appeals to the customers?		
Chapter C	**Article**	**Composition of a mobility as a service offer for university students based on willingness to pay and its determinants**
	RQ RO	How should MaaS offers be designed for university students? to develop a MaaS offer appealing to promising customer segments
	Theory	(1) Choice theory (2) Service-dominant logic
	Method	(1)Conjoint analysis to estimate utility and willingness to pay (2)Cluster analysis for identifying differing benefit segments
⇒ Open question: Is the customers' willingness to pay high enough to cover the MaaS (platform) costs?		
Chapter D	**Article**	**Estimation of joint value in Mobility as a Service ecosystems under different orchestrator settings**
	RQ RO	How does the joint value created differ in private MaaS ecosystems from a public MaaS ecosystem? to discover how the MaaS ecosystem can be offered profitably
	Theory	Explanations for joint value creation in ecosystems
	Method	Market simulations to determine the joint value created under different orchestrator and operating model settings
Chapter E	**Conclusion**	

Figure A-6: Structure of the thesis (own elaboration)

Chapter B: Multi-method analysis to identify criteria interrelations for sustainability assessment of urban transportation services

Abstract

To comply with the European Green Deal, decarbonisation of transportation is decisive, especially a shift towards more sustainable transportation services is essential. Due to the tripartite nature of sustainability (society, environment and economy), multiple interrelated criteria are part of the sustainability assessment of transportation services. Discovering these interrelations between criteria to anticipate conflicts and integrate them appropriately into multi-criteria analysis is important for ranking urban transportation services. This paper presents a novel, two-folded methodology for assessing the sustainability of different urban transportation services. First, Integrative Structural Modelling with Polarity (ISM-P) is used for universally identifying sustainability criteria interrelationships and weighting them. Second, the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method is applied to a sustainability assessment of five specific urban transportation services (public and sharing). In conclusion, applying the methodology to the example of urban transportation services in the Ruhr region, the importance of public transportation as the most sustainable alternative is proven.

Keywords

Multi-criteria decision analysis; Interpretive structural model; PROMETHEE; Sustainable transportation; Germany

1. Introduction

Decarbonisation, as demanded by policy-makers, is crucial for climate protection, especially in transportation (Canzler and Wittowsky, 2016; Pathak et al., 2019). The goal of the European Green Deal – meeting stated sustainability and policy targets – can only be achieved if transportation emissions are reduced by 90% by 2050 (European Environment Agency, 2020). This emphasises the key role that transportation sustainability plays in meeting major regulations (Hickman and Banister, 2019). Sustainable transportation furthermore enables social participation and creates jobs (Kraus and Proff, 2021). The enhancement of sustainable transportation is referred to by the avoid-shift-improve framework: Unnecessary trips should be avoided, a modal shift towards transportation services other than private cars should happen, and vehicle efficiency must be improved (Banister, 2008). The modal shift is of relevance. In industrialised countries, car dependence is high and most of the cars have combustion engines (Proff, 2019). Multimodality, i.e. the plurality of transportation options, contributes to achieving the modal shift (Canzler and Wittowsky, 2016). To prioritise modes in terms of sustainability, the status quo of sustainability in transportation must first be assessed. Due to the best-known tripartite nature of sustainability (economy, environment and society), the three sustainability dimensions are usually analysed together (de Almeida Guimarães and Leal Junior, 2017). This is a difficult task due to the complexity of transportation with different benefits and drawbacks for the society (Kraus and Proff, 2021).

Accordingly, multiple criteria must be considered simultaneously when assessing different transportation services (Macharis et al., 2010; Miller et al., 2016). Therefore, Multi-Criteria Decision Analysis (MCDA) is gaining importance (Wallenius et al., 2008) to assess the sustainability of a given transportation alternative (Cinelli et al., 2014; Nechi et al., 2019). However, due to the diverging sustainability dimensions, trade-offs are inevitable (Byggeth and Hochschorner, 2006). The lack of research on competing sustainability goals (Aarseth et al., 2017) and on how to deal with interrelated criteria (Kraus and Proff, 2021) demonstrates the need for a holistic multi-method approach to systematically and transparently assess criteria interdependencies in MCDA, especially for sustainable urban transportation. This research aims to fill this gap by answering the following RQs:

1. How can the interrelations between sustainable transportation criteria be identified and systematised?
2. How can the interrelations between sustainability criteria best be considered in MCDA?
3. Illustrated by the example of the Ruhr area: Which is the most sustainable transportation service?

This article is organised as follows: Section B.2 provides a background on prescriptive decision theory, MCDA including conflict and sustainable transportation criteria. Section B.3 describes the proposed methodological framework, including Interpretive Structural Modeling with polarity (ISM-P) and Matriced’ Impacts Croise's Multiplication Appliquee a UN Classement (MICMAC; Duperrin and Godet, 1973). MICMAC analysis is often applied as a complementary method to ISM: While ISM maps a hierarchy between criteria, MICMAC structures each criterion depending on its comparative importance (Shen et al., 2016), helping to prioritise the criteria and identify the most influential drivers (Pathak et al., 2019). MICMAC was chosen because it also provides visual support for prioritisation with its driving/dependence power matrix (Tan et al., 2019). PROMETHEE is described as exemplary MCDA approach. The methodology is applied empirically in Section B.4. Section B.5 discusses the results, and Section B.6 draws conclusions.

2. Background

2.1. Prescriptive decision theory

Prescriptive decision theory is an increasing research field aiding decision-makers through decision models to evaluate outcomes (Dyer and Smith, 2020). The steps of decision analysis are (Keeney, 1982):

(1) Problem formulation: The decision problem is structured and alternatives are compiled. A goal hierarchy is compounded. Possible conflicts are identified.
(2) Objectives quantification: Value judgments for the alternatives are made to quantify the fulfilment of a goal.
(3) Preference determination: Value trade-offs are made to evaluate alternatives and the preference structure.
(4) Alternatives evaluation and comparison: Based on utility, a ranking of the alternatives is performed.

The complexity of decision problems and their analysis is caused by multiple interrelated goals sometimes requiring trade-offs in the problem formulation. Decision analysis is important for identifying and resolving conflicts because it provides support in the process through formal models (Keeney, 1982; Wallenius et al., 2008).

2.1.1. Types of goal interrelations

Interrelated goals are polar and influence each other either positively or negatively: A positive effect of one goal on the fulfilment of another is reached by complementary goals. Negative interrelations are shown in conflicting goals. If conflict is inherent trade-offs are necessary. In the most drastic case, antinomy, the goals categorically exclude each other. Goals must be decomposed into sub-goals, which are then assessed to understand the relation and solution possibilities for the conflicts (Nilsson et al., 2016).

2.1.2. Multi-criteria decision analysis (MCDA)

MCDA deals with decisions based on multiple goals expressed as criteria (Wallenius et al., 2008). Many MCDA applications rank alternatives by using conflicting criteria simultaneously following four steps:

(1) Alternative action compilation: The alternatives are either an infinite (Multi-Objective Decision-Making (MODM)) or a discrete (Multi-Attribute Decision-Making (MADM)) number. MODM uses mathematical functions like goal programming, whereas MADM serves as a decision aid (Renatus and Geldermann, 2016).

(2) Criteria collection: The criteria set must be a complete set of non-redundant, measurable, and relevant criteria (Witt et al., 2020) which are weighted according to their importance in reaching a goal.
(3) Performance evaluation: A decision table is composed and data on the alternatives for each criterion are collected (Keeney, 1982).
(4) Performance aggregation: The performances of each alternative are aggregated to select the one scoring the highest (Keeney, 1982) using various MCDA algorithms: MADM belong either to the American or the European Schools. American researchers use Multi-Attribute Utility Theory (MAUT), such as the Analytic Hierarchy Process (Saaty, 2012). Due to its restrictive assumptions it is less suitable applicable for decision aid in sustainability (Vincke, 1986). European researchers focus on outranking approaches that avoid the assumption of compensation between attributes (Stewart, 1992). Two well-known approaches are Elimination Et Choix Traduisant la Realite (ELECTRE) and PROMETHEE (Brans and Mareschal, 2005). One disadvantage of ELECTRE is the arbitrary determination of threshold values, which PROMETHEE tries to eliminate (Zimmermann and Gutsche, 1991). The course of this background is visualised in Figure B-1. Resulting from this classification, PROMETHEE is the most adequate MCDA method for the problem described in Section B.1.

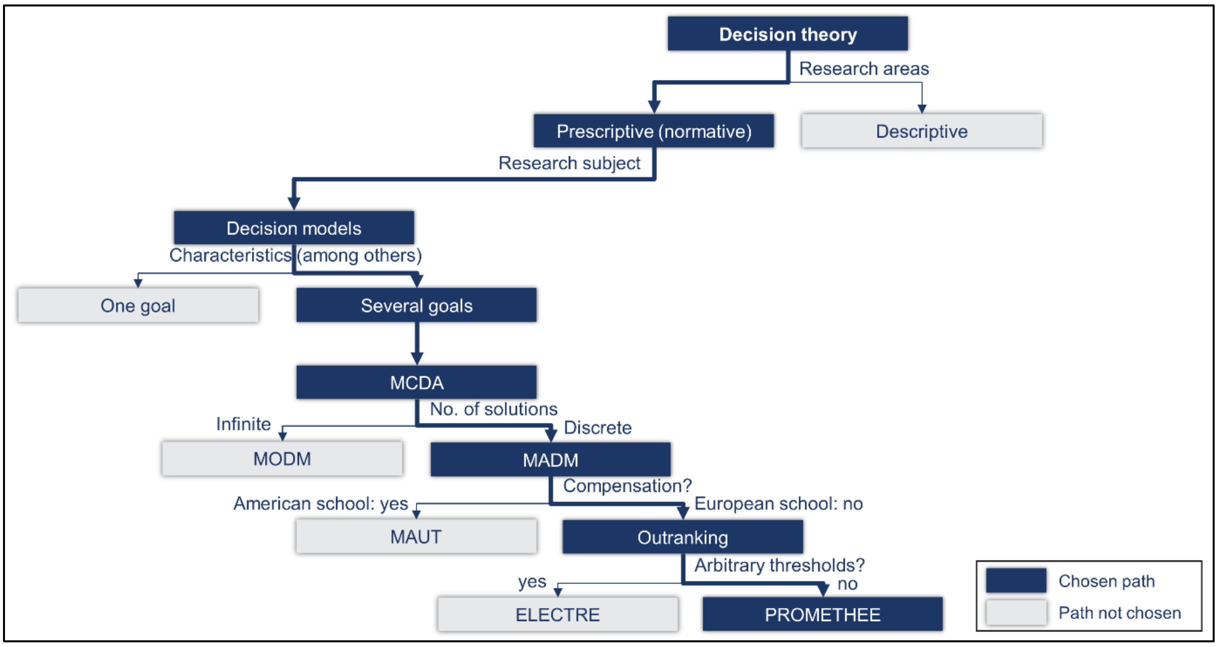


Figure B-1: Classification of MCDA approaches (own elaboration)

2.2. Research on conflict and MCDA

Literature regarding the explicit inclusion of conflict into MCDA is still sparse. One research stream includes interpersonal (stakeholder) conflicts. For instance, Losa and Belton (2006) combined MCDA and conflict analysis with a multi-actor perspective but without the application of a specific MCDA method (Losa et al., 2001).

Another research stream focuses on conflict analysis models for conflicting alternatives in MCDA, especially by combining PROMETHEE and a conflict analysis test. For instance, a conflict analysis model was developed and applied to an investment decision problem by van Huylenbroeck (1995), whereas Wu et al. (2020) applied the model to a site selection problem.

Only Girubha et al. (2016) explicitly analysed the criteria hierarchy and interrelations in MCDA so far. They used ISM to analyse the degrees of criteria dependencies but without explicitly including conflict.

Consequently, the investigation of conflicting criteria as representation of inherent goal conflict has not been included into MCDA, although stated important in the decision analysis literature (Keeney, 1982; Wallenius et al., 2008).

2.3. Literature review: sustainability assessment (criteria) of urban transportation services

Following Chen et al. (2020), previous sustainability assessments of transportation services were reviewed, focussing on the research objective, methods used, and criteria applied. Gössling et al. (2019) applied a cost-benefit analysis to evaluate different transportation modes. A drawback of this method is the difficulty to express certain criteria (e.g. accidents or air pollution) in monetary terms. Stefaniec et al. (2020) studied inland transportation based on the three sustainability dimensions using data envelopment analysis and a regional comparison without the aim to evaluate different transportation modes. Miller et al. (2016) exclusively analysed the sustainability of public transportation using the three sustainability dimensions and system effectiveness in a composite sustainability index. They used weighting based on probabilities without focussing on criteria interrelations. To assess the eco-efficiency of passenger transportation, de Almeida Guimarães and Leal Junior (2017) only applied environmental and economic criteria due to a lack of access to social data, although stated necessary to include all dimensions. Awasthi et al. (2018) used fuzzy numbers in MCDA to evaluate sustainable mobility projects such as new tramway creation using criteria of the three sustainability dimensions and technical criteria, but they did not apply real data in the evaluation of the infrastructural alternatives. Further literature uses PROMETHEE to evaluate the sustainability performance of transportation systems (Antanasijević et al., 2017;

Caravaggio et al., 2019; Santos et al., 2019) as well as ISM (Pathak et al., 2019). However, because of the focus of these studies on other main aspects (pavement scenarios, freight, or transportation as a criterion only) the transferability of the criteria (e.g. GDP) to urban transportation services is insufficient.

These studies highlight the need to a) further analyse sustainability criteria relevant for transportation services, as previous studies in the field had different research objectives and divergent methods, impeding transferability and b) identify criteria interrelations and trade-offs which were not (sufficiently) addressed, although stated necessary, especially for sustainability assessments (Aarseth et al., 2017) in transportation.

To address research gap a), a systematic literature review was conducted, resulting in a criteria set of 33 sustainability criteria for the three dimensions (11 economic, 13 social and 9 environmental criteria) based on 21 papers (see Kraus and Proff, 2021). The dimension with most counts was the social one (82 mentions). The criteria mentioned the most in the papers were air pollution, energy consumption and noise (14 times), GHG emissions and safety (13 times), operating cost (12 times), health and travel time (11 times). Research gap b) is addressed in this analysis.

3. Methodological framework for interrelated multi-criteria decision analysis

The proposed framework essentially keeps the decision process as stated in prescriptive decision theory and in MCDA and is supported by ISM-P (Step 1.1) and PROMETHEE (Steps 2 to 4), adjusting it to the requirements for this research: to present a holistic method suitable for sustainability assessment with inherently conflicting criteria.

ISM is selected because it can handle complexity caused by several criteria interrelations as in MCDA (Warfield, 1974). It is especially used for the assessment of sustainability in general (e.g. Ghobakhloo and Fathi, 2021; Pathak et al., 2019), and sustainable transportation (e.g. Santos et al., 2019; Tarei et al., 2021). ISM provides a framework of sustainability criteria interrelations regarding urban transportation services universally applicable to urban areas. PROMETHEE facilitates the identification of areas of improvement for alternatives (Brans and Mareschal, 2005). The framework is shown in Figure B-2.

The problem formulation (Step 1) structures the decision by defining the overall goal and the underlying goal system (Step 1.1). This step is extended to integrate ISM-P (Steps 1.1.1-1.1.5), including polar relations in a universally applicable framework (RQ1) and to determine the driving and dependence power of the criteria.

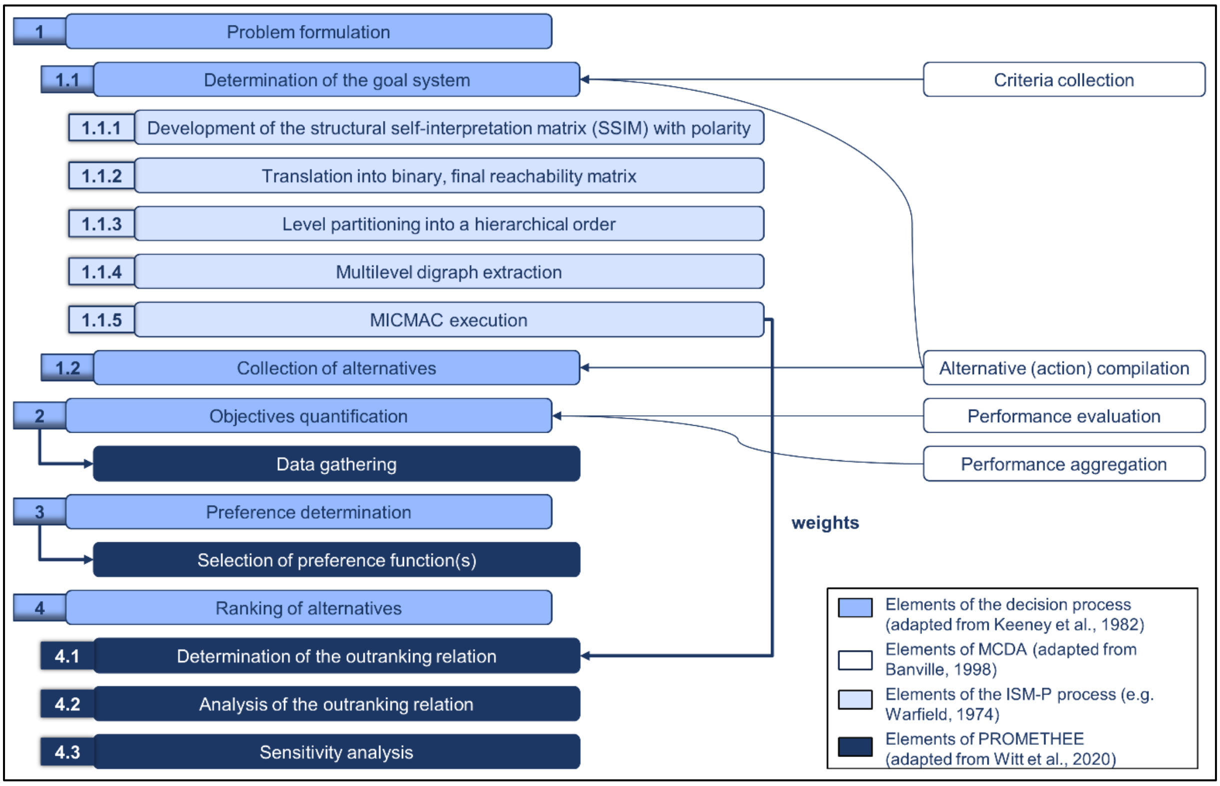


Figure B-2: Proposed integrated ISM-P PROMETHEE method (based on Banville et al., 1998)

3.1. Interpretive Structural Modeling with Polarity (ISM-P)

The basic steps are the following (Warfield, 1974):

(1) Development of the Structural Self-Interpretation Matrix (SSIM) with polarity,

(2) Translation into binary, final Reachability Matrix (RM),

(3) Level partitioning into a hierarchical order, and

(4) Multilevel digraph extraction.

In Step 1.1.1, the contextual relation is discovered. The influence of one item i on another j is discovered and clarified as follows (Attri et al., 2013):

- O: no relation,
- X: mutual dependency between i and j,
- V: relation from i to j only,
- A: relation from j to i only.

The inclusion of polarity increases its explanatory power (Sushil, 2018).

For transforming the SSIM into the RM in Step 1.1.2, the entries are converted into binary symbols:

- V and X: 1,
- A and O: 0.

The entries are then checked for the transitivity axiom. Where this axiom is not adhered to, “*1” is added for the Final Reachability Matrix (FRM) (Attri et al., 2013). Level partitioning is performed in Step 1.1.3 by applying an algorithm with a reachability, antecedent, and intersection set for each criterion based on the FRM (Sushil, 2018).

In Step 1.1.4, a directed graph from the RM is constructed with the hierarchical levels from FRM (Attri et al., 2013). MICMAC is added (Step 1.1.5). The driving power is the row sum of a criterion in the FRM and the dependence power the column sum. The criteria classification is as follows (Pathak et al., 2019):

- Autonomous: low driving and dependence power,
- Dependent: highly dependent with low driving power,
- Linkage: both highly dependent and driving, and
- Independent: high driving power but low dependence.

The results of MICMAC analysis are integrated into PROMETHEE (RQ2) as criteria weights for the specific case application: The dependence axis is turned at the y-axis because dependent criteria should be addressed with lower priority (Tan et al., 2019). The straight-line method based on the arithmetic mean, as developed by Baatz, is proposed for weight calculation (see Eq. (B.1), Pahl et al., 2007). Then, the criteria vectors are normalised by dividing each value by the column total (Brucker et al., 2004). As the sustainability paradigm postulates, all sustainability dimensions are weighted equally (Silva et al., 2010).

$$w_i = \frac{\frac{dp_{i_d} + (N - dd_{i_d})}{2}}{\sum_{i=1}^{n} \frac{dp_{i_d} + (N - dd_{i_d})}{2}} * \frac{1}{D} \quad \text{(B.1)}$$

with w_i = Weight of criterion i

dp = Driving power

i_d = Criterion i of dimension d

dd = Dependence power

N = Number of criteria

D = Number of sustainability dimensions (3)

The universally applicable results of ISM-P and the alternatives to be evaluated (Step 1.2) are integrated into PROMETHEE (Steps 2-4) as the specific sustainability assessment.

3.2. Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE)

PROMETHEE consists of the following steps (Witt et al., 2020):

(1) Data gathering,

(2) Selection of preference function(s),

(3) Determination of the outranking relation,

(4) Analysis of the outranking relation and

(5) Sensitivity analysis.

First, a pairwise comparison of the two alternatives' $a_j \in \{a_1, a_2, \ldots, a_m\}$ performance scores $c_i(a_j) \coloneqq x_{ij}$ on each criterion $c_{ij} \in C = \{c_1, c_2, \ldots, c_n\}$ is done (Witt et al., 2020). Therefore, data must be gathered regarding alternatives and its criteria scores (Step 2). Second, for each criterion, a maximisation or minimisation objective must be stated (Keeney and Winterfeldt, 2012). The differences $d_i(a_j, a_k) = x_{ij} - x_{ik}$ are input for a preference function (Step 3) modelling intra-criteria preference (Brans and Mareschal, 2005).

Third, the weights w_i with $\sum_{i=1}^{n} w_i = 1$ for all criteria are aggregated to find the outranking relations (Eq. (B.2), Step 4.1 in Figure B-2):

$$(a_j,\ a_k) = \sum_{i=1}^{n} w_i \times P_i(a_j,\ a_k) \qquad \text{(B.2)}$$

This step uses Eq. (B.1) based on MICMAC execution for this specific framework. From the value differences, the preference values are deducted using the preference functions. The outranking relations are calculated regarding outranking flows: The positive outranking flow indicates the intensity with which an alternative dominates all others (Eq. (B.3)), whereas the negative flow shows its degree of domination (Eq. (B.4)).

$$\varphi^+(a_j) = \frac{1}{m-1} \times \sum_{a \in A} \pi(a_j, a) \qquad \text{(B.3)}$$

$$\varphi^-(a_j) = \frac{1}{m-1} \times \sum_{a \in A} \pi(a, a_j) \qquad \text{(B.4)}$$

Fourth, the partial ranking PROMETHEE I is analysed, including incomparability of alternatives (Eq. B.5)):

$$\varphi(a_j) = \varphi^+(a_j) - \varphi^-(a_j) \qquad \text{(B.5)}$$

By aggregating φ^{+} and φ^{-}, a complete ranking (PROMETHEE II) is provided, in which a_j is preferred over a_k if $\varphi(a_j) > \varphi(a_k)$ (Witt et al., 2020).

The alternative ranking provides recommendations over all alternatives (RQ3), while graphical representations allow recommendations for each alternative. This framework also reviews the conflicting criteria identified in Step 1.1.1: If they are also visible through divergent performance scores of alternatives on the conflicting criteria pair in PROMETHEE, recommendations are formulated (Step 4.2). Fifth, sensitivity analysis (Step 4.3) with alternative weights tests model robustness (Keeney, 1982; Witt et al., 2020).

4. Sustainability assessment of urban transportation services

4.1. Problem formulation

The proposed framework was applied for the goal of sustainability evaluation of transportation services in the German Ruhr metropolitan area as an exemplary case, a metropolitan area with over five million inhabitants and a high traffic density (Fina et al., 2021). The potential for increasing sustainability of existing transportation services offered through providers in the area's most populous cities Bochum, Dortmund, Duisburg, and Essen was analysed.

4.1.1. Determination of the goal system

The determination of the goal system and the criteria collection regarding sustainable transportation was based on a systematic literature review conducted by Kraus and Proff (2021). In accordance with Section B.2.3, since a pairwise comparison of the 33 criteria found in the systematic literature review conducted by Kraus and Proff (2021) would not have been manageable, a literature-based pretest was conducted to find out which criteria adhere to the requirements of relevance, measurability and non-redundancy for the specific research goal stated in Section B.4.1. Based on this, twelve criteria from the three sustainability dimensions were selected and validated by the experts to decrease the number of survey questions in SSIM development. Table B-1 depicts the criteria chosen, including the objectives and indicators.

Table B-1: Criteria, objectives and indicators for evaluating the sustainability of transportation services in the Ruhr area (adapted from Kraus and Proff, 2021)

No.	Criterion	Objective	Indicator
EN1	Air pollution	min	Mode-specific air pollution (NOx & PM10)
EN2	Energy consumption	min	Ratio of life-cycle energy consumption to passenger-km
EN3	GHG emissions	min	Life-cycle emission intensity of GHG
EC1	Operating cost	min	Operational, maintenance and fuel costs
EC2	Occupancy	max	Overall system (vehicle) capacity utilisation rate
EC3	Revenue	max	Total revenue of an organisation
EC4	Demand	max	Modal split
SO1	Safety	max	Ratio of dead people to passenger-km travelled per mode (min)
SO2	Travel speed	max	Average speed in a city
SO3	Affordability	max	Ratio of user cost for transportation to income (min)
SO4	Reachability	max	Percentage of citizens reaching next transportation service within 10 minutes
SO5	Equality	max	Share of citizens with physical/psychological access to transportation service
Note: EN = environmental, EC = economic, SO = social sustainability dimension			

ISM

Based on these criteria, ISM was performed. Both MICMAC and ISM are methods based on expert opinions as an input (Tan et al., 2019). To ensure data validity and reliability the following principles for qualitative data were obeyed by (see Azevedo et al., 2013; Ghobakhloo and Fathi, 2021; Shen et al., 2016; Shi et al., 2017; Tan et al., 2019):

- Thorough selection of experts invited based on knowledge about the topic,
- Invitation of experts from different disciplines and both industry and academia for data triangulation,
- Establishment of relation in ISM only following the majority rule based on opinion convergence,
- Intense cross-validation of the established logical relations by all authors as investigator triangulation,
- Sending detailed criteria definitions previously to the experts for ensuring internal validity, and
- Comparing the results with previous research regarding sustainable transportation for ensuring external validity.

Nineteen expert opinions were collected through semi-structured interviews with 21 transportation experts (one of which was a group discussion with three experts), guided through an online survey. Additionally, the survey was answered by 21 experts without interviews (see similar Ruiz-Benitez et al., 2017; Trivedi et al., 2021), resulting in a total dataset of 40 expert opinions. An overview of the interviewed experts' profiles is provided in Table B-2.

Table B-2: Profile of experts that participated in semi-structured interviews (own elaboration)

Expert Code	Organisation	Job position	Experience [years]
A	E-Scooter sharing	Regional manager	8
B	Transport association	Strategist digital offers	21
C	E-bike sharing	Product manager bike sharing	13
D	Public utility (transportation)	Team leader operational control	4
E	Foundation research	Project manager	10
F	Public transportation provider	Mobility researcher	31
G	City	Head of strategic mobility planning	19
H	Car sharing	Sales manager	18
I	Public association (transportation)	Head of mobility development unit	18
J	Municipality	Public transportation mediator	8
K	IT provider	Chief Executive Officer	15
L	Bike sharing	Account manager	5
M	Municipality	Mobility specialist	19
N	Municipality	Information Technology Systems chief advisor	25
O	University	Project coordinator	10
P	Transportation service manufacturer	Founder	40
Q	University	Research associate (PhD)	9
R	University	Research associate	5
S	Municipality	Research associate	10
T	University	Research associate	5
U	Public transportation provider	Platform manager customer management	4

For each criteria relationship, the experts indicated whether a connection existed and if so, whether it was mutual or unidirectional. Furthermore, polarity was expressed as "the more i/j, the more/less j/i". According to the majority rule (see Shen et al., 2016), links were only added if they were found in more than 20 datasets. ISM was performed using SmartISM (Ahmad and Qahmash, 2021).

Pairwise criteria comparisons for SSIM

Table B-3 shows the SSIM with the resulting relationships.

Table B-3: SSIM for sustainability criteria of transportation services (own elaboration)

SSIM	EN1	EN2	EN3	EC1	EC2	EC3	EC4	SO1	SO2	SO3	SO4	SO5
EN1	O											
EN2	V+	O										
EN3	O	A+	O									
EC1	O	O	O	O								
EC2	V+	V+	V+	V+/-	O							
EC3	O	O	O	O	O	O						
EC4	V+	V-	V-	V-	O	V+	O					
SO1	O	O	O	V-	O	V+	V+	O				
SO2	V-	V-	V-	V-	O	V+	V+	O	O			
SO3	O	O	O	O	O	V+/-	V+	O	O	O		
SO4	V+	V-	V-	V-	V+	V+	V+	O	O	O	O	
SO5	O	O	O	V-	V+	V+	V+	O	O	O	O	O
Meaning A: only relation from j to i; V: only relation from i to j												

Reachability matrix with transitivity

Likewise described in Section B.3.1, a RM was developed based on the SSIM, adding transitive relations.

Level partitioning

Based on the FRM, the reachability, antecedent and intersection sets were gathered for each criterion. For instance, for air pollution (EN1), the reachability set only consisted of itself, but the antecedent set included nine criteria. Because the intersection set only consisted of EN1, it was assigned to the first level and removed from all remaining sets.

Multilevel digraph extraction

After level partitioning four levels were extracted. The digraph presented in Figure B-3 shows that all social criteria are important for sustainability evaluations because they appear at the base level. The environmental criteria air pollution (EN1) and GHG emissions (EN3) and the economic criteria operating cost (EC1) and revenue (EC3) are at the top. Negative relationships exist between demand (EC4) and energy consumption (EN2) and between demand (SO1) and operating cost (EC1). The relationship between occupancy (EC2) and operating cost (EC1) is negative in absolute terms, but positive in relative terms.

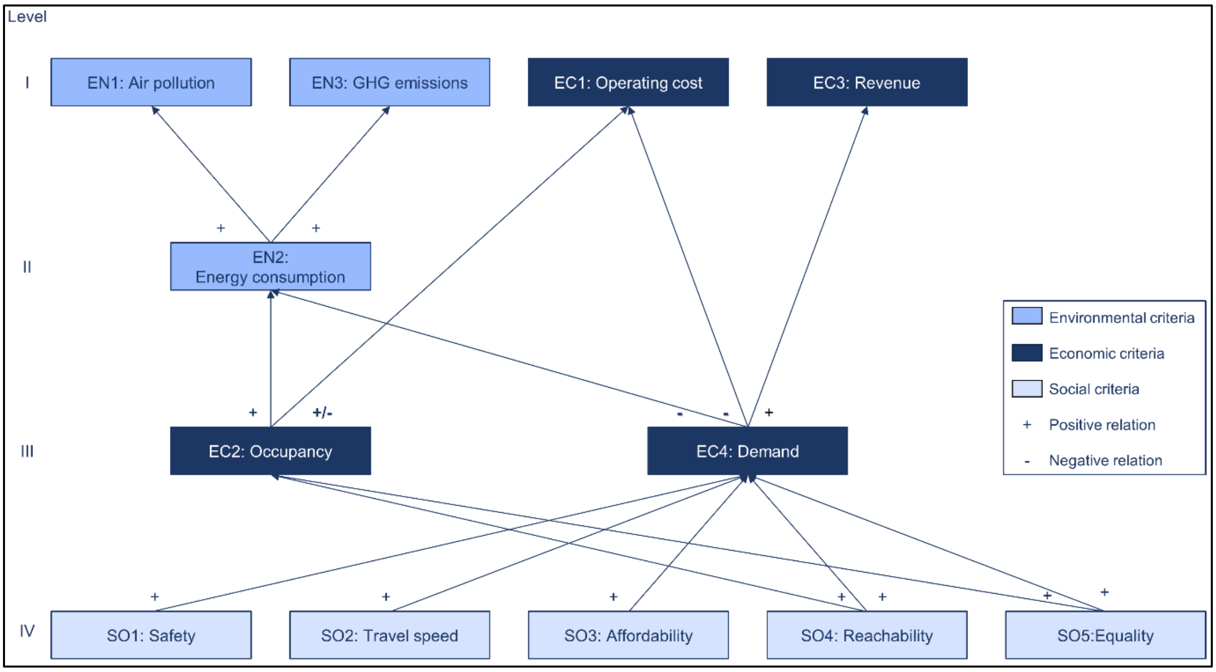


Figure B-3: Digraph representing polar relations between sustainability criteria of transportation services (own elaboration)

MICMAC

As MICMAC analysis showed (see Figure B-4), only occupancy (EC2) is autonomous. All environmental criteria, operating cost (EC1) and revenue (EC3) are dependent. The social criteria are drivers and demand (EC4) does not belong to only one quadrant. More information on the analysis is available in the Appendix 1. The values of driving power and dependence power are input for Eq. (B.1), the criteria weighting: The higher the driving power and the lower the dependence power, the higher the criteria weight, and vice versa.

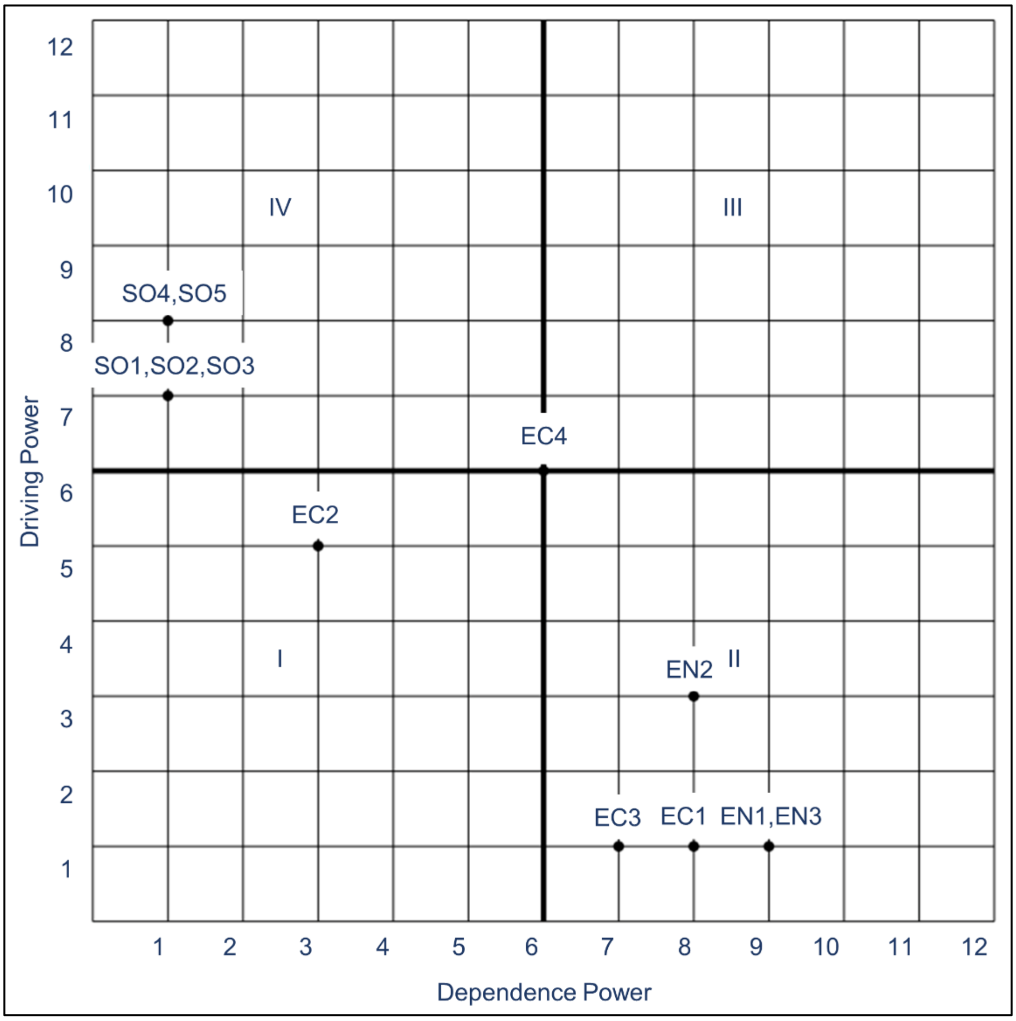


Figure B-4: Driving/dependence power matrix resulting from MICMAC analysis (own elaboration)

4.1.2. Collection of alternatives

In the next steps specific transportation services all offered by the same transportation service providers in the four cities of the Ruhr area were evaluated (König et al., 2016), leading to an exclusion of taxi operators (no single operator in all cities), privately owned modes and walking. The services chosen are existent also in other global metropolitan areas (OECD/ITF, 2020):

- A1: Public buses
- A2: Tramways
- A3: Car sharing (combustion engine, station-based)
- A4: E-scooter sharing
- A5: Bike sharing (without engine)

Interregional traffic was excluded, as the focus of the study is on urban, i.e. intra-city, transportation.

4.2. Objectives quantification

PROMETHEE

Data gathering

Visual PROMETHEE was used for the next steps (Mareschal, 2013). The data collected for quantification was obtained from personal interviews, survey data collected as part of a project, and secondary data used for own calculations, unless otherwise possible. For non-disclosure reasons, monetary values (EC1 and EC3) were converted into qualitative data. The decision table with the performance scores of each alternative is shown in Table B-4.

4.3. Preference determination

Selection of generalised criteria and preference functions

Since most users have implemented preference functions with linear preference (Type III; Witt et al., 2020), this type was also selected. The preference threshold was defined as the range of values for the criterion, as described in Tsoutsos et al. (2009) (see Table B-4).

4.4. Ranking of alternatives

4.4.1. Outranking relation determination

To determine the outranking relations, the weights were allocated with Eq. (B.5) and the MICMAC results. Table B-4 shows the weights assessed. As for revenue (EC3), the weight was calculated as follows:

$$w_{EC3} = \frac{\frac{1 + (12 - 7)}{2}}{18.5} \times \frac{1}{3} = 0.054$$

The environmental criterion weighted the highest was energy consumption (EN2), among economic criteria occupancy (EC2) and among social criteria no huge discrepancies were observable.

Table B-4: Decision table as data input for PROMETHEE (own elaboration)

Crite-rion	Unit	Ob-jec-tive	Weight [%]	A1	A2	A3	A4	A5	Prefer-ence thre-shold	Sources
EN1[1]	g/pkm	min	8.89	0.42	0.09	**0.53**	0.03	**0.02**	0.517	Umweltbundesamt (2021)
EN2[1]	MJ/pkm	min	15.56	0.93	0.91	**2.91**	1.25	**0.69**	2.220	OECD/ITF (2020)
EN3[1]	CO2eq/ pkm	min	8.89	65.00	64.58	**207.08**	106.25	**58.33**	148.750	OECD/ITF (2020)
EC1[2]	zy€/ customer capacity/	min	4.50	3.00	**1.00**	4.00	2.00	**5.00**	4.00	Expert interviews (confidential)
EC2[1,2]	month	max	12.61	3.00	3.00	**5.00**	2.00	**1.00**	4.00	DriveNow (2018); Umweltbundesamt (2022); own calculations based on Civity (2019), Technologiestiftung Berlin (2019) and InnaMoRuhr survey
EC3[2]	% of vehicle/	max	5.41	**4.00**	**4.00**	**1.00**	3.00	2.00	3.00	BOGESTRA (2021); Kapalschinski (2021); Paravicini (2021); Schlesiger (2012)
EC4[3]	system	max	10.81	19.11	**44.21**	**0.05**	0.11	0.97	44.166	Own calculations based on InnaMoRuhr survey
SO1[1]	mio. €/year	min	6.52	0.19	**0.00**	1.27	**27.40**	9.10	27.397	Own calculations based on Destatis (2022a); Destatis (2022b); Gebhardt et al. (2021) and Nobis and Kuhnimhof (2018)
SO2[3]	%	max	6.52	11.70	11.80	**28.75**	18.70	**11.63**	17.125	Gerike et al. (2020a); Gerike et al. (2020b); Gerike et al. (2020c)
SO3[3]	Deaths/1 bn. pkm/	min	6.52	**0.06**	**0.06**	**9.73**	8.63	0.14	9.676	Own calculations based on InnaMoRuhr survey
SO4[3]	year	max	6.88	**74.49**	**74.49**	6.74	**5.06**	27.75	69.431	Own calculations based on InnaMoRuhr survey
SO5[3]	km/h	max	6.88	**98.93**	**98.93**	98.33	**98.14**	**98.14**	0.791	Own calculations based on InnaMoRuhr survey

Notes: [1] Transportation service-specific data; [2] Transportation service operator-specific data; [3] City-specific data.
The dimensions EN, EC and SO were weighted equally (1/3).
EC1, EC2 and EC3 used qualitative data.
Red numbers = worst alternative, green numbers = best alternative

4.4.2. Analysis of the outranking relation

The Graphical Analysis for Interactive Aid (GAIA) web visually represents the distance between criteria (GAIA plane) and the performance scores as net outranking flows (spider web) of the five alternatives on all criteria (Figure B-5): the further away from the centre, the higher the net flow score (Mareschal, 2013). Travel speed (SO2) for instance is high for car sharing (A3) but low for tramways (A2) and bike sharing (A5).

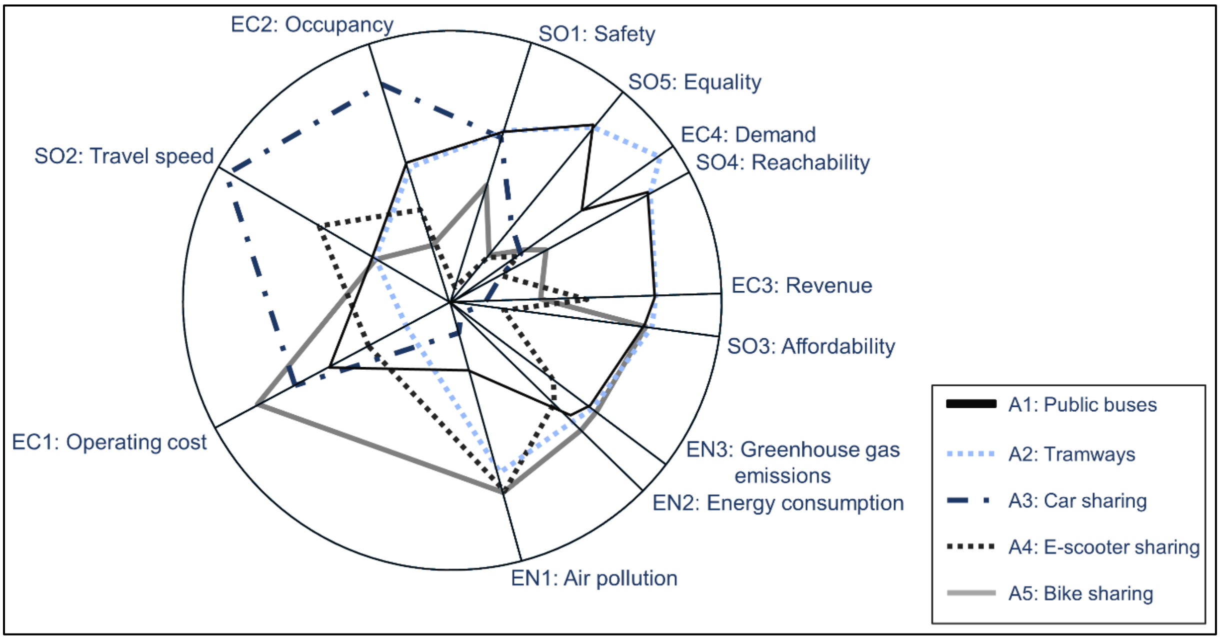


Figure B-5: GAIA web representing the unicriterion net Flow of alternatives based on Visual PROMETHEE (own elaboration)

4.4.3. Sensitivity analysis

The ranks were compared to those resulting from equal weighting (w_i = 1/12), as usually done in PROMETHEE (Witt et al., 2020). The unicriterion net flows as full rank orders (PROMETHEE II) from the proposed weighting were compared to the new weights as shown in Figure B-6. As for equal weights, buses (A1) and bike sharing (A5) slightly improved φ. Since the rank order remained the same, with tramways (A2) being the most sustainable alternative and car sharing (A3) the least one, model robustness was proven.

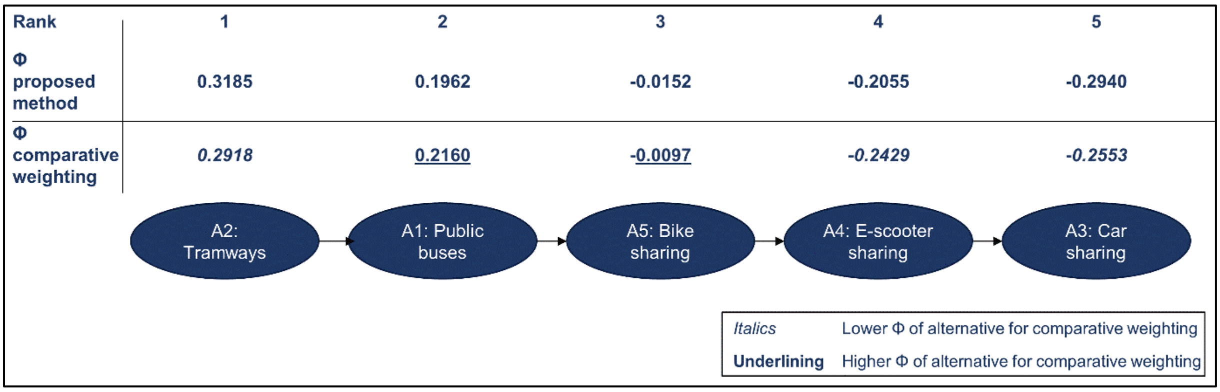


Figure B-6: Sensitivity analysis comparing the full rank order (PROMETHEE II) with different criteria weights (own elaboration)

5. Discussion

5.1. Empirical results

The main outcomes of the model formulation are a) the identification of conflicting criteria using ISM-P and b) the classification of the criteria according to their driving and dependence power using MICMAC analysis. They are useful regardless the transportation service or city examined. As for a), higher occupancy (EC2) and higher demand (EC4) increase the absolute operating cost (EC1) and demand (EC4) also increases energy consumption (EN2). To address the latter conflict, in general, transportation managers need to focus on increased system efficiency, e.g., through greater energy efficiency (using vehicles with lower specific energy consumption or more direct routing). These solutions can decrease energy consumption while lowering the operating cost and should hence be prioritised. Regarding b), the outcome of MICMAC analysis showed that the social sustainability criteria are the main drivers, whereas environmental criteria are rather dependent. Priority should be given to meeting the social sustainability criteria, in particular reachability (SO4) and equality (SO5), due to their influence on demand, e.g., by providing more (virtual) stops with barrier-free access.

PROMETHEE showed that public transportation services (tramways (A1) and buses (A2)) are the most sustainable alternatives (φ = 0.3185 and φ = 0.1962, see Figure B-6), followed by bike sharing (A5), e-scooter sharing (A4) and car sharing (A3). The importance of public transportation for sustainability goes in line with the discussion in the literature (Banister, 2008). Buses scored especially high on social criteria (affordability (SO3), reachability (SO4) and equality (SO5)), tramways also on economic criteria (e.g., demand (EC4)).

A more differentiated interpretation of the potential for improvement for each alternative regarding the sustainability dimensions (Figure B-5) shows that tramways (A2) should be improved in terms of operating cost (EC1), travel speed (SO2) and occupancy (EC2). Public buses (A1) need to improve air pollution, e.g. through electrification, which can also increase energy efficiency. Car sharing (A3) scores high on travel speed (SO2), occupancy (EC2) and operating cost (EC1) but must focus on lower energy consumption and GHG emission levels, e.g. through using battery electric vehicles charged with renewable energies. E-scooter sharing (A4) causes low levels of air pollution (EN1) but is especially unsafe (SO1) and has low demand (EC4). Bike sharing (A5) scores high on environmental criteria but is rather unsafe (SO1) and unequal (SO5). Both e-scooter (A4) and bike sharing providers (A5) should develop new business models to improve the financial performance and increase demand (EC4). Subsequently, an integrated offer of transportation services in which the weaknesses of one mode are outweighed by the strengths of another is needed, such as MaaS.

Special attention in the formulation of recommendations is paid to the conflicting criteria discovered through ISM-P and divergent performance scores of alternatives on these, validating the criteria conflict. The conflict between demand (EC4) and operating cost (EC1) is reflected in the performance scores of tramways (A2), which have the highest demand, but also costs. Since demand drives costs, efficiency levels in transportation should be increased. Also, for operating cost (EC1) and occupancy (EC2), the negative effect stated in ISM is evident for bike sharing (A5) in the PROMETHEE performance scores: the low operating costs are also due to low occupancy. To increase occupancy without increasing operating costs, better bike relocation systems based on real-time usage data should be developed. A negative relationship between demand (EC4) and energy consumption (EN2) was not proven for a specific alternative, which shows that decoupling is possible. The divergence of the scores of alternatives regarding two of the three negatively related criteria pairs demonstrates the usefulness of this combination. Although the Ruhr area was the use case due to its multi-layered structure the formulated decision model including the criteria and the weights can also be used in other regions, with possible local adaptation.

5.2. Methodological application

The presented multi-method approach is based on two levels. On the macro-level, concerning urban transportation in general, criteria interrelationships were assessed via ISM and expert opinion regardless of the specific city or transportation service under consideration. By having invited different stakeholders from different regions to participate, a criteria hierarchy was created that is useful for other case applications related to sustainable transportation. The generality was furthermore ensured by having collected criteria from a systematic literature review. The polarity of criteria relations, especially conflict, was discovered in ISM and later included in the performance score analysis of transportation service alternatives.

MICMAC analysis as an additional step in ISM was used to weight the criteria according to their driving and dependence power. Usually, weighting is based on the preferences of the decision-makers, whereby subjectivity is explicitly included. Here, a more objective criteria weighting based on criteria interrelations discovered through MICMAC was presented. It is therefore universally transferable and more objective, which was the aim of this research. Regarding weighting, the arithmetic mean was one option, although others do also exist (Girubha et al., 2016).

On the micro-level, PROMETHEE was used for specific transportation services available in the Ruhr region. A strength of PROMETHEE is its ability to integrate different kinds of data. Therefore, to provide anonymity of service providers, some data were translated into ordinal values. Another possibility could have been including fuzzy numbers of qualitative data. The settings used were based on previously executed research (see e.g. Tsoutsos et al., 2009) but could also be varied, e.g. the preference function type.

Sensitivity analysis showed that the alternative ranking did not change with equal weighting. On one hand, this is a sign of model and result robustness, on the other, the impact of this kind of weighting method is discussable. One reason for the robustness is that equal weights to the three sustainability dimensions on a higher level were defined.

As for the evaluation of the integrated framework, the knowledge of which objectives diverge (ISM-P) proved to be correct in most cases and provides help to deduct differentiated recommendations for each transportation service after having structured the problem and the goal hierarchy. The integration of polarity in ISM before the alternative ranking was therefore useful.

6. Conclusions, limitations and outlook

The article proposed a novel approach to explicitly integrate the complexity of sustainable mobility, arising out of different analytical levels, spatial scales, transportation modes, and necessary multivariate procedures for criteria interdependencies, into decision analysis by combining ISM-P and PROMETHEE. As for RQ1, the best way to systematise interrelationships among criteria is ISM, for the extensions adopted (polarity and MICMAC analysis) and for their wide applications in transportation research. It is furthermore the only method applied so far to MCDA regarding inter-criteria relations found in the literature review. The criteria interrelations are best considered by weighting them according to their driving and dependence power and by including negative relations when analysing the alternative performances on diverging criteria, especially for formulating recommendations (RQ2). Regarding RQ3, the importance of public transportation in sustainable mobility is proven because tramways and public buses scored highest.

There are several limitations in the interpretation of the results. First, transportation and mobility behaviour are complex topics, so a simplification of the model was necessary in terms of (a) the number of criteria included, (b) the number of alternatives selected and (c) the investigation area selected for the application. In addition, city-specific data were not available for all criteria and alternatives. For example, survey-based data were used to develop the model for some quantifications (Table B-4), which were not representative because the respondents were university students and employees. Limitations also arise from the methods used. Inflation increased after data collection (spring 2021) as well as fuel prices, leading to a discussion about a nationwide reduction in public transportation fares in Germany. Hence, this analysis should be repeated hereafter. Future research should extend these results as follows:

- Other criteria sets, alternative mobility options and different cities should be analysed;
- New city-specific data should be collected to enable a sustainability city ranking regarding the entirety of available transportation services and the mobility behaviour, e.g. as a continuous monitoring system;
- Other methods for statistical validation of the identified dependencies, such as structural equation modelling, should be applied;
- A look at sustainable future scenarios is also important to deduce policies that enable viable business models for transportation service providers.

The main concept of mobility services like MaaS is to place users at the centre of transport services and offer them tailored mobility solutions based on their individual needs. Therefore, it is a new paradigm in the transport planning sector to a seamless and connected mobility offer as one toolkit for a sustainability mobility transition. With the advent of such solutions, complexity rises and subsequently, new decision models with multiple conflicting goals are needed. Including the interrelations transparently into decision analysis is facilitated with this proposed method and is applicable to most sustainability assessments of transportation services. Therefore, the study serves as a reference for other cities that want to assess the sustainability of their transportation services.

Chapter C: Composition of a Mobility as a Service offer for university students based on willingness to pay and its determinants

Abstract

The uptake of Mobility as a Service (MaaS) is imminent, especially among university students, a customer group likely to promise superior revenue. Because research on students' willingness to pay (WTP) for MaaS is still missing, this study provides an analysis on students' MaaS preferences, including differences between students, preferences of services, and their WTP to design MaaS bundles and discover the revenue potential. A conjoint analysis was conducted among 1,165 students at the University Alliance Ruhr, Germany. The average WTP was €26.81 for a monthly MaaS package. Offering integrated MaaS packages increased utility. Three benefit segments based on transportation attribute importance (for e-scooters, bike and car sharing and on- demand e-shuttles) were identified: car users, frugal bike users, and generous multimodal flexibles. The results showed that latent variables such as attitudes and perceptions explain differences between the segments. Revenue is significantly higher for offering segment-specific MaaS packages than for a generic one.

Keywords

mobility as a service; MaaS, willingness to pay, clusters, mobility behaviour, Germany

1. Introduction

MaaS is an emerging technology reshaping the structure of the automotive industry (Adner and Lieberman, 2021; Fournier et al., 2020; Júnior et al., 2019). It is characterised by the integration of several transportation modes, individualisation, a digital platform, and collaborative consumption through sharing models (Jovic and Baron, 2019). The "young generation" (age 18−25) has a higher affinity for shared and multimodal transportation and often participates in the age-based life event of university studies, which influences mobility demand (Proff, 2019; Shaheen et al., 2016). Thus, commuters of large universities and regional university alliances have been of focal research interest. Students had significantly different trip frequencies, mode choices and distances travelled from the general population (Hafezi et al., 2019; Khattak et al., 2011). Students are an important target group due to their role as the future generation of mobility demanders (Nordfjærn et al., 2019). Furthermore, retaining students as customers increases long-term revenue. In Germany, the average annual gross salary of academics is around 34% higher than the gross salary of people without a university degree (StepStone GmbH, 2021). Thus, promoting MaaS to university students is one leverage for future revenue potential. However, students are a heterogeneous customer group with significantly differing mobility preferences (Groth et al., 2021). Because, in general, segmentation is gaining increasing popularity in transportation research (Nash and Mitra, 2019), it is essential to uncover which segments exist and which specific variables lead to significant differences between customer segments. By doing so, MaaS offers that are appealing to the most users possible can be designed.

This research applies conjoint analysis, an indirect price query evaluating product bundles (Eggers and Sattler, 2011; Völckner, 2006), to measure WTP for MaaS. Although evidence is limited (Polydoropoulou et al., 2020a), preliminary research indicates that the WTP is generally beneath cost-covering prices (Liljamo et al., 2020; Proff and Szybisty, 2019). Thus, when designing a MaaS model, its revenue potential must be considered. Even though WTP and MaaS bundling have been assessed in previous studies (e.g., Guidon et al., 2020; Ho et al., 2018, 2020; Matyas and Kamargianni, 2019; Mulley et al., 2020; Reck et al., 2020), as well as segmentation of MaaS customers (e.g. Alonso-González et al., 2020; Farahmand et al., 2021; Vij et al., 2020), those topics have not been researched for university students. Consequently, this study aims to answer the following research questions:

1. What relative importance do students have for different MaaS attributes and, therefore, WTP?
2. Which homogeneous student segments result from benefit segmentation and in which variables do they differ significantly?
3. How does revenue potential change from offering one generic preference-maximising MaaS package to creating segment-specific integrated MaaS offers?

The remainder of this paper is structured as follows. First, a literature review is presented to support the need for an empirical examination (Section C.2). In Section C.3, the theoretical background and explanations are provided to formulate assumptions made on MaaS market opportunities regarding university students. In Section C.4, the empirical study for the University Alliance Ruhr in Germany is described, followed by the analysis and market simulations with 1,165 respondents and the presentation of the results in Section C.5. The study concludes with implications for theory and practice, limitations, and an outlook in Section C.6.

2. Literature review

2.1. University students' mobility behaviour

Given the nascent status of extant literature on university students' WTP for mobility offers, our review focuses on a broader field of previously researched topics concerning students' mobility, among others, mode choice (Nash and Mitra, 2019). Compared with other age groups, university students are more mobile, multimodal, and willing to use alternative modes, especially walking and cycling (Bagdatli and Ipek, 2022; Cadima et al., 2020; Páez and Whalen, 2010; Whalen et al., 2013; Zhou, 2012). Students are more likely to associate an enjoyable commute with active transportation than with motorised modes (Páez and Whalen, 2010). In developing countries like Brazil, especially in rural areas, casual carpooling is a common way to commute among public university students (Gandia et al., 2021a). Students (millennials) are more likely to use MaaS offers due to their features such as customisation and monthly subscription plans (Gandia et al., 2021b). Companies usually target the generation young for disruptive technologies as bike and car sharing (Nash and Mitra, 2019). However, not all students commute sustainably.

Numerous studies have investigated the determinants of students' mode choice with varied findings. Mobility preferences differ depending on the students' income: The "young cosmopolitans" are multimodal and have postmaterial values, whereas the "middle class" still values car ownership (Groth et al., 2021). Furthermore, transportation lifestyles are highly dependent on other sociodemographic aspects. For instance, students living with their families are more transit-dependent (Nash and Mitra, 2019 with regard to Canada). Variance in car usage is furthermore explained by situational (e.g. car access, weather conditions, trip destination) and personal variables (e.g. commuting habits, perceived behavioural control and social norm) (Klöckner and Friedrichsmeier, 2011). Hence, the built environment also influences transportation mode choice (Nash and Mitra, 2019). Regional differences must therefore be considered in the analysis. The COVID-19 pandemic led to further changes in mode choice: car ownership increased the likelihood of students to use public transportation less (Bagdatli and Ipek, 2022). Meanwhile, Zhou (2012) discovered that choosing walking, biking, or public transportation correlates with gender and age. Multimodal travel behaviour increases the utility of modes alternative to cars. The effect of gender on car usage is ubiquitous. Car dependency is higher for female students (Nash and Mitra, 2019), but in the group of young people (aged 16-29), in general, more men choose private transportation, whereas women tend to share transportation and walk (Maciejewska et al., 2019). Nordfjærn et al. (2019) showed that bike choice is determined by psychological and situational factors. Demand for public transportation increased if train services increased frequency and bus tickets were cheaper, as investigated by Bilbao Ubillos and Fernández Sainz (2004). Moreover, costs, personal attitudes, and travel demand measures also influence choice significantly, as concluded by Whalen et al. (2013). Because the determinants of mode choice vary, one obstacle is finding unambiguous predictors for the supposedly homogeneous segment of students.

2.2. MaaS and WTP

MaaS bundles mobility offers, fosters cooperation across the transportation stakeholders, and integrates transportation services into one interface (Kamargianni and Matyas, 2017). Additionally, MaaS is defined as the “3Bs”: bundles, brokers, and budgets (Hensher, 2017). In particular, budgets are important because the price of MaaS is the most critical determinant of its uptake (Alyavina et al., 2020). It is determined through WTP, the maximum price a buyer would accept for a given offer (Bowman and Ambrosini, 2000; Fojcik and Proff, 2014; Günthner et al., 2021).

Some studies have already analysed the WTP of potential users for specific MaaS bundles. In a study conducted in Finland by Liljamo et al. (2020), €137 was the average price considered suitable for a monthly package, with a median of €100. According to Jang et al. (2021), potential users in the Netherlands had a positive utility for a price up to €180 for MaaS but a negative utility for €210 or more. High price sensitivity is given for a monthly subscription, but longer contracts are preferred as found in a study conducted in the Netherlands (Caiati et al., 2020). However, heterogeneity is significant between individuals’ WTP for mobility bundles, as found among respondents in the UK (Polydoropoulou et al., 2020a). Although added value is seen in MaaS (i.e., information transparency and improved services), none of the potential customers was willing to pay for this in the study by Alonso-González et al. (2020) in the Netherlands. Regarding specific modes, a study by Ho et al. (2018) found that WTP for one-day access of car sharing is approximately $34 but WTP for a day of unlimited public transportation use is only $6 in Australia. Furthermore, WTP based on the reason for travel has been analysed in Australia: it is higher for a medical trip (around $14) than for shopping ($8) or a social trip ($7) (Mulley et al., 2020).

Because WTP is derived from utility, another research topic in MaaS is the utility that unimodal offers provide. One study in the Netherlands showed that the primary driver of MaaS utility is public transportation, followed by bike and car sharing (Feneri et al., 2020). Another study conducted in Switzerland found that car sharing and public transportation have higher utility when offered in a bundle than (e-)bike sharing and taxi services (Guidon et al., 2020).

Regarding the tariff structure, MaaS either includes pay-as-you-go (PAYG) options, which are only paid for when needed, or subscriptions composed of several mobility offers (Jittrapirom et al., 2017). A study in the United Kingdom and Australia found that, in general, subscription is preferred over PAYG options but that it varies among customer segments (Ho et al., 2020). In Germany, price-sensitive people without a fixed income prefer PAYG options (Stopka et al., 2018). In Australia, young to middle-aged respondents, as well as individuals with higher education are in general more likely to use MaaS (Vij et al., 2020), demonstrating the need for research on university students. Because the outcomes of previous studies are heterogeneous, further research should include promising customer groups as specific target respondents (Reck et al., 2020). To fill this gap, assumptions on students' MaaS preferences and WTP are derived from choice theory and the service-dominant logic.

3. Assumptions

3.1. Choice theory

Since the 1960s, economic consumer theory has focussed on variations in behaviour and how to model them (McFadden, 2001) by transforming assumptions about desires into demand functions (Ben-Akiva and Lerman, 1985). According to this theory, a customer always chooses the utility-maximising offer among all other alternatives (McFadden, 1986). Lancaster (1966) posited that consumers derive utility from several product attributes (Ben-Akiva and Lerman, 1985). The underlying utility theory is concerned with individual choices, values, and preferences (Fishburn, 1968). Both discrete choice and classical economic consumer theory suppose that utilities vary among consumers. Therefore, segmentation and the integration of socioeconomic variables are areas of research in both choice and utility theory (Ben-Akiva and Lerman, 1985). However, because attitudes and perceptions fluctuate, customer preferences were found to likely include random components (McFadden, 1986). Hence, random utility theory surged, first in psychology through Thurstone (1927) and later in economic research through Marschak (1974). Because the consumers' utilities are not certainly known to the researcher, they are taken to be random variables, still assuming that the individual only chooses utility-maximising options. The random error included explains observational deficiencies by the researcher and missing information about the product, such as unobserved attributes or taste variations (Manski, 1973, 1977). Thus, it accounts for the differences between the actual choice and the predicted one from the empirical demand assessment (Ben-Akiva and Lerman, 1985).

The random utility theory is an interpretation of probabilistic choice theory, adding the probability with which an individual selects one option among a finite set of alternatives. It is successful due to its integration of heterogeneous unobserved characteristics as taste and perception-forming mechanisms and experience into choice behaviour. Hence, in accordance with random utility, McFadden introduced latent variables as an extension of the theory of rational choice. According to this theory, consumers first gather information about the possible alternatives, then they apply probability rules to transform the information into attributes before entering the cognitive decision process of aggregating perceived attribute levels into a utility index (McFadden, 2001). The consumer is modelled as a black box, and the decision process is mapped from input (e.g., experience) to output (purchase decisions) (McFadden, 1986). The latent variables added are psychological factors to explain variability, making them an important recent research object (Ben-Akiva and Lerman, 1985; McFadden, 2001; Vij and Krueger, 2017). Attitudes influence perceptions as part of the choice process, stating that utility maximisation is only one out of many factors in decision making. In particular, the perceptions of attributes, such as mental accounting for cost and time, are rather unexplored but important aspects of the decision process (McFadden, 2001). Transportation preferences and motivation or affect are further parts of the decision process, as well as past commuting experience and socioeconomic factors forming memory about commuting. Behavioural intention is also part of the black box (McFadden, 1986). An overview of the latent variables in the black box of the customer choice process is shown in Figure C-1 connected with links of psychological factors (dotted arrows).

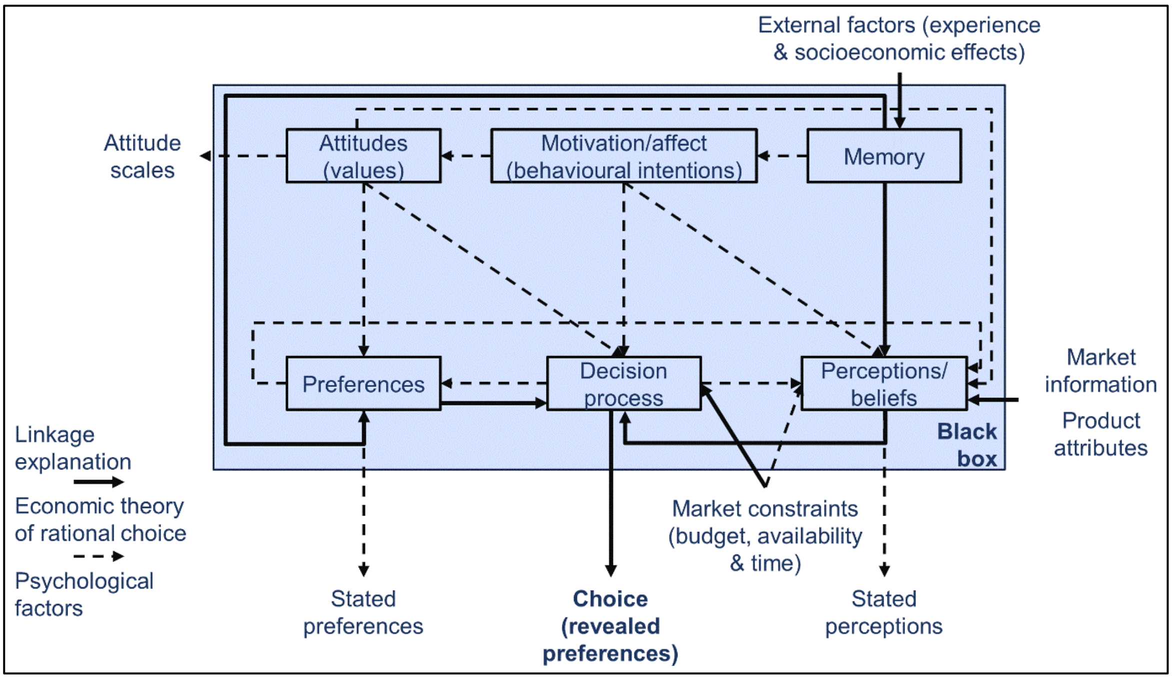


Figure C-1: The choice process in consumer decision-making (based on McFadden, 1986, p. 276 and McFadden, 2001, p. 356)

The developed choice models are, among others, applied to detect price effects on demand. Both price importance and mode choice are heterogeneous (McFadden, 1986, 2001). The latent variables in Figure C-1 also serve to find differences between consumer segments that are homogeneous in their utility from transportation modes found through benefit segmentation (Wind, 1973). The following assumptions were formulated in line with choice theory:

A1a *Students differ in their price sensitivity with respect to latent variables of the choice process.*

A1b *Benefit segments differ in the latent variables of the choice process.*

3.2. Service-dominant logic

Another explanation concerning utility and how it depends on the context (but from a resource-based perspective) is the service-dominant logic. It builds on value co-creation together with the customers as operant resources through reciprocal service exchange. This logic consists of four main axioms: 1) service as the basis of exchange, 2) value co-creation by many actors, including the customer, 3) the function of all actors as resource integrators, and 4) the determination of value by the customer alone (Vargo and Lusch, 2013).

The importance of service integration is given because the customer value depends on the specific resource combination a service comprises (axiom 3, resource integration) (Lusch et al., 2007; Sawhney et al., 2006; Vargo and Lusch, 2013, 2016). To increase the value, standardised components are combined for individual requirements in a modular system (Davies et al., 2007). Because each customer values a certain offer differently, consumer orientation calls for heterogeneous and demand-responsive customised offers (axiom 4, individualisation; Danneels, 2003; Vargo and Lusch, 2004b, 2016).

The central research object in the service-dominant logic is value and its definition. Although all parties are value beneficiaries and value creators, value can only be determined by the customer (Lusch and Vargo, 2006). The existence of value-in-use (utility) is the premise for value-in-exchange (revenue), whereby the (monetary) value-in-exchange is determined by the customer (via WTP; Grönroos, 2008). Thus, the value proposition is the promise of a link of value-in-exchange to the customer to value-in-use (Lusch et al., 2007; Vargo and Lusch, 2004a). A better understanding of how value is perceived by the heterogeneous customers leads to more effective pricing, which helps firms appropriating value and thereby generating economic rents (Dutta et al., 2003; Lusch et al., 2007).

The service-dominant logic is an appropriate explanation for the sake of MaaS because an essential part of the business model is bundle composition into multimodal offers consisting of different mobility offers (axiom 3) in accordance with the individual customer value (axiom 4)

(Hensher, 2017; Reck et al., 2020; Sommer et al., 2021). Consequently, we derived two assumptions. A2a follows axiom 3, whereas A2b is formulated in accordance with axiom 4:

A2a The students' utility for a multimodal integrated mobility package (MaaS) is higher than for unimodal PAYG offers.

A2b The revenue potential is higher for offering segment-specific MaaS packages than for one generic MaaS bundle.

Summarising the aforementioned, Table C-1 provides an overview over the four research assumptions to be investigated in the following sections.

Table C-1: Assumptions about MaaS offers for university students (own elaboration)

Code	Assumption
A1a	Students differ in their price sensitivity with respect to latent variables of the choice process.
A1b	Benefit segments differ in the latent variables of the choice process.
A2a	The students' utility for a multimodal integrated mobility package (MaaS) is higher than for unimodal PAYG offers.
A2b	The revenue potential is higher for offering segment-specific MaaS packages than for one generic MaaS bundle.

4. Empirical study

4.1. Study design

To investigate the stated assumptions and discover the market opportunity of MaaS among university students, first, utilities and the derived WTP were assessed. This assessment was performed using conjoint analysis because it is a methodology for WTP estimation from utilities following random utility theory (McFadden, 1986). Benefit segmentation is performed based on the relative importance of transportation attributes calculated through conjoint analysis (DeSarbo et al., 1995). Based on the clustering, various statistical tests were used to look for differences between the groups.

Conjoint analysis is the best method for estimating WTP for new products, such as MaaS (Hair et al., 2010). Some recent applications corroborate the usefulness in this field of research (see e.g. Stopka et al., 2018 or Maas, 2021).

It is used for converting subjective responses on product alternatives evaluated as a bundle of attributes into estimation parameters of part-worth utilities in a decompositional manner through indirect price queries (Eggers and Sattler, 2011; Green and Srinivasan, 1978). The choice-based conjoint analysis depicts an actual purchase decision most realistically and is therefore preferred over ratings and rankings (Souka et al., 2020). The following steps are used in the analysis (Eggers and Sattler, 2011):

1. Determination of the study design,
2. Definition of the choice design,
3. Survey design,
4. Model estimation, and
5. Analysis and interpretation.

The first three steps belong to data collection, Step 4 is part of analysis and results (also called statistical analysis) and the last one is renamed discussion of results. The analysis and results part involves examining the specific assumptions (Table C-1), as shown in Figure C-2, through descriptive statistics, tests for differences, cluster analysis and market simulations.

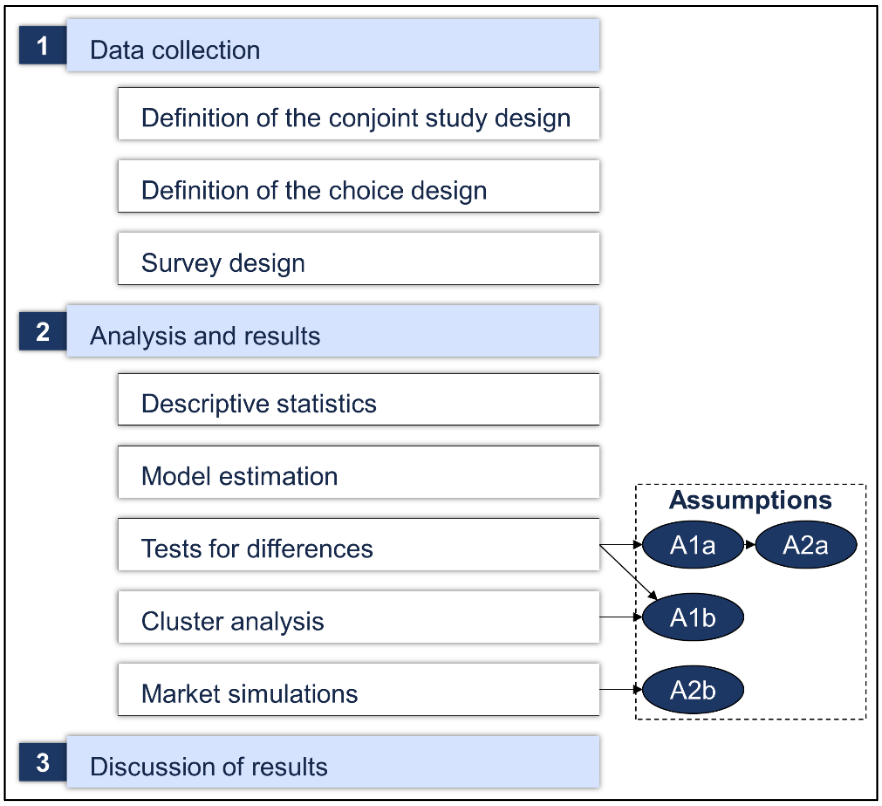


Figure C-2: Research design (adopted from Eggers and Sattler, 2011, p. 39 and Gandia et al., 2021a, p. 6)

In the model estimation, transforming choices into part-worth utilities based on a utility function is crucial (Eggers and Sattler, 2011; Green and Srinivasan, 1978; Orme and Chrzan, 2017). The hierarchical Bayes model is the one most widely applied for this, especially in transportation modelling (McFadden, 1986, 2001). It is a hierarchical multinomial logit model because it consists of two levels: the superordinate model for population averages and the subordinate one for individual-level utility estimation. The superordinate one assumes a multivariate normal distribution, complementing the information inefficiency of individual estimation (Eggers and Sattler, 2011). As shown in Eq. C.1, the vector of part-worths β of individual i consists of a vector of means of the distribution of part-worth utilities of each individual (α) and a matrix of covariances and variances of the distribution of part-worths across individuals (D) (Orme and Chrzan, 2017):

$$\beta i \sim Normal\ (\alpha, D) \tag{C.1}$$

On the subordinate level (Eq. C.2), the choice probability for an alternative among all other ones is estimated for each respondent (Orme and Chrzan, 2017):

$$U_{jm} = B_j X_m + \varepsilon_{jm} \tag{C.2}$$

with

U_{jm} = utility and random error for the respondent j and the mth alternative,

B_j = vector of part-worth utilities for the jth respondent,

X_m = vector of design codes describing alternative m, and

ε_{jm} = independent and identically distributed right-skewed Gumbel distributed random variable for respondent j and alternative m.

A post hoc methodology for finding customer subgroups is benefit segmentation, based on the benefits of a customer sought from a product attribute as output data from conjoint analysis (DeSarbo et al., 1995; Wind, 1973). It was introduced by Haley (1968) as an alternative approach based on causal factors instead of sociodemographic variables because the latter are rather poor predictors of individual choice. Either the part-worth utilities or relative importance values serve as a basis for segmentation (Andrews et al., 2002; Hair et al., 2010). As executed by Souka et al. (2020), this research forms segments based on relative importance. A common approach for determining homogeneous benefit segments is cluster analysis (Hair et al., 2010), in which segment sizes and numbers are only determined by the choice-based conjoint data (DeSarbo et al., 2001). Because price highly correlates with the remaining attributes in conjoint analysis, it must be excluded (Hair et al., 2010; Wind, 1973). In general, cluster analysis based on a non-hierarchical method, mostly k-means, is used for segmentation (Gurcaylilar-Yenidogan, 2014; Hair et al., 2010). Furthermore, the latent variables in Figure C-1 are examined in their ability to significantly distinguish segments and price sensitivity using tests of differences.

The last part in analysis and results (Figure C-2) is the transformation of the part-worth utilities into predicted market choices through market simulations. A method for estimating relative demand curves is sensitivity analysis for product attributes. Thus, WTP is determined as the point at which a rising price leads to the product under investigation no longer being the preferred one (Eggers and Sattler, 2011). Another useful method for market simulation is to optimise products for revenue (Orme, 2010).

4.2. Empirical setting

This study was conducted as part of the research project “InnaMoRuhr” (concept of an integrated, sustainable mobility for the University Alliance Ruhr) funded by the Ministry of Transport of North-Rhine Westphalia in Germany. It aims to develop concepts for the mobility of members of the University Alliance Ruhr and to validate them via simulations and field trials. The University Alliance Ruhr consists of the universities of Duisburg-Essen, Bochum, and Dortmund and is in the German Ruhr metropolitan area. The alliance comprises a total of approximately 136,000 members, of which 120,000 are students. A first step in the project was identifying mobility demands and practices using surveys (Handte et al., 2022). For this aim, all members were contacted to participate in a survey, and 10,782 valid and complete records were gathered. The 10,782 survey respondents could opt to further participate in the survey for conjoint analysis subject to this research, which was conducted from April 20 to May 25, 2021. Their answers in the conjoint analysis were matched with their previous answers in the survey about mobility demands and practices.

4.3. Data collection

An adaptive choice-based conjoint analysis was chosen as conjoint study design using Sawtooth Software to combine the advantages of time efficiency of choice-based conjoint analysis and of realistic price adaptions through a summed price option. To decrease linear dependency from the other attributes, a random shock ranging from −30% to +30% of the summed price was integrated in the choice design, and prices were rounded to the nearest €10 (Orme and Chrzan, 2017). The study included the following MaaS transportation attributes: car sharing, (e-)bike sharing, e-scooter sharing, and on-demand e-shuttles. The selected mobility offers are also represented globally in cities (OECD/ITF, 2020). Public transportation was not included because all participants have a discounted subscription provided by the universities. Because it is considered the backbone of MaaS (see e.g. Pangbourne et al., 2020) and there is a focus on sustainable mobility in the project setting, MaaS bundles should not be offered as supplementary but as complementary services to public transportation. Therefore, on an integrated MaaS platform (app), intermodal routes should take public transportation into account and the semester ticket should be stored for fare calculations and ticket checks. Hence, the goal should be to merge the systems into one in the medium term.

For each transportation attribute, three different levels were defined, following previous studies (e.g. Souka et al., 2020) and to avoid a number-of-levels effect (Verlegh et al., 2002). The attributes and the level prices were collected via a combination of literature analysis on MaaS bundling, adapted to the students' smaller available income and market research in the four cities the University Alliance comprises (Duisburg, Essen, Bochum, and Dortmund). This resulted in different numbers of trips, distance, or time contingents as service levels depending on the existent offers. Furthermore, all attributes included a PAYG level. The attributes and levels with their costs for summed pricing used in this research are listed in Table C-2.

Table C-2: Elements of the MaaS offers and their monthly costs as an input for conjoint analysis[1] (own elaboration)

Attributes		**On-demand e-shuttle**	**Price [€]**	**Car sharing**	**Price [€]**	**(E-) bike sharing**	**Price [€]**	**E-scooter Sharing**	**Price [€]**
Attribute levels	**1**	PAYG	0	PAYG	0	PAYG	0	PAYG	0
	2	Up to 10 trips at one university	22	Up to 3 h or 100 km	14	Up to 30 min normal bike, any number of times	10	Up to 10 trips or 50 min	17
	3	Up to 10 trips among the universities	48	Up to 6 h or 200 km	30	Up to 30 min e-bike, any number of times	15	Up to 20 trips or 100 min	34

[1] For the sake of conciseness, although the package includes a pedelec, the attribute is called (e-) bike sharing

The survey design was as follows. First, a build-your-own task was shown in which the respondents could select their preferred level for each attribute, thereby composing their favourite MaaS package. Afterwards, each respondent was shown eight choice sets with three alternatives in each one. These tasks were generated automatically with an algorithm producing near-orthogonal design and avoiding dominated concepts (Sawtooth Software, 2014). A none-option was not included in the choice sets; however, respondents were asked their real WTP for each chosen alternative.

5. Analysis and results

5.1. Descriptive statistics

In total, 1,487 students completed the survey for the conjoint analysis. Data cleaning was performed to enhance data quality by removing respondents replying faster than the 10th percentile or slower than the 90th percentile, following Souka et al. (2020). Moreover, answer consistency was chosen as a further cleaning criterion using the root likelihood of each respondent, as described in Orme (2019). Altogether, 318 respondents were excluded. The final sample consisted of 1,165 respondents.

The answers in the mobility behaviour survey were combined with the conjoint data to provide a sociodemographic sample description. The female gender was slightly overrepresented (609, 52.1%); 540 male (46.2%) and five non-binary (0.4%) respondents participated, with 11 not indicating their gender. The majority (942, 80.6%) of the respondents were aged between 20 and 29 years, supporting that university studies are an age-based life event. Of the final sample, 156 respondents (13.4%) were older than 29 years and 66 (5.7%) younger than 20 years; one person did not respond. Additionally, as expected, the indicated monthly net income was relatively low, with the largest income group being €750 up to €1,000 (271, 23.3%). Overall, 34.6% had a monthly income lower than €750 (403), and 30.0% had one higher than €1,000 (349); 142 participants did not respond (12.2%). Most of the participants possessed a driver's licence (1,064, or 91.3%). In terms of available transportation modes (n = 1,106), 702 (63.5 %) had access to at least one car (any combustion type), 860 (77.8%) to a normal bike, 48 (4.3%) to an e-bike and 76 (6.9%) to an e-scooter.

5.2. Model estimation

The hierarchical Bayes model estimated has a goodness of fit (McFadden's *Pseudo* R^2) of 0.617, proving internal model validity (McFadden, 1979). The statistical significance of the model parameters was computed via asymptotic t-tests (Louviere et al., 2010), as shown in Table C-3. Apart from the attribute levels "PAYG" and "up to 20 trips or 100 minutes" (significant at the 0.05 level) for e-scooter sharing, all parameters were significant at the 0.01 level.

From these attribute parameters, relative importance was computed by dividing the range of attribute levels by the sum of ranges of all attributes (Hair et al., 2010), as shown in Table C-4. The price attribute was by far the most important one (69.9%), which is not surprising given the relatively low income of the respondents (Proff, 2020). Bike and car sharing were valued almost equally high with 9.6% and 9.4%, respectively, followed by on-demand e-shuttles (6.5%) and e-scooter sharing (4.6%). Heterogeneity is observable through considerable standard deviations (Souka et al., 2020), especially for the price importance (12.34).

Table C-3: Hierarchical Bayes parameter estimates (own elaboration)

Attribute	Attribute level	Mean part-worth utility	SD
On-demand e-shuttle	PAYG	−8.63**	20.66
	Up to 10 trips at one university	2.28**	12.34
	Up to 10 trips among the universities	6.35**	17.50
Car sharing	PAYG	−9.61**	29.35
	Up to 3 h or 100 km	3.20**	10.51
	Up to 6 h or 200 km	6.41**	25.73
(E-)bike sharing	PAYG	−22.54**	24.18
	Up to 30 min normal bike, any number of times	11.41**	15.24
	Up to 30 min e-bike, any number of times	11.13**	15.98
E-scooter sharing	PAYG	0.13	14.91
	Up to 10 trips or 50 min	0.67**	7.83
	Up to 20 trips or 100 min	−0.79*	12.42
Price	€0	144.69**	44.63
	€20	59.52**	25.97
	€30	38.51**	22.30
	€40	19.54**	17.98
	€50	−1.54**	12.68
	€60	−20.54**	11.65
	€70	−35.16**	11.58
	€160	−205.02**	58.31
Notes: N = 1,165; SD, standard deviation; zero-centred part-worths lead to negative utilities, which can only be interpreted in relation to other part-worths for the same attribute. * Parameter is significant at the 0.05 level (two-tailed). ** Parameter is significant at the 0.01 level (two-tailed).			

Table C-4: Relative importance of Mobility as a Service package attributes (own elaboration)

Attribute	Relative importance [%]	SD
Price	69.94	12.34
(E-)bike sharing	9.60	6.14
Car sharing	9.35	6.84
On-demand e-shuttle	6.46	5.59
E-scooter sharing	4.64	3.23
Notes: N = 1,165; SD, standard deviation; due to the rounding of the data, the sum of the relative importance does not equal 100%”		

Table C-5 shows the change in WTP for each attribute regarding the reference level (PAYG). Negative values reflect disutility of an offer integration relative to the PAYG option. Competitive products as the unimodal options (levels 2 and 3) with the prices indicated in Table C-2 were included in the simulation. As WTP is additive (Mulley et al., 2020), the maximum WTP for a MaaS offer of shuttle usage among the universities, 6 hours or 200 km car sharing, e-bike sharing, and PAYG e-scooter sharing was €26.81.

Table C-5: WTP estimation resulting from market simulation (own elaboration)

Attribute (level)	WTP	SD	Attribute (level)	WTP	SD
On-demand e-shuttle			**(E-)bike sharing**		
PAYG	RL		**PAYG**	RL	
Up to 10 trips at one university	3.67	43.00	**Up to 30 min normal bike, any number of times**	7.95	54.04
Up to 10 trips between the universities	13.44	142.91	**Up to 30 min e-bike, any number of times**	8.06	46.95
Car sharing			**E-scooter sharing**		
PAYG	RL		**PAYG**	RL	
Up to 3 h or 100 km	−4.22	67.88	**Up to 10 trips or 50 min**	−5.63	39.72
Up to 6 h or 200 km	5.31	48.41	**Up to 20 trips or 100 min**	−3.05	46.47
Notes: N = 1,165; SD, standard deviation; RL, reference level.					

5.3. Tests for differences

The definition of MaaS contains the bundling of at least two transportation modes (Caiati et al., 2020). Because PAYG means that an offer is not integrated into the monthly package (as for assumption A2a), the preferred level for the transportation attributes should be different than PAYG for at least three of the four attributes. Paired t-tests for differences between the mean part-worth utilities of PAYG and the other two attribute levels for each mode were performed, and the results are shown in Table C-6.

Another important aspect regarding WTP and utility is understanding the determinants. Hence, assumptions A1a and A1b were tested. Because utilities estimated through hierarchical Bayes models are calculated from choice experiments, variables from Section C.3.1 with a sufficiently large N were used, namely:

- memory (from experience; previous mode choice since the COVID-19 outbreak; the possession of a driver's license and combustion car and bike availability),
- attitudes (environmental awareness and social norm for cars, public transportation and bikes),
- preferences (the priorities for commute [speed, price, environment, comfort, safety, reliability and enjoyment]),
- perceptions (the overall evaluation of cars, public transportation and bikes), and
- motivation/affect (affinity for technology and self-efficacy).

Furthermore, socioeconomic factors (gender, age, income, and household size) were included in the analyses.

Table C-6: Paired t-tests for differences between PAYG and other transportation attribute levels (own elaboration)

Attribute (level)	Mean part-worth utility	SD	T	df	p
On-demand e-shuttle					
PAYG	−8.63	20.66	−15.47	1,901	< 0.001**
Up to 10 trips at one university	2.28	12.34			
PAYG	−8.63	20.66	−18.875	2,267	< 0.001**
Up to 10 trips among the universities	6.35	17.50			
Car sharing					
PAYG	−9.61	29.35	−14.02	1,458	< 0.001**
Up to 3 h or 100 km	3.20	10.51			
PAYG	−9.61	29.35	−14.01	2,289	< 0.001**
Up to 6 h or 200 km	6.41	25.73			
(E-)bike sharing					
PAYG	−22.54	24.18	−40.54	1,963	< 0.001**
Up to 30 min normal bike, any number of times	11.41	15.24			
PAYG	−22.54	24.18	−39.65	2,018	< 0.001**
Up to 30 min e-bike, any number of times	11.13	15.98			
E-scooter sharing					
PAYG	0.13	14.91	−1.10	1,760	0.27
Up to 10 trips or 50 min	0.67	7.83			
PAYG	0.13	14.91	1.62	2,255	0.11
Up to 20 trips or 100 min	−0.80	12.42			

Notes: N = 1,165; SD, standard deviation.
* Parameter is significant at the 0.05 level (two-tailed).
** Parameter is significant at the 0.01 level (two-tailed).

The results were analysed with IBM SPSS software. First, because price was of the highest importance, meaning that price sensitivity was high (Orme and Chrzan, 2017), we analysed whether respondents with different characteristics in the latent variables are significantly different in their price sensitivity, using a similar approach as Liljamo et al. (2020). As a requirement for discriminant analysis is metric data and not all data are metric, for comparability issues, we used the less restrictive Kruskal-Wallis test for most of the metric and ordinal data; whenever the requirements for a one-way analysis of variance (ANOVA) for continuous variables were met, this test was applied. The t-test was used for binary variables (gender because the *n* for non-binary respondents was too low).

The results showed that regarding socioeconomic variables, there are significant differences in price sensitivity only among income groups (Kruskal-Wallis: $H = 19.77$; $df = 7$; $p = 0.01$). According to one-way ANOVA for latent variables regarding price sensitivity (assumption A1a), the respondents' preferences (priorities in mode choice), differed by amount; for different levels of the priority of comfort, a significant difference is shown in price sensitivity ($F(2, 1{,}162) = 3.78$; $p = 0.02$). A weak significant difference in price sensitivity was given for the priority of price ($F(2, 1{,}162) = 2.75$; $p = 0.07$), for environmentally friendly commuting ($F(2, 1{,}162) = 2.67$;

p = 0.07) and safety (F(2, 1162) = 2.54; p = 0.08). The degree of preference of the speed (F(2, 1,162) = 0.75; p = 0.47); the enjoyment of commute (F(2, 1,119) = 0.72; p = 0.49), as well as the reliability of the transportation service (F(2, 1,162) = 0.29; p = 0.75), were not significantly different in price sensitivity. Other latent variables concerning experience measured as previous mode choice (bike, car and public transportation) as well as environmental attitude, affinity for technology, and self-efficacy, showed no differences in price sensitivity.

5.4. Cluster analysis

Segmentation regarding the relative attribute importance values yields further customer insights. Hence, a cluster analysis based on benefit segmentation was performed based on the transportation attributes. This way, segment-specific mobility packages can be composed while also searching for statistically significant differences in latent variables between the segments. Using k-means, a three-cluster result was found to be appropriate, reaching a higher silhouette than cluster solutions with other numbers (0.329) (Rousseeuw, 1987). The mean share of preference (SOP) and standard deviation of relative importance for each cluster and the total population is presented in Table C-7.

Table C-7: Resulting segments from benefit clustering (own elaboration)

Transportation attribute	**Segment 1 (n = 257)**	**SD**	**Segment 2 (n = 756)**	**SD**	**Segment 3 (n = 152)**	**SD**	**Total (N = 1,165)**	**SD**
	Mean SOP [%]		Mean SOP [%]		Mean SOP [%]		Mean SOP [%]	
Segment name	**Car users**		**Frugal bike users**		**Generous multimodal flexibles**			
On-demand e-shuttle	6.00	0.04	4.50	0.03	**17.20**	0.06	6.50	0.06
Car sharing	**19.10**	0.06	5.90	0.03	**9.80**	0.05	9.40	0.07
(E-)bike sharing	7.20	0.05	**10.80**	0.06	7.80	0.05	9.60	0.06
E-scooter sharing	4.70	0.03	4.10	0.03	**7.40**	0.04	4.60	0.03
Max. WTP for MaaS package	€25.25		€21.57		**€54.02**		€26.81	
Notes: SD, standard deviation; Since price as an attribute of relative importance is excluded from the analysis, percentages do not round up to 100; Bold numbers indicate a higher importance in a segment than in the total sample.								

The three resulting segments are described in the following paragraphs. Segment 1 ("car users") was especially characterised by a higher relative importance of car sharing (19.15% compared with 9.35% for the overall population). Segment 2 ("frugal bike users") had a higher preference for bike sharing than the overall mean (10.77% compared to 9.60%), whereas all other importance weights were slightly lower. Except for bike sharing, the importance weights of all transportation services were higher in segment 3 than for the mean ("generous multimodal flexibles"), especially for e-shuttles (17.22% versus 6.46%). Segment 2 (frugal bike users) was the largest segment (756 respondents). Segment 3 (generous multimodal flexibles) consisted of 152 respondents and Segment 1 (car users) of 257. Segment 3 had a slightly higher proportion of female students (56.67%) than the average (53.00%). The other segments had a similar gender distribution as the total (diverse respondents were excluded due to low numbers). The median age for all segments was 20 to 24 years and the median income was €1,000 to €1,250 for all segments. In terms of sociodemographic distribution, the segments did not differ significantly, however, they differed in WTP: Segment 3 had the highest WTP (€54.02), followed by Segment 1 (€25.25) and Segment 2 (€21.57). Tests for differences between the benefit segments discovered how customers differed by the latent variables described in Section C.3.1. The tests used were χ^2-tests for nominal data (see Table C-8), also indicating Cramer's *V* for effect size measurement, Kruskal-Wallis for ordinal data (see Appendix 2) and one-way ANOVA for continuous variables (see Table C-9), followed by Bonferroni's method for pairwise segment comparisons. Regarding the nominal data, significant differences existed between the segments in previous mode choice ($\chi^2(6) = 0.35$; $p < 0.001$; $V = 0.17$), car availability ($\chi^2(2) = 14.46$; $p < 0.001$; $V = 0.11$) and bike availability ($\chi^2(2) = 8.10$; $p = 0$ 0.02; $V = 0.86$) (experience).

The results of the Kruskal-Wallis test showed statistically significant differences in income ($H = 6.96$; $df = 2$; $p = 0.03$) (Segments 1–2) as the only variable explaining differences in socioeconomic variables. The income was the highest in Segment 3. Regarding priorities for commute (preferences), several aspects were statistically different between the segments: speed ($H = 9.84$; $df = 2$; $p = 0.01$) and price ($H = 11.15$; $df = 2$; $p < 0.01$) (Segments 1–2), environmental aspects ($H = 19.82$; $df = 2$; $p < 0.001$) and comfort ($H = 25.84$; $df = 2$; $p < 0.001$) (Segments 1–2, 2–3), as well as enjoyment ($H = 6.06$; $df = 2$; $p = 0.05$) (Segments 2-3). Regarding the perceptions of different modes, significant differences exist for the car ($H = 7.70$; $df = 2$; $p = 0.02$) (Segments 1–2) and the bike ($H = 10.17$; $df = 2$; $p < 0.01$) (Segments 2–3). Additionally, social norms (attitudes) were statistically different between segments regarding public transportation ($H = 9.14$; $df = 2$; $p = 0.01$) (Segments 1–2, 2–3), bikes ($H = 7.11$; $df = 2$; $p = 0.03$) and cars as well ($H = 14.77$; $df = 2$; $p < 0.001$) (both Segments 1–2).

Table C-8: χ²-tests of differences between segments (own elaboration)

Variable	Total (N = 1,165)	Segment name			χ²	df	N	p
		Car users (n = 257)	Frugal bike users	Generous multimodal flexibles (n = 152)				
Gender, n (%)					0.94	2	1,149	0.62
Male	540 (47.00)	120 (47.24)	355 (47.65)	65 (43.33)				
Female	609 (53.00)	134 (52.76)	390 (52.35)	85 (56.67)				
Previous mode choice, n (%)					35.50	6	618	< 0.001**
Combustion car	178 (28.80)	56 (40.88)	86 (21.50)	36 (44.44)				
Public transportation	130 (21.04)	23 (16.79)	89 (22.25)	18 (22.22)				
Bike	85 (13.75)	10 (7.30)	68 (17.00)	7 (8.64)				
By foot	225 (36.41)	48 (35.04)	157 (39.25)	20 (24.69)				
Driver's license, n (%)					1.60	2	1,165	0.45
Yes	1.064 (91.33)	239 (93.00)	689 (91.44)	136 (89.47)				
No	101 (8.67)	18 (7.00)	67 (8.86)	16 (10.53)				
Combustion car available, n (%)					14.46	2	1,106	0.001**
Yes	693 (62.66)	169 (68.15)	421 (58.72)	103 (73.05)				
No	413 (37.34)	79 (31.85)	296 (41.28)	38 (26.95)				
Normal bike available, n (%)					8.101	2	1,106	0.017*
Yes	860 (77.76)	179 (72.18)	576 (80.33)	105 (74.47)				
No	246 (22.24)	69 (27.82)	141 (19.67)	36 (25.53)				
Notes: * Parameter is significant at the 0.05 level (two-tailed). ** Parameter is significant at the 0.01 level (two-tailed).								

Table C-9: Results of one-way ANOVA between segments (own elaboration)

Variable		Sum of sqares	df	Mean square	F	p
Environmental awareness	Between groups	4.61	2	2.31	5.33	0.01**
	Within groups	503.09	1,162	0.43		
	Total	507.70	1,164			
Self-efficacy	Between groups	1.16	2	0.58	1.67	0.19
	Within groups	402.95	1,162	0.35		
	Total	404.11	1,164			
Affinity for technology	Between groups	1.13	2	0.56	1.70	0.18
	Within groups	385.06	1,162	0.33		
	Total	386.18	1,164			
Note: ** Parameter is significant at the 0.01 level (two-tailed).						

Regarding one-way ANOVA (Gurcaylilar-Yenidogan, 2014), a significant difference was found for environmental awareness (attitudes) ($F(2, 1,162) = 5,323$; $p = 0.01$) (Segments 2–3). However, affinity for technology and self-efficacy (motivation/affect) were not significant, as shown in Table C-9.

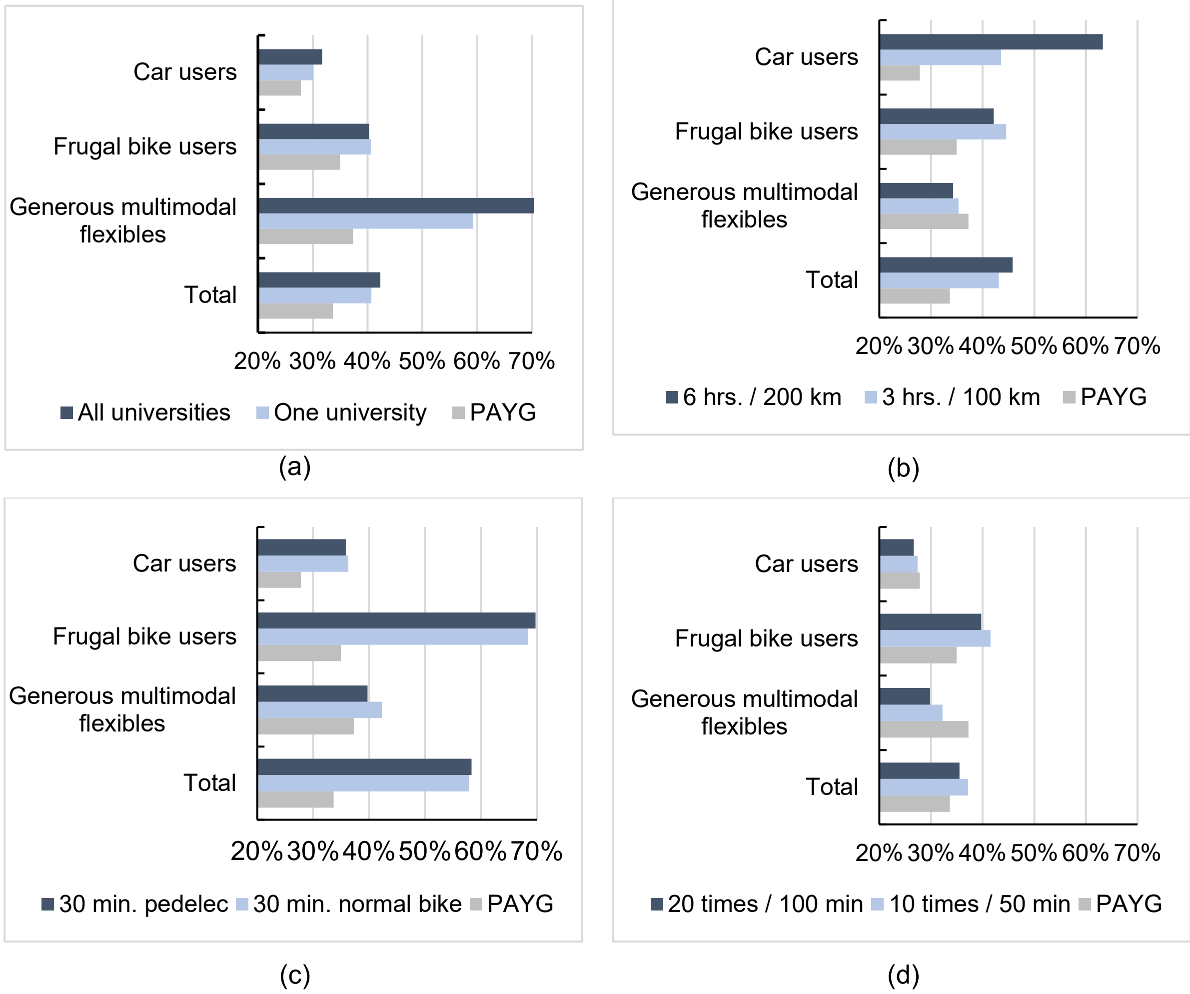
To conclude, at the 0.05 level, the following latent variables were significantly different between segments:

- memory (previous mode choice, car and bike availability)
- attitudes (environmental awareness, social norm for the car, public transportation and the bike)
- preferences (priorities for commuting: environment, comfort, price, speed, enjoyment)
- perceptions (attitude towards the bike and the car)

Income as a socioeconomic variable also differed significantly between the clusters. The only variable category from Section C.3.1 that does not show statistical differences is motivation/affect. Consequently, assumption A1b was accepted for almost half of the latent variables.

5.5. Market simulation

The different preferences of attribute levels for each segment were measured through sensitivity analyses. In a competitive scenario one attribute level was changed while all other offers and attribute levels were held constant to assess a change in SOP caused by one attribute level. Because SOPs are a close alternative to market share, in this way, relative demand curves are generated (Orme, 2010). For this simulation, the competitive products were the unimodal ones for attribute levels 1 and 2 with the prices as indicated in Table C-2. Figure C-3 shows that regarding the shuttles, Segments 1 and 3 and the total population favoured the offer among all universities, whereas Segment 2 slightly preferred the service at one university. Segment 1 and the total population preferred car sharing for 6 hours or 200 km; Segment 2, for 3 hours or 100 km, and Segment 3 preferred the PAYG option. Segment 2 and the total population favoured e-bike sharing, whereas Segments 1 and 3 had a higher SOP for normal bikes. PAYG was the preferred e-scooter sharing level for segments 1 and 3. Segment 2 and the mean respondents had a higher SOP for the PAYG inclusion.



Notes: n (car users) = 257; n (frugal bike users) = 756; n (generous multimodal flexibles) = 152; N (Total) = 1,165.

Figure C-3: Sensitivity analyses on relative preference of the benefit segments and the mean population of (a) an on-demand e-shuttle, (b) car sharing, c) (e-) bike sharing and (d) e-scooter sharing (own elaboration)

Based on this analysis, MaaS bundles were composed from the most preferred attribute levels for each attribute, for the total population and for the segments. The package prices from Table C-2 were summed. For instance, the total price from the individual prices in Table C-2 for the car user-specific package 1 is:

€48 (up to 10 trips among the universities on-demand e-shuttle)

+ €30 (up to 6 h or 200 km car sharing)

+ €10 (up to 30 min normal bike, any number of times)

+ €0 (PAYG e-scooter sharing) = €88.

Again, the unimodal offers as levels 2 and 3 with the prices listed in Table C-2 were the competition. As seen in Table C-10, the composed packages differed for every segment.

Table C-10: MaaS packages composed of attribute levels with highest SOP for segments and the total respondents (own elaboration)

Mobility package	**On-demand e-shuttle**	**Car sharing**	**(E-)bike sharing**	**E-scooter sharing**	**Price [€]**
Package car users	Up to 10 trips among the universities	Up to 6 h or 200 km	Up to 30 min normal bike, any number of times	PAYG	88
Package frugal bike users	Up to 10 trips at one university	Up to 3 h or 100 km	Up to 30 min e-bike, any number of times	Up to 10 trips or 50 min	68
Package generous multimodal flexibles	Up to 10 trips among the universities	PAYG	Up to 30 min normal bike,any number of times	PAYG	58
Total (generic)	Up to 10 trips among the universities	Up to 6 h or 200 km	Up to 30 min e-bike, any number of times	Up to 10 trips or 50 min	110

To determine the revenue potential for the segments, first, revenue was simulated for introducing one generic package to all respondents. Then, it was assessed for introducing the three segment-specific offers as shown in Table C-10. The market simulation showed that 0.05% of the respondents would choose the generic offer. Scaling up for the potential N of 100,210, based on the percentage of respondents in the mobility behaviour survey finding mobility apps useful for the University Alliance Ruhr, the total revenue potential is expressed by the following equation:

$$Revenue_{Generic} = SOP * N * Price = 0.05\% * 100{,}210 * €110 = \underline{€5{,}885.29}$$

When offering the three segment-specific MaaS packages, 0.33% choose the package for Segment 1, 0.02% the MaaS offer for Segment 2 and 2.73% the Segment 3-specific package. The revenue potential is expressed by the following equation:

$$Revenue_{Segments} = \sum_{k=1}^{3}(SOP_k * N_{Population} * Price_k) =$$

$$0.33\% * 100{,}210 * €88 + 0.02\% * 100{,}210 * €68 + 2.73\% * 100{,}210 * €58$$

$$= €28{,}496.30 + €1{,}268.82 + €158{,}266.29 = \underline{€188{,}031.41}$$

with k = number of the segment-specific package, as shown in Table C-10. The results are without rounding errors. The test for difference between both revenues is shown in Table C-11, with the means downscaled for each respondent. Because the revenue potential of segment-specific packages was significantly higher, assumption A2b was accepted.

Table C-11: Revenue potential for generic and segment-specific MaaS packages (own elaboration)

Revenue	**Mean**	**SD**	**T**	**df**	**p**	**Assumption A2b**
Segment-specific	1.88	6.61	9.32	2,328	< 0.001**	accept
Generic	0.06	0.79				

5.6. Discussion of results

The students' WTP for MaaS and latent variables showing differences in choice were analysed, and segment-specific MaaS packages were composed to discover the revenue potential of a MaaS offer for university students. To answer the research questions, bike and car sharing were the most important transportation attributes to university students among urban transportation options, followed by on-demand e-shuttles and e-scooter sharing.

Although appearing to be a homogeneous customer segment regarding socioeconomic aspects, university students differed by transportation mode importance and price sensitivity. The latent variables of choice theory introduced by McFadden were not related to differences in price sensitivity because only different levels of priority of comfort for commuting (preferences) showed significant differences in price sensitivity at the $\alpha = 0.05$ level. Regarding the priorities of safety and reliability, no statistical difference was identified probably because these aspects are a prerequisite rather than a priority for choice. Hence, assumption A1a could only be confirmed to a very limited extent in this study.

Through benefit segmentation, three homogeneous segments resulted: car users, frugal bike users, and generous multimodal flexibles. The results of this study align with those of Ruhrort et al. (2014) regarding the importance of attitudes as explanatory variables of difference, but it also found norms to be important variables. Experience (previous mode choice) also differed between segments, just as Liljamo et al. (2020) found. In total, the benefit segments differed in social norms, experience, environmental awareness, priorities for commuting, perceptions, and income (assumption A1b). Only motivation/affect did not significantly differ among the segments.

Regarding the utility of MaaS as an integrated multimodal offer, assumption A2a was accepted because only for e-scooters the utility of the PAYG option was higher than the integration. Utility was higher for integrated bundles than for PAYG, contrary to the finding by Stopka et al. (2018).

The general as well as the segment-specific maximum WTP was lower than the price for the preferred composed MaaS package, supporting the results by Matyas and Kamargianni (2019) and Liljamo et al. (2020). This is one possible reason for the large statistically significant difference in revenue potential between a generic and segment-specific MaaS packages (approximately 30 times higher; assumption A2b), which is in line with the findings by Hensher et al. (2020): The gap between the cost (€110) of the generic offer and the maximum WTP for the packages (€26.81) results in a small SOP of only 0.05%. By contrast, SOP for the cheaper segment-specific offers was 3.08% combined.

6. Implications, limitations, and outlook

The practical implications of our study evidence that WTP and MaaS package preferences are heterogeneous, underlining the importance of segmenting the customer group. If no information about product preferences is available, another practical approach could be clustering based on the latent variables that provided significant differences among benefit segments. We acknowledge the difficulty of this approach, but we also proved its monetary implications. In the long term, binding students early can generate revenue. Because WTP currently is below the costs of the offer, additional revenue streams must be found, such as advertising, data analysis and sales and cross-selling commissions (Hager and Karl, 2021; Sarasini et al., 2017).

Regarding theoretical implications, latent variables from McFadden's choice theory are less helpful for explaining the differences in price sensitivity but good for differences between benefit segments. To the best of our knowledge, this is the first study to have investigated this topic of differentiating MaaS benefit segments among latent variables. Our study shows that more personalised, integrated offers provide students higher value, as stated by the service-dominant logic (Sawhney et al., 2006; Vargo and Lusch, 2004a), depending on the price. We thus showed that the integration (axiom 3) and individualisation (axiom 4) apply for MaaS, especially for students as customers.

This study had five key limitations. First, the focus lied on university students as a customer group. To create platform effects and economies of scale for MaaS, it is also necessary to estimate WTP for other groups. Second, this research was conducted in Germany. Although it complements the list of previous research performed in other countries, WTP is calculated in the specific regional context of market competition. The results are thus not transferable in total to other countries. Third, the MaaS packages under investigation did not include public transportation because all students already had a subscription. Fourth, although we included several latent variables for statistical testing, the information we retrieved regarding price sensitivity was limited. Fifth, our market simulations did not analyse profit because cost calculations for the MaaS platform were outside the scope of this study.

Future research regarding MaaS as an ecosystem (Kamargianni and Matyas, 2017) can use our results for creating the operating model to bridge the gap between users' WTP and costs for a MaaS offer. In particular, subsidising users through effective pricing to attract more people to the platform is one field of future research (Eisenmann et al., 2006). Bonuses and tax reliefs are another possibility (Alyavina et al., 2020). Reallocating subsidies for car usage towards MaaS systems can decrease user costs to increase its attractiveness and, thus, demand and revenue potential. To create a profitable MaaS ecosystem, economies of scale are necessary (Marcocchia and Maniak, 2018). Hence, other customer segments should be researched. In the case of universities, these are the employees such as professors and technical staff. Additionally, our findings should be validated for university students and similar offers in other countries to compare the WTP. Other methodologies and parameter estimation models exist for WTP, which should also be tested in further studies. Furthermore, it is unclear whether the platform on which these MaaS solutions are offered is a separate platform or integrated into an existing platform. Closely related to this question is the issue of platform orchestration, which is intensively discussed in the recent literature on MaaS (Kamargianni and Matyas, 2017). This also involves governance issues that are of great importance for future research.

As the importance of public transportation in MaaS is empirically proven (Feneri et al., 2020; Guidon et al., 2020), it must be included as a further attribute in future research. Including more latent variables to explain price sensitivity is another future task.

With the increasing interest in personalised and multimodal mobility, MaaS is highly relevant for the automotive industry (Covarrubias, 2018; Silva et al., 2021; Tinnilä and Kallio, 2015). University students are a group willing to adopt new mobility services and are expected to have a higher income in the long term. Therefore, extending business towards MaaS and taking advantage of market opportunities among students promises revenue on the long run for actors in the automotive industry.

Chapter D: Estimation of joint value in mobility as a service ecosystems under different orchestrator settings

Abstract

Background Ecosystems aim to create joint value that is higher than the sum of the value added of the single companies combined. However, for Mobility as a Service (MaaS) ecosystems, the economic potential is not yet proven. This concurs with the definition of MaaS ecosystems and the debate about who should be the orchestrator – a private or a public entity.

Purpose This article therefore delivers a first approach to quantify the joint value of publicly and privately orchestrated MaaS ecosystems.

Methodology The value estimations are based on potential user preference analysis combined with market simulation and different volume discounts granted to a private orchestrator in the agency model.

Findings The results show that due to the high costs of all ecosystem actors in this asset-heavy industry, no profits are made in all constellations. The least value is destroyed when a private orchestrator receives 2% discount. Thus, added value must be created, for example through data analysis and advertising. Cities and governments must hence reallocate subsidies and support all MaaS actors to build a viable ecosystem.

Keywords

Conjoint analysis, Mobility as a Service (MaaS), Ecosystems, Joint value creation, Orchestrator

1. Introduction

MaaS is said to foster the mobility transition in travel behaviour from automobility dependence towards more sustainable transportation modes (Alyavina et al., 2020). It is a well-established concept in transportation science that combines multiple publicly or privately owned transportation modes (Wells et al., 2020), taking a user-centric perspective in integrating data from transportation services and user preferences to provide information and transportation bundles (Ye et al., 2020).

To date, the economic feasibility of MaaS is still not proven (Covarrubias, 2018; Hensher and Hietanen, 2023; Liljamo et al., 2020; University of Sydney, 2022). However, in the automotive sector, a shift from selling cars to offering mobility services is increasingly seen (Schulz et al., 2021a). In this context, the concept of ecosystems, a novel form of value network in strategy science, has gained increasing attention from both industry and academia (Jacobides et al., 2018). A starting point for companies to cooperate in such an ecosystem is the estimation of joint value created (Dattée et al., 2018). Hence, it is important to show the surging new ways of joint value creation to convince firms in participating in the ecosystem design (Adner, 2017). Until now, MaaS ecosystems are created and discussed mainly for their environmental and social benefits (see e.g. Alyavina et al., 2020; Fournier et al., 2020; Jittrapirom et al., 2017; Karlsson et al., 2020; Mehdizadeh et al., 2022; Strömberg et al., 2018; Wells et al., 2020). While economic outcomes of MaaS are still absent in research (Schulz et al., 2021a; Smith et al., 2020), the financial impact of an ecosystem perspective in other markets is proven, especially for big platform businesses (PwC, 2022). Taking on an ecosystem perspective implies creating more value jointly through synergies with partners of which each partner captures a share through offering an overarching value proposition to the customers (Jacobides et al., 2018). Since MaaS has failed to generate this overarching value an absent ecosystem perspective is perceivable.

The need for an ecosystem perspective in MaaS is formulated in academia (Hensher et al., 2020). As no universally accepted definition of the MaaS ecosystem exists, it has been researched regarding the necessary stakeholders (Kamargianni and Matyas, 2017) and the business model of the orchestrator (Polydoropoulou et al., 2020b) but with different conceptual boundaries. The fuzziness of the term is also reflected in the fact that in strategy research not all stakeholders are ecosystem partners, contrary to Kamargianni and Matyas (2017) for MaaS, as only those with multilateral dependencies and non-generic complementarities (Jacobides et al., 2018) are. This also explains the ambiguous estimations of the market potential of MaaS (see e.g. Business Wire, 2020; Deloitte, 2021; Karjalainen, 2020). It is therefore essential to define the MaaS ecosystem, in accordance with strategy research, unambiguously in a first step in order to derive value elements and partners necessary for value creation calculations.

The possible joint value created furthermore depends on whether the ecosystem orchestrator is a public or a private institution. Public ecosystem orchestrators want to create value for the ecosystem stakeholders instead of capturing the value mainly for themselves: They create a public good (without profit) through the ecosystem (Daymond et al., 2022). Contrary to that, private orchestrators create value to internalise it. The amount of value depends on the prices paid to the other ecosystem actors offering their services. Price-based scenarios regarding the mobility transition represent a research gap (Mehdizadeh et al., 2022).

The following research questions result:

1. How is the MaaS ecosystem unambiguously defined?
2. What value elements does the MaaS ecosystem comprise?
3. How does the joint value creation differ in private-driven MaaS ecosystems from a public-driven ecosystem?

To answer these questions, user preference analysis and market simulations to calculate the joint value created are applied, using the example of an academic MaaS offer. Universities are of particular interest because young people and academics are more receptive to adopting new sustainable and app-based mobility services such as MaaS (Bagdatli and Ipek, 2022; Bonham and Koth, 2010; Rayle et al., 2014; Schulz et al., 2021a; Ye et al., 2020).

The paper is structured as follows. The theoretical and conceptual background to answer the research questions is provided in Section D.2, including a definition of the value elements of the MaaS ecosystem and the design of an operating model. Section D.3 describes the methodology used. Section D.4 presents the analysis and results. A subsequent discussion of the results is provided in Section D.5. The study terminates with conclusions in Section D.6.

2. Background

2.1. Joint value creation in transaction ecosystems

Ecosystems are understood in strategy science as partnership networks in which an overarching value proposition as a joint customer solution is tailored by the companies' individual value streams (e.g. Dattée et al., 2018; Leclercq et al., 2016). Jacobides et al. (2018) define ecosystems as "a set of actors with varying degrees of multilateral, non-generic complementarities that are not fully hierarchically controlled" (p. 2264). A focus lies on modularisation, and complementarity must be given both in consumption and production due to complementary resources (economies of scope). Adner (2017) defines these specific 'ecosystems as structure' as "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize" (p. 42). The binding alignment structure, multilateral relationships between partners, the defined set of partners, and the joint focal value proposition from this definition can be translated into building blocks of ecosystem design according to Lewrick et al. (2018) and Dattée et al. (2018) (see Figure D-1). Resulting from customer information, the focal value proposition of the ecosystem is formulated (Adner, 2021). It is the goal of the platform (Polydoropoulou et al., 2020b) to deliver the proposed value by arranging the necessary value elements in a certain manner for the value to be delivered ("operating model"; Lewrick et al., 2018). Certain value drivers such as network effects and economies of scope are leveraged through the platform. Control and access to the platform are ensured (“governance”; Adner, 2017). Then, the expected joint value created via the platform can be calculated (Adner, 2021).

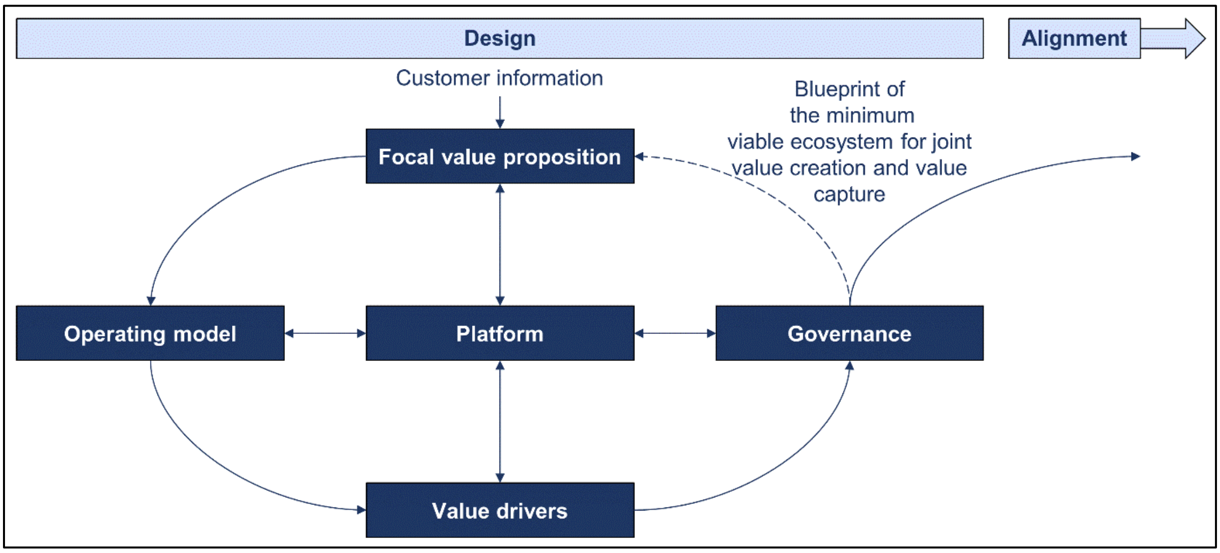


Figure D-1: Joint value creation as outcome of a minimum viable ecosystem (based on Adner, 2021 and Lewrick et al., 2018)

The joint value created by the company, the buyer and the supplier in a vertical chain is determined by the customer’s WTP (Lusch et al., 2007) and the opportunity cost, i.e., the minimum monetary value a supplier accepts in exchange for his/her resources (Tower et al., 2021). The amount of value appropriated (“economic rent”) by each actor is determined as follows (Ross, 2018):

- The difference between WTP and the price is a buyer’s appropriated value.
- The difference between the price and the cost is the company’s appropriated value.
- The difference between the opportunity cost and the company’s cost for the acquired services is the supplier’s appropriated value (Brandenburger and Stuart, 1996).

When shifting the perspective from a vertical chain to an ecosystem, the joint value created increases as added value is built (economies of scope) (Gawer, 2014; Normann and Ramírez, 1993). This added value is only achieved when companies integrate external competencies jointly (Hannah and Eisenhardt, 2018), thereby shifting the focus to an external perspective (Parker et al., 2016).

2.2. Ecosystem orchestrator

The ecosystem orchestrator provides financial resources and/or labour and the rules for value creation, which determine the financial outcome for all participating actors (Teece, 2019). The orchestrator also aligns all ecosystem members to the focal value proposition and is responsible for the coordination of activities and for providing resources and infrastructures (Lingens et al., 2021). It is the main decision-maker on frameworks, rules and principles for growth, thereby being responsible for the governance mechanisms (Lewrick, 2022). To increase the attractiveness of participation, the orchestrator must ensure that all partners benefit and appropriate value (Lang et al., 2020). There are three types of orchestrators: a) the "player orchestrator" with a commercial interest, using the coordination for its own advantage, b) the "facilitator orchestrator" with a non-commercial interest in ecosystem development and c) the "sponsor orchestrator" as a venture capitalist with a commercial interest as an outsider (Pikkarainen et al., 2017), whereas the latter is outside the ecosystem.

2.3. Research on MaaS ecosystems

The ecosystem perspective is inherently included in the MaaS concept, which has been defined as an ecosystem since its emergence (Hietanen, 2014; Murati, 2020). MaaS is generally defined as the "3B's": the brokers, the budgets and the bundles (Hensher, 2017). MaaS can further be defined as a service ecosystem, in which value creation between the app (platform) provider (i.e. the orchestrator) and the transportation service providers (TSPs) takes place (Schulz et al., 2021a).

The MaaS ecosystem orchestrator is either a private company or a state- or municipality-owned public entity (König et al., 2016). Public orchestrators search for efficiency and utilisation benefits, thereby increasing the number of users. The advantage is easier approval and maximised social surplus, as prices are equal to the marginal costs (van den Berg et al., 2022). Disadvantages include difficulties in innovation, scaling and bureaucracy (Kamargianni and Matyas, 2017) and scarce development resources (Polydoropoulou et al., 2020b). These disadvantages are the advantages of private orchestrators. Although public authorities may have only limited influence to orchestrate (Mukhtar-Landgren and Smith, 2019), private orchestrators might promote unsustainable technologies (Kamargianni and Matyas, 2017). In contrast, Wong et al. (2020) assumed that governments might not be keen to be orchestrators. The private and public actors in the MaaS ecosystem simultaneously compete and cooperate to create, deliver and capture value (Polydoropoulou et al., 2020b), i.e., they are in "co-opetition" (e.g. Bengtsson and Kock, 2014). A further option are public private partnerships for

MaaS (Eckhardt, Aapaoja and Haapasalo, 2020) but since the type of collaboration is not unambiguously defined it is out of scope of this research.

Transferring ecosystem definitions (Section D.2.1) to MaaS, the joint focal value proposition is to create seamless mobility through a unique service combination (Karinsalo and Halunen, 2018). The defined set of partners comprises the customers, the MaaS orchestrator, the data provider, the transport operator, and occasionally the government (Hensher et al., 2020; Schulz et al., 2021a). Multilateral relationships are given if the TSPs also interact between themselves to increase resource complementarity. A binding alignment structure only exists if all parties adhere to a standard on the platform. Combining ecosystem complementarities with MaaS integration levels (see Hensher et al., 2020; Sochor et al., 2018) ranging from 0 to 4, only level 3-MaaS offers (i.e. offers in which not only generic information is provided, but also booking and payment options are included (Eckhardt et al., 2016; Pretzsch et al., 2020) as well as transportation service bundling (Esztergár-Kiss et al., 2020; Kamargianni et al., 2016) can be classified as ecosystems, which are few (Sochor et al., 2018), showing that transportation service bundling is necessary for complementarity in consumption (Esztergár-Kiss et al., 2020; Kamargianni et al., 2016). One reason is that the possible joint value creation, necessary for a minimum viable ecosystem to survive and grow is still not analysed (Tsouros et al., 2021). As for RQ1, the fact that numerous studies needed to be analysed together to create this transparent definition of the MaaS ecosystem proves the previous gap in the literature regarding its definition.

2.4. Value elements and operating model in the MaaS ecosystem

To calculate the joint value created in the MaaS ecosystem, the value elements as inflow (revenue) and outflow (costs) must be gathered (see Figure D-2). The value inflow elements are:

- Ecosystem revenue as the number of MaaS adopters times the prices paid by them;
- Value appropriation by the orchestrator, consisting of
  - Price discounts for the transportation service (price paid by the customer minus the discounted price for the transportation service) as the basic value and
  - Additional value as revenue for data analysis and advertisements for private orchestrators; and
- Value appropriation by the TSPs as new profits/losses made by each TSP for the additional subscriptions as their value appropriated.

The ecosystem revenue from the customers is determined by the WTP and preference for PAYG or subscription models. Subscriptions of package options of complementary products are superior (Yan and Bandyopadhyay, 2011) because they can lead to higher social welfare, consumer surplus and company benefit (Randhawa and Kumar, 2008). The price should not be higher than individual sales/cost of transportation offers (Hager and Karl, 2021). The second element is the discount from the TSPs depending on the underlying MaaS model: an "agency model" or a "merchant model" (Hager and Karl, 2021; König et al., 2016). In the agency model, transportation capacities (Kamargianni and Matyas, 2017) are bought by the orchestrator from the TSPs for wholesale prices (van den Berg et al., 2022). In the merchant model, commissions are paid by the TSPs to the orchestrator for reselling (Pickford and Chung, 2019). In a private MaaS offer the orchestrator also gets revenue from other value-adding services (Aapaoja et al., 2017; Kamargianni and Matyas, 2017; Pangbourne et al., 2020), e.g. advertisements, cross-selling commissions and subsidies (Hager and Karl, 2021). The state has an important role as facilitator, providing funding for the initial uptake of the MaaS ecosystem (Meurs et al., 2020; Wong and Hensher, 2021). Data analytics should be provided for the public sector (Sarasini et al., 2017).Value outflow elements for providing the MaaS solutions found in the literature concern the expense for the transportation service (for the orchestrator and the TSPs made by new trips generated) (Hager and Karl, 2021) and for the platform, including variable costs for payment integration (Sochor et al., 2018; van den Berg et al., 2022) and insurance (Kamargianni and Matyas, 2017; Polydoropoulou et al., 2020b) and fixed costs for the service (customer support), and platform development (personnel) and infrastructure (König et al., 2016). From a sustainability perspective, impact assessment could comprise even further indicators, such as modal shift (to know whether the customers are new for the TSPs), total travel costs per individual, and the number of new customers (Eckhardt, Lauhkonen and Aapaoja, 2020) which lie outside of this scope due to the ecosystem perspective from strategy research.

These value elements had to be collected from different sources, proving the research gap for RQ2. Hence, one all-encompassing study quantifying the joint value created in such an ecosystem (RQ3) is also still missing. Therefore, Figure D-2 shows an operating model of the MaaS ecosystem based on the agency model which the most integrated MaaS operators use (Hager and Karl, 2021; König et al., 2016). The model comprises the above-mentioned value elements with a public ("facilitator orchestrator") and a private ("player orchestrator") MaaS ecosystem orchestrator. Several public transportation operators (PTOs) from several cities and TSPs for other private providers are on the supply side. The additional value stream of public entities is created by providing a public good whereas private orchestrators internalise it. Subsidies and cross-selling are not considered since the existence and quantity are less discussed in the literature. Multilateral relationships for increased resource complementarity are not included due to the difficult monetary valuation.

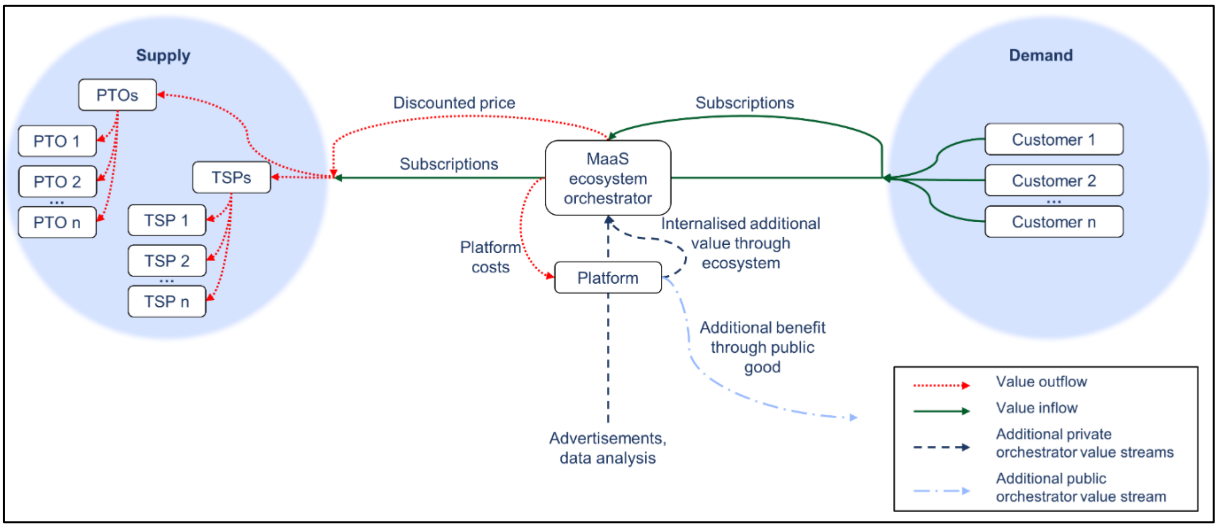


Figure D-2: Agency operating model of a public or private MaaS orchestrator (adopted from Aapaoja et al., 2017 and Kamargianni and Matyas, 2017)

3. Methodology

To calculate the value elements previously mentioned, market simulations based on market data and choice experiments were used. Different competitive scenarios were simulated, especially for services that lack historical data (Eggers and Eggers, 2011), such as highly integrated MaaS ecosystems (Sochor et al., 2018). An approach combining previous studies by Eggers and Eggers (2011), Jeon et al. (2010) and Tseng et al. (2012) adjusted for the aim of this research was used.

The basis for this study is conjoint analysis, a method to find the product attributes that maximise the consumers' preference (Jeon et al., 2010) for new services (Hair et al., 2010). Conjoint analysis follows random utility theory (McFadden, 1986), stating that a consumers' utilities U for product attributes are unobservable latent constructs with a systematic component V and a random component ε, representing all unsystematic effects. V links product attributes (X) to preference estimates β in choice-based conjoint analysis. Often, a multinomial logit model (MNL) is used to estimate preferences (Eggers and Eggers, 2011; Huang et al., 2021), for instance in MaaS (Maas, 2021). Especially the choice-based approach is useful because the discrete choice behaviour provides the best representation of real market decisions and actual demand patterns (Eggers and Eggers, 2011; Souka et al., 2020). The steps in conjoint analysis are the determination of sample and procedure, the definition of the conjoint settings and the examination of results (Eggers and Eggers, 2011).

The second methodological step is choice simulation. The preferences calculated via conjoint analysis can be used to estimate adoption behaviour and purchase probabilities can be estimated in prediction models (Eggers and Eggers, 2011; Orme, 2010) with competitive market scenarios using market data. Hence, market share based on customers' choice simulation is predicted to determine the best product composition (Jeon et al., 2010). The simulation consists of the identification of the research focus, sensitivity analysis to estimate demand curves (Orme and Chrzan, 2017) and product price optimisation to calculate the market share (adopted from Eggers and Eggers, 2011 and Tseng et al., 2012).

The third step estimates the joint value created: The predicted market share from the choice simulation is used in combination with real market data (Tseng et al., 2012) to quantify the required value elements from Section D.2.4. This allows the estimation of the value elements and the joint value created. The steps are visualised in Figure D-3.

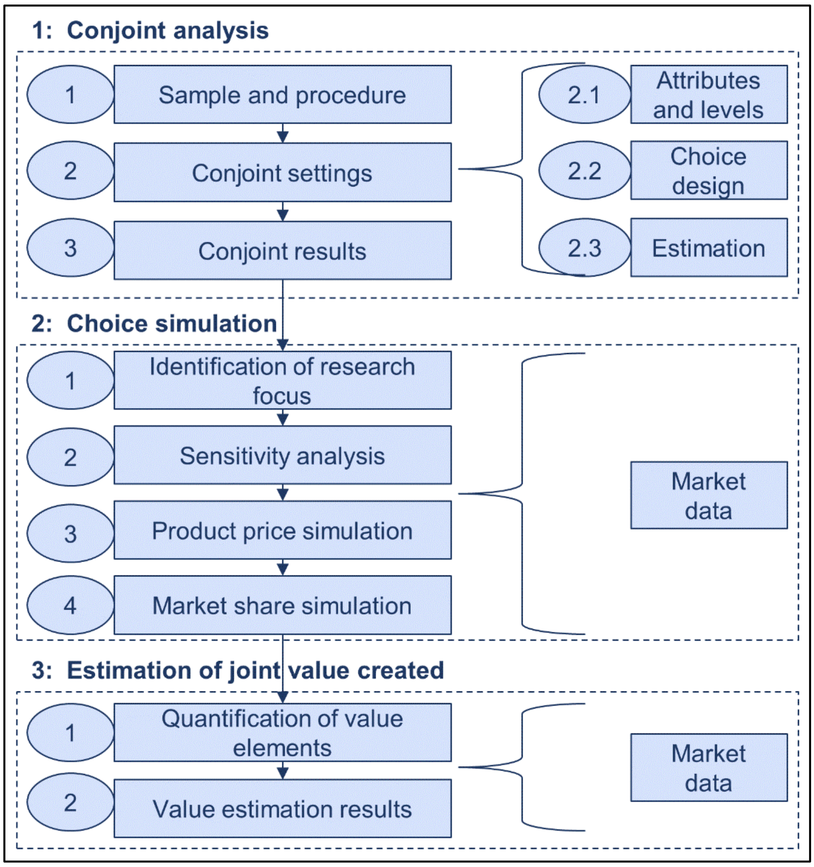


Figure D-3: Methodology combining conjoint analysis and choice simulation (own elaboration based on Eggers and Eggers, 2011, Jeon et al., 2010 and Tseng et al., 2012)

4. Analysis and results

4.1. Conjoint analysis

4.1.1. Sample and procedure

This study is part of the research project "InnaMoRuhr" (integrated sustainable mobility for the University Alliance Ruhr), involving the universities Duisburg-Essen, Bochum and Dortmund in Germany, members of the University Alliance Ruhr. It aims to examine whether a MaaS ecosystem for the concerned customer segments of approximately 119,000 students and 16,000 university employees could enhance the modal shift and lead to a more sustainable travel. The University Alliance Ruhr is of particular interest because a) the Ruhr Area is one of the biggest metropolitan regions in Europe with high traffic density (Fina et al., 2021), b) two of the three universities involved belong to the ten biggest in Germany (Bada, 2019) and c) joint research and study programs induce interregional travel between the universities (Universitätsallianz Ruhr, 2022).

As part of the project, a survey about mobility behaviour and mobility demand was answered by 10,782 students and employees of the universities in April and May 2021. In the last survey section, the respondents could opt to participate in a conjoint study consisting of two different surveys, one for employees and one for students, using Sawtooth Software. Students have a compulsory public transportation (PT) subscription, hence, a stated choice experiment with this attribute was not necessary as the revealed choice is provided. Furthermore, attributes and levels were modified to the lower income of students. The surveys consisted of a build-your-own task and eight choice tasks. After data cleaning, the data basis for conjoint analysis consisted of 503 employees and 1,165 students.

4.1.2. Conjoint settings

Only transportation modes available in the four university cities and offered by one operator/ one association were included in the conjoint analyses as attributes, each with three monthly attribute levels: PAYG (for students and employees), one intermediate and one high level of service inclusion (following e.g. Jittrapirom et al., 2017):

- PT (for employees only): 1) PAYG, 2) monthly subscription for one city or 3) monthly subscription for the tariff association (local representatives of PTOs (Schulz et al., 2021a) comprising defined areas of operation),
- Car sharing (CS): 1) PAYG, 2) 3 h/100 km contingent (students and employees) or 3) 6 h/200 km contingent (students) or 9 h/300 km (employees) respectively,

- Bike sharing (BS): 1) PAYG, 2) 30 min contingent per trip on a normal bike, or 3) 30 min contingent per trip on an e-bike (both students and employees) and
- E-scooter sharing (ES): i) PAYG, ii) 10 trips/50 min or iii) 20 trips/100 min contingent (both students and employees).

On-demand e-shuttles were originally included but then deleted for joint value creation as no real market data was available. Furthermore, the price was included as a summed pricing attribute. The hierarchical Bayes algorithm was used to model the part-worth utilities of all attribute levels as direct input for market simulation.

4.1.3. Conjoint results

McFadden's *Pseudo* R^2, a measure for the goodness of fit of hierarchical Bayes was 0.617 for the student conjoint analysis and 0.618 for employees, proofing model validity (McFadden, 1979). The calculated relative importance in both samples shows a high price sensitivity in both analyses and a valuation of PT by employees higher than all other sharing attributes combined.

4.2. Choice simulation

4.2.1. Identification of research focus

As for the private orchestrator setting, based on the agency operating model, the value created depends heavily on the discounts provided by the TSPs. The joint value created was calculated using three different amounts as discussed in the literature: 2% (van den Berg et al., 2022), 5% (Hager and Karl, 2021) and 10% (Zipper, 2020). In the real case, PT provides a 2% discount as a maximum. Hence, this value was not altered. For the publicly orchestrated MaaS ecosystem all discounts from cooperations are passed to the customers to maximise the social surplus (see Appendix 3.1). Therefore, four orchestration settings are distinguished:

1. a public one,
2. a 2% discount private setting,
3. a 5% discount private setting and
4. a 10% discount private setting.

As a basis for all further calculations, the market size for MaaS was determined based on the percentage of students and employees indicating the perceived usefulness of mobility apps with either "rather applies" or "fully applies" in a survey about mobility behaviour and mobility demand (7,333 students and 3,449 employees). The market size for students was extrapolated as N_{Stud} = 103,210 (86.77%) and N_{Emp} = 12,988 (79.25%) for employees for the three universities. The competing products were the unimodal offers for full prices (see Appendix 3.1).

4.2.2. Sensitivity analysis

MaaS packages for students (Table D-1) and employees (Table D-2) were composed with at least two transportation modes included with a level different than PAYG (Jittrapirom et al., 2017). Table D-1 shows that students value multimodal packages as apart from $P4_{Stud}$ all packages include three modes with a service level higher than PAYG. As for the employee packages in Table D-2, ES is not integrated in the MaaS packages with a service level higher than PAYG.

To determine these MaaS packages potentially offered, sensitivity analyses based on the respondents' preferences were performed. Because mobility users are heterogeneous (Groth et al., 2021), a scientifically reasonable reduction to the most important package offers is benefit segmentation (see Wind, 1973) based on cluster analyses (Eggers and Eggers, 2011; Hair et al., 2010). The Ward algorithm was implemented in k-means to group the respondents into clusters. For both student and employee data, the three-cluster solution provided the best results. The most preferred transportation attribute levels were included. Whenever the difference to the next lower attribute level was lower than one percent, an additional level was included. The sensitivity analysis was applied to the resulting clusters and the total sample.

Table D-1: MaaS packages for students resulting from segment-specific sensitivity analysis (own elaboration)

Package name	CS	BS	ES
$P1_{Stud}$	6 h/200 km	e-bike	10 trips/50 min
$P2_{Stud}$	6 h/200 km	normal bike	20 trips/100 min
$P3_{Stud}$	6 h/200 km	e-bike	20 trips/100 min
$P4_{Stud}$	6 h/200 km	normal bike	PAYG
$P5_{Stud}$	6 h/200 km	normal bike	10 trips/50 min
$P6_{Stud}$	3 h/100 km	e-bike	20 trips/100 min
$P7_{Stud}$	3 h/100 km	e-bike	10 trips/50 min

Regarding the students, the clusters did not differentiate in their preference of CS (6 h/200 km), only Cluster 2 had less than 1% difference to the 3 h/100 km level. The total and Cluster 2 preferred e-bike sharing, Clusters 1 and 3 normal bike sharing. Only Cluster 3 preferred ES as a PAYG option, all other clusters and the total preferred 20 trips/100 min inclusion, although this preference was less than 1% to the 10 trips/50 min level.

Table D-2: MaaS packages for employees resulting from segment-specific sensitivity analysis (own elaboration)

Package name	PT	CS	BS	ES
P1$_{Emp}$	tariff association	9 h/300 km	e-bike	PAYG
P2$_{Emp}$	one city	9 h/300 km	e-bike	PAYG
P3$_{Emp}$	tariff association	PAYG	e-bike	PAYG
P4$_{Emp}$	tariff association	9 h/300 km	PAYG	PAYG

Regarding the employees, only Cluster 1 prioritised the inclusion of PT in one city. All other clusters and the total preferred PT as a subscription for the tariff association. CS was preferred as a 9 h/300 km level for the total and Cluster 1 and as a PAYG option for Clusters 2 and 3, although the latter had less than a 1% preference difference to the 9 h/300 km level. Apart from Cluster 3 (PAYG preference), all other clusters and the total preferred e-bike sharing inclusion.

4.2.3. Product price simulation

Starting with the presentation of the calculations, results for the 5% discount private setting will be exemplarily shown. All remaining calculations are listed in the Appendix 3.3. The prices in the publicly orchestrated MaaS setting were the summed discounted prices for the transportation service according to market analysis (see Appendix 3.1) due to subsidised services by the cities and the higher negotiation power. For each privately orchestrated setting, market simulation with profit and number of MaaS adopters (share of preference) as two simultaneous optimisation goals was performed, following Eisenmann et al. (2006). Price ranges between the summed prices with and without the discounts provided by the TSPs were simulated for the packages created with inclusion of the competing offers. For instance, in the 5% discount private setting, the price range for P1$_{Emp}$ (PT in the tariff association, 9 h/300 km car sharing and e-bike sharing) was between the full price (standalone) as upper bound:

$$P_{upper} = €155.17\,(PT) + €53.63\,(CS) + €15.00\,(BS) = \underline{€223.80}$$

and the passing of all possible price discounts to the customer as lower bound (see 5% discount in Appendix 3.1):

$$P_{lower} = €152.07\,(2\%\ discount\ PT) + €50.95\,(5\%\ discount\ PT) + €14.25\,(5\%\ discount\ BS) = \underline{€217.27}$$

Within this price range all packages were simulated with variations of €0.05 to simultaneously optimise profit and market share, respectively. Graphical determination of elbow points in the market simulation was used to select the prices: Starting with the highest adoption rate possible, whenever the subsequent decrease of profit was significantly higher than the increase in MaaS adoption rate, the solution and its underlying package prices were chosen (see Appendix 3.2).

4.2.4. Market share simulation

Market simulations were performed to determine the MaaS adoption rate for the packages with the resulting prices. Percentages from the conjoint analysis sample were extrapolated to the market size determined in Section D.4.2.1 using Eq. (D.1):

$$N_{adopters_{i,j}} = \frac{n_{i,j\ choosing\ PK_{i,j}}}{n_{i,j\ survey\ participants}} * N_{i,j} \quad \text{(D.1)}$$

with n = number of survey participants, N = market size, i = students, j = employees, PK = MaaS package P number K.

In the 5% discount private setting, 6,466 students (6.26%, N_{Stud} = 103,210) and 3,529 employees (27.17%, N_{Emp} = 12,988) adopted the MaaS offers (see Table 3-3 in Appendix 3.3 for remaining results). This was the basis for the estimation of joint value creation from these MaaS packages.

4.3. Estimation of joint value created

4.3.1. Quantification of value elements

Following Section D.3 based on the explanations in Section D.2.1, the overarching key decision factors are elements for the value estimation: a) value appropriation by the orchestrator, and b) value appropriation by the TSPs.

a) Value appropriation orchestrator (VA_O)

The first part of the VA_O calculation is the value inflow as the basic value for the orchestrator (BV_O) calculated as shown in Eq. (D.2). The BV_O for the private orchestrator in the 5% discount private setting was (all settings see Table 3-4; price differences as input data see Table 3-5 in Appendix 3.3):

$$BV_O = \sum N_{adopters_{i,j}} * \left(Price_{PK_{i,j}} - discounted\ Price\ TSP\ \in PK_{i,j}\right) \quad \text{(D.2)}$$

$$BV_{Opriv5\%} = (6378 * €1.55 + 88 * €0.0025) + (51 * €6.53 + 51 * €1.50 + 3118 * €\text{-}0.02 + 309 * €5.78) = €9{,}886.12 + €2{,}145.36 = \underline{€12{,}031.48.}$$

Following Eq. (D.3), the additional value for private orchestrators (AV_O) was calculated as follows:

$$AV_O = AV_{O_{Ads}} + AV_{O_{Data}} = \sum N_{adopters_{i,j}} * \frac{\frac{views}{month}}{customer} * \frac{revenue\ rate}{view})/12 + \frac{data\ selling\ revenue\ per\ year}{12} \quad (D.3)$$

Starting with the revenue from advertisements, it was assumed that based on the average trips made before the pandemic and the scope of performances, each user viewed the MaaS app on average 20 times per month. In the topic area of work and education in Europe, 0.0586€ revenue per view and year could be generated (Google AdSense, 2022). The value was calculated for the 5% discount private setting as:

$$AVO_{Ads_{priv5\%}} = \frac{(6378 + 88) + (51 + 51 + 3118 + 309) * 20 \frac{\frac{views}{month}}{customer} * €0.0586 \frac{revenue\ rate}{view}}{12} = \underline{€976.18.}$$

According to interviews with fellow researchers, cities and municipalities pay around €10,000 per year per data set received. Because data from four different cities could be received, the monthly added value was:

$$AVO_{Data} = \frac{4 * €10{,}000/year}{12} = \underline{€3{,}333.33.}$$

Hence, the monthly additional value for the orchestrator in the 5% discount private setting was:

$$AVO_{priv5\%} = €976.18 + €3{,}333.33 = \underline{€4{,}309.51.}$$

The remaining AV_O calculations are listed in Table 3-6 (Appendix 3.3). Following Eq. (D.4), the value outflow of the orchestrator (VO_O) consists of the variable and fixed costs as follows:

$$VO_O = C\ var_{pay} + C\ var_{ins} + C\ fixed_{computer\ scientist} + C\ fixed_{service} + C\ fixed_{IT} \quad (D.4)$$

$$VO_{Opriv5\%} = €16{,}082.65 + €16{,}082.65 + €5{,}000 + €2{,}500 + €696.67 = \underline{€40{,}361.97.}$$

The remaining calculations can be found in Table 3-7 and additional information regarding the data used in Tables 3-8 and 3-9 (Appendix 3.3). The value appropriated by the orchestrator (VA_O) was calculated using Eq. (D.5). In the 5% discount private setting, the orchestrator appropriated the following amount (all settings see Table 3-10 in Appendix 3.3):

$$VA_O = BV_O + AV_O - VO_O \quad (D.5)$$

$$VA_{Opriv5\%} = €12{,}031.48 + €4{,}309.51 - €40{,}361.97 = \underline{€\text{-}24{,}020.98.}$$

b) Value appropriation TSPs (VA_{TSP})

First, we analysed whether the MaaS adopters already had a subscription with a TSP to calculate the new revenues from MaaS (NRM) to the TSPs by using Eq. (D.6). For the 5%

discount private setting, this value was calculated as follows (all settings see Tables 3-11 and 3-12 in Appendix 3.3 for input data).

$$NRM_{TSP} = \sum New\ subscriptions_{TSP_{PK_{i,j}}} * \ discounted\ Price\ TSP\ \in PK_{i,j} \tag{D.6}$$

$$NRM_{PT_{priv5\%}} = €0 + €0 + €157{,}997.20 + €23{,}418.26 = \underline{€181{,}415.45.}$$

$$NRM_{CS_{priv5\%}} = €179{,}998.40 + €1{,}107.70 + €2{,}598.37 + €2{,}598.37 + €13{,}756.10 = \underline{€200{,}058.94.}$$

$$NRM_{BS_{priv5\%}} = €1{,}003.20 + €726.75 + €726.75 + €42{,}099.25 = €44{,}555.95.$$

$$NRM_{ES_{priv5\%}} = \underline{€3{,}260.40.}$$

Especially PT and CS gained new revenue. Multiplied with each TSP's ratio of overall profits/losses (EBIT) to revenue (Eq. (D.8)), the value appropriated per TSP (VA_{TSP}) was as follows (see Tables 3-13 and 3-14 for all settings and additional data in Appendix 3.3):

$$VA_{TSP} = \ NRM_{TSP} * \frac{EBIT}{Revenue\frac{TSP}{year}} \tag{8}$$

$$VA_{PT_{priv5\%}} = €181{,}415.45 * (-0.57) = \underline{€\text{-}103{,}129.64.}$$

$$VA_{CS_{priv5\%}} = €200{,}058.94 * 0.11 = \underline{€22{,}391.91.}$$

$$VA_{BS_{priv5\%}} = €44{,}555.95 * (-1.33) = \underline{€\text{-}59{,}185.15.}$$

$$VA_{ES_{priv5\%}} = €3{,}260.40 * (-1.33) = \underline{€\text{-}4{,}330.90.}$$

Only CS was profitable and can therefore appropriate value.

4.3.2. Value estimation results

As presented previously, the value inflows and outflows were also calculated for the three remaining settings (see Appendix 3.3 also for assumptions). Both the value inflow (BV_O and AV_O) and the value outflow (VO_O) were the highest for the 10% discount private setting (€27,376 and €48,254 respectively). Regarding the VA_O (net value), the 2% discount private setting led to the least loss made by the orchestrator (€-19,158) (see Figure D-4).

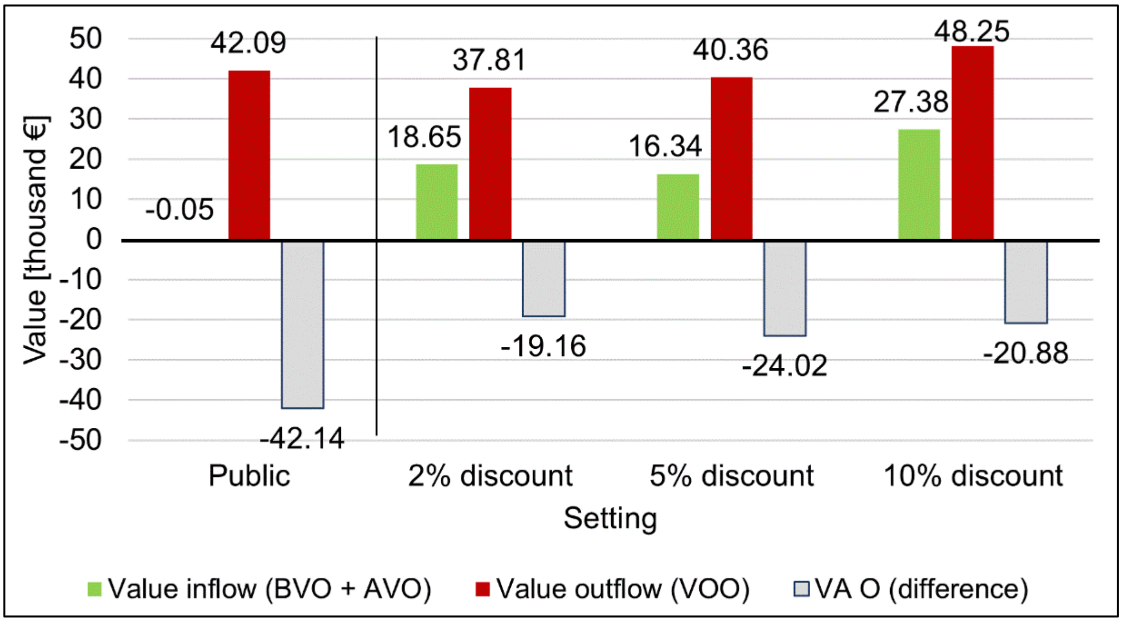


Figure D-4: Value inflow, value outflow, and value appropriated by orchestrator in different operator settings per month (own elaboration)

The value appropriated per TSP and setting was only positive for CS in all settings since this was the only company already making profits, as shown in Figure D-5. All other TPSs did not make profits (yet) from transportation and PT relies intrinsically on subsidies and cannot make any profit. Nonetheless, PT provides social benefits such as accessibility and equality. Although revenue could be increased, the costs per trip exceeded the earnings.

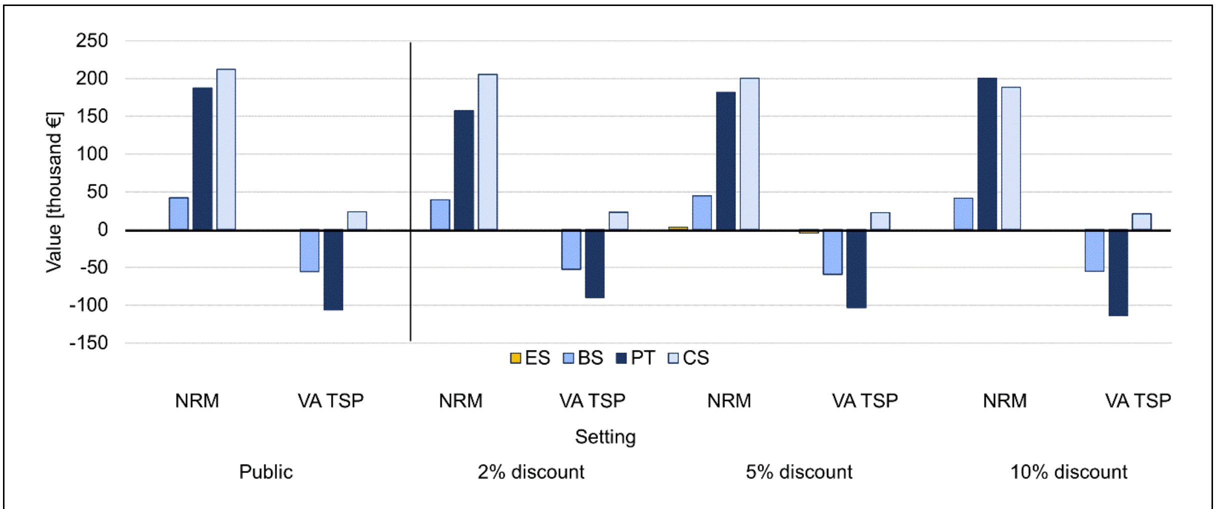


Figure D-5: New MaaS revenue and value appropriated by the TSPs in different operator settings per month (own elaboration)

A graphical representation of the joint value created by the ecosystem actors (orchestrator and TSPs) is provided in Figure D-6. The 2% discount private setting was the one destroying the least value (€-138,264), which was appropriated to more than half by PT (€-89,557).

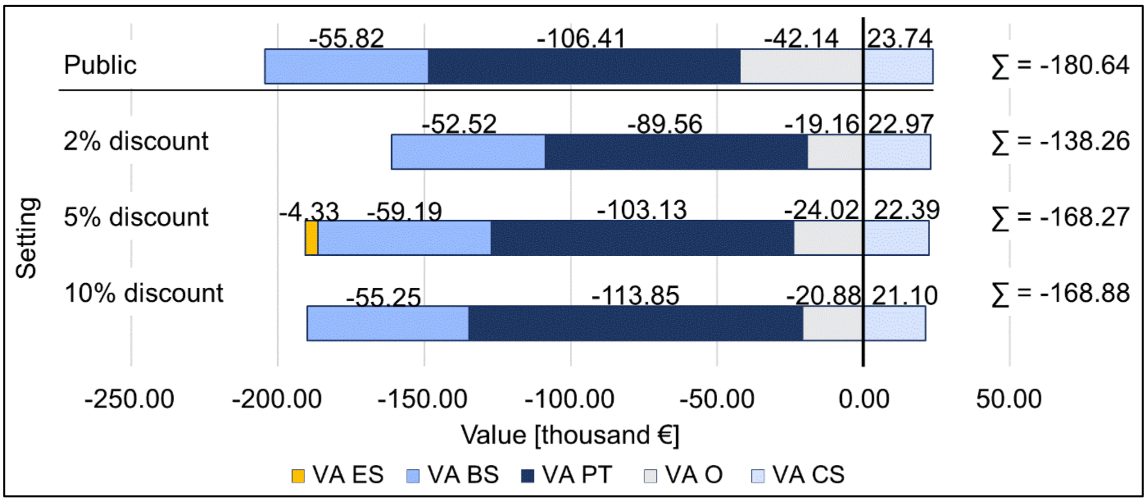


Figure D-6: Comparison of joint value destroyed in different operator settings per month (own elaboration)

5. Discussion

To answer the question: "[…] what sort of financial return might prospective MaaS businesses expect?" by Hensher et al. (2020), we discuss the results as follows. In no setting, neither public nor private orchestration, value could be created. Moreover, trade-offs are visible between profit and adoption rate (see Table 3-3 in Appendix 3.3) and between value inflow and VA_O (see Figure D-4): The 10% discount private setting provided the highest value inflow, but the least joint value was destroyed in the 2% discount private setting. Hence, although gaining new customers, which is especially important because mobility budget is price sensitive (Caiati et al., 2020) and customer data is a highly valued good (Anthony Jnr et al., 2020), this paper contributes to the increasing research stream on joint value destruction instead of value creation because the net outcome of resource integration and service exchange is negative, especially due to a loss of financial resources. The main reason is that joint value creation is not possible by economies of scale (platform effects) alone due to fixed-step costs in the asset-heavy transportation industry. Hence, increasing the market share increases the loss because the net joint value is negative. We showed that regarding research in surging ecosystems, the term "value formation" might be more appropriate since only few (mobility) ecosystems are able to actually create value (Schulz et al., 2021a). Explanations for the negative value appropriation are provided as follows.

Regarding the negative VA_O, the variable costs for the MaaS platform listed in Section D.2.4 (payment integration and insurance) directly depend on the market share and exceed the contribution margins of almost all TSPs, especially because no additional WTP for service bundling is given (Alonso-González et al., 2020). Regarding the negative VA_{TSP}, the reasons for their losses are among others, COVID-19-induced travel restrictions. The private TSPs only recently entered the new mobilities market in Germany, which is still volatile, causing insecurity and (initial) losses. Regarding the PTOs, since they are non-profit organisations in Germany, they must not make profits and are hence subsidised by the federal states (VDV, 2021). It is feasible because PT drives the customers' utility of MaaS (Schulz et al., 2021a), which is also visible in our study.

Four suggestions to solve the trade-offs result from this analysis. First, in the initial stage, subsidies are necessary, not only for the TSPs but also for the integration of the MaaS platform (Meurs et al., 2020; Wong and Hensher, 2021). Subsidising PT discounts during high air pollution levels is one possibility to increase the market share. Nonetheless, the customers' WTP must be increased. Thus, second, an added value for the customers by the MaaS platform must be provided, for instance through artificial intelligence to dynamically adjust route planning on behaviour, preferences, or environmental factors such as vehicle capacity utilisation (Schulz et al., 2021a). Third, further revenue streams, e.g., for cross-selling, need to be realised, which goes in line with current debates about the transformation from MaaS to Mobility as a Feature, stressing the importance of further services apart from mobility (Covarrubias, 2018). Fourth, since profit margins per package are quite low for our researched customer groups, expansion to other customer groups or other regions should succeed. However, this might pose a problem for PT: Although the transport association has some authority in the price setting, it is the cities that provide concessions and special negotiations for each corresponding PTO. As for the private offer, scaling up is easier because no city boundaries are given. Through the platform, transaction costs of complementarily produced products, especially for the coordination of activities and resources (competencies) of the partners are reduced (Barney, 1991).

Although MaaS ecosystems are currently not profitable, by attracting more users, especially for value-added services, sticking with the ecosystem can pay off in the long run. By scaling and diversifying the offer, from a mid- and long-term perspective, ecosystems can create joint value because more partners are attracted to participate, the so-called platform effect (Cusumano et al., 2019). Subsidising the more price-sensitive market side on platforms for this aim is a common practice (Eisenmann et al., 2006). Because in our research, apart from car sharing, all TSPs need subsidies to be able to operate, it is of the utmost importance to fundamentally reallocate subsidies paid following the efficiency and service level provided and to thus change the market settings for the whole transportation system (Schulz et al., 2021a).

Some calculations are beyond the scope of this study. Initial investment costs for the platform setup are not considered. Because transportation has fixed-step costs, a reliable calculation of the TSPs' costs was not possible. We used publicly available data instead to calculate approximations. Secondary value streams could be reached as higher utilisation of vehicles increases efficiency and decreases operating costs (Aapaoja et al., 2017; Kamargianni and Matyas, 2017), which could not be calculated due to missing data availability. For the same reason, neither the cross-selling potential nor the subsidies are included in the calculations, although proven to be important. Furthermore, the quantification of the buyers' value appropriated as described in Section D.2.1 also lies outside this scope. The results are calculated with data collected in our research area and probably differ in another study area due to different regulatory and economic conditions (Polydoropoulou et al., 2020b).

Future research can build on this outcome and should focus on the following aspects:

- The joint value creation should be estimated for other settings, for other customer segments and for income levels different from university students' and including further diversified services (e.g. including ride hailing operators).
- A longitudinal study on existing MaaS ecosystems can discover the development of joint value creation over time in different ecosystem phases.
- A shift in subsidy grants in urban transportation away from private car privileges should be discussed and simulated regarding its effect on joint value creation in MaaS ecosystems.
- Governance aspects and their influence on joint value creation should be investigated, especially regarding data and access to customer information (Cottrill, 2020; Schulz et al., 2021a).
- Also, a business model for the MaaS orchestrator must be designed that specifies the profit model but also defines the resource allocation, competitive advantage, and value architecture (Proff and Szybisty, 2019).
- The definition of value should be broadened to include also non-monetary aspects (see e.g. Kraus and Proff, 2021), for instance using multi-criteria decision analysis when comparing privately and publicly orchestrated MaaS ecosystems (Schulz et al., 2021a).

6. Conclusions

This research is the first to quantify the actual value created in a MaaS ecosystem, following the more restrictive ecosystem definitions from business strategy research. It complements existing studies on MaaS by taking on the economic perspective (Tsouros et al., 2021).

To answer the first RQ regarding the definition of a MaaS ecosystem, a MaaS offer is an ecosystem where functions such as ticketing and payment are integrated, and seamless mobility is provided through mobility packages, thereby creating value superior to unintegrated value chains. Regarding RQ2 about the value elements the MaaS ecosystem comprises, we answer as follows: Apart from the subscriptions sold, the commissions or bulk discounts from TSPs must be considered, as well as the new customers and revenue for the TSPs, in relation to their ratios of EBIT to revenue. Fixed and variable costs for IT infrastructure, personnel, payment integration and insurance are paid. Private MaaS ecosystem operators must furthermore create additional value via advertisements or data analysis to sell to municipalities. Regarding RQ3, the superiority of private MaaS is dependent on the discount provided by the TSPs in the agency operating model. None of the settings creates joint value under the current circumstances, but for the 2% discount private setting, the least joint value is the destructed.

Our study shows that under the current circumstances, joint value can neither be created in public- nor private-driven MaaS ecosystems. Additional revenue from data and added services is essential for MaaS to thrive. This goes in line with recent discussions about the transition from mobility as a service to mobility as a feature (University of Sydney, 2022).

Chapter E: Conclusion

1. Summary of the results

As outlined in Chapter A, there are many hypothesised effects in favour of MaaS, such as its positive impact on transportation sustainability, responsiveness to customer expectations, and its profitability (see for instance Alyavina et al., 2020; Guidon et al., 2020; Kamargianni and Matyas, 2017). All these factors have contributed to the enthusiastic reception of MaaS in recent years in industry and academia (Deloitte, 2021; Wong et al., 2020). However, there is a lack of in-depth research on whether MaaS has these properties (Ho, 2022; Orozco-Fontalvo and Moura, 2023; Smith et al., 2023) and how the aforementioned effects are interlinked. The aim of this thesis was filling these research gaps by answering the RQs and ROs previously formulated in Section A.2 as follows.

1.1. Sustainability

Starting this investigation with a focus on sustainability, whether MaaS can contribute to a sustainable mobility shift depends to a large extent on the mobility services that can be booked within the app (Canzler and Wittowsky, 2016). RQ1 therefore related to the sustainability level of transportation services to integrate into an urban MaaS offer. With a focus on the Ruhr area, the aim was to find out which of the services offered in the four cities of Duisburg, Essen, Bochum, and Dortmund was the most sustainable (RQ1). Specifically, all existing providers should be evaluated according to their sustainability impact (RO1). Therefore, Chapter B presented a multi-method analysis to identify criteria interrelations by implementing ISM and MICMAC as a weighting method into PROMETHEE as exemplary MCDA.

RQ1 can be answered as follows: The most sustainable transportation service in the Ruhr area are tramways (φ = 0.3185) or public transportation in general (buses compared to tramways; φ = 0.1962) when comparing them with bike sharing (φ = -0.0152), e-scooter sharing (φ = -0.2055) and car sharing (φ = -0.2940). This is particularly because buses and trams perform best in terms of revenue, affordability, accessibility and equity compared to the sharing alternatives, with trams also performing best in terms of safety and demand. (see Table B-4), although these are not the criteria with the highest weighting (5.41% to 10.81% compared to 15.56% for energy consumption).

RO1, the evaluation of the mobility service providers according to their sustainability impact, was performed using prescriptive decision theory as an explanation. It was shown that interrelations between criteria in transportation are best identified and systematised using ISM because of its uniqueness in applications in MCDA with inter-criteria relations and its diverse applications in transportation research, especially adopting modifications and extensions such as MICMAC and ISM-P (Girubha et al., 2016; Sushil, 2018; Tarei et al., 2021). The consideration of the interrelations in MCDA should happen by weighting the criteria according to their driving and dependence power calculated with MICMAC. It can be used transparently in the straight-line weighting method based on the arithmetic mean, normalising the criteria vectors and weighting the sustainability dimensions equally in the ranking of alternatives in PROMETHEE (Brucker et al., 2004; Pahl et al., 2007; Silva et al., 2010). This proves to be a transparent and more objective method for criteria weighting than the usual direct elicitation of the decision-makers' opinions regarding the importance of each criterion. The sustainability rating of each transportation service for each criterion could be differentiated in the GAIA web (see Figure B-5).

Hence, the contributions of this chapter are two-fold: first, the methodology was further developed before it could be applied in a second step to analyse the available transportation offers in the Ruhr area. The analysis showed the importance of public transportation for sustainable mobility, especially of tramways.

1.2. Customer centricity

RQ2 referred to the detailed design of MaaS offers for university students since they generally have a higher acceptance of new technologies (Gessner et al., 2023; Nash and Mitra, 2019; Nordfjærn et al., 2019) and no comprehensive research has been conducted on this specific customer group yet (Gandia et al., 2021b). Asking this question was important because the design of MaaS offers can lead to a high number of combinatorial options, increasing complexity (Maas, 2021; Stopka, 2020). As university students differ in their preferences (Groth et al., 2021), the aim was to develop a MaaS offer for specific customer segments among students (RO2). Hence, Chapter C aimed at the composition of a MaaS offer for students based on WTP and its determining factors. Based on choice theory and the service-dominant logic, it was assumed that latent variables of the choice process (e.g., motivation, perceptions, and attitudes) differ in benefit segments and that a) multimodal integrated mobility packages and b) segment-specific MaaS packages increase the students' utility and thus, revenue potential.

Bearing this in mind, RQ2 was answered using choice-based conjoint analysis with the derived questionnaire answers of 1,165 students in the University Alliance Ruhr. In general, students proved to be highly price sensitive (relative importance = 69.9%), although the high standard deviation (12.34) reveals user heterogeneity. Bike sharing and car sharing were the most important transportation attributes to university students among urban transportation options (relative importance = 9.60% and 9.35%, respectively), followed by on-demand e-shuttles (6.46%) and e-scooter sharing (4.64%). The integration value of multimodal mobility packages was statistically proven as only for e-scooter sharing the pay-as-you-go (PAYG) attribute level part-worth utility was higher than the inclusion of a budget in the bundle. Therefore, to answer RQ2, when designing a generic MaaS offer that maximises WTP, the offer includes:

- on-demand e-shuttles (up to 10 trips among the Ruhr universities),
- car sharing (up to 200 km or 6 hours),
- bike sharing (e-bike rental of up to 30 minutes without trip amount restriction) and
- e-scooter sharing as a PAYG option

for €26.81 per month. Hence MaaS offers for university students do not necessarily need to include the e-scooter sharing budget. If only maximising market share is considered, e-scooter sharing would also be included (up to 50 minutes or 10 trips) but the offer should be adapted to the generally high price sensitivity.

Hence, and to follow heterogeneity, benefit segmentation based on the relative transportation attribute importance using k-means clustering revealed the existence of three segments (RO2): the “generous multimodal flexibles” (WTP = €54.02, n = 152) with 17.22% preference for e-shuttles compared to 6.46% for the mean, “frugal bike users” (WTP = €21.57, n = 756) with bike sharing preference of 10.77% compared to 9.60% for the mean and “car users” (WTP = €25.25, n = 257) with 19.15% importance of car sharing compared to 9.35% (mean). The MaaS bundles were designed for each segment including the most preferred attribute levels for each transportation attribute and the summed prices for the attribute levels were chosen (see Table C-10). These are:

- generous multimodal flexibles: e-shuttles among the universities, car sharing and e-scooter sharing as PAYG options, and bike sharing as e-bike rental for €58;
- frugal bike users: e-shuttles at one university, car sharing up to 3 h/100 km, bike sharing as e-bike rental and e-scooter sharing up to 10 trips/50 min for €68; and
- car users: e-shuttles among the universities, car sharing up to 6 h/200 km, bike sharing with normal bikes, and e-scooter sharing as PAYG option for €88.

The market simulation showed that only 0.05% of the respondents would choose the generic offer, compared to 3.08% for three segment-specific offers, showing a significant difference in revenue potential ($T(2{,}328) = 9.32$; $p < 0.001$). Consequently, it is proven that it is more beneficial to design a MaaS offer palette appealing to the three customer segments (i.e., with an increased revenue potential) instead of one generic offer. Although appearing to be homogeneous in socioeconomic aspects, university students have different transportation attribute preferences and price sensitivity, which is also shown in differences between the segments regarding psychological factors.

1.3. Supply-side profitability

Concluding with the profitability of MaaS and paying particular attention to the ongoing debate on the preferred role of the orchestrator in the ecosystem (public or private, see e.g. Hensher et al., 2023; Krauss et al., 2022; Reck et al., 2020), RQ3 focussed on the difference between ecosystem value jointly created in publicly and in privately orchestrated MaaS ecosystems. Using the agency model from the literature, market simulations were conducted based on explanations for superior value creation in ecosystems (see e.g. Chen et al., 2022; Cusumano et al., 2019). The more general objective (RO3) was to discover how to profitably offer a MaaS ecosystem.

In the first step, the MaaS ecosystem was defined as an offer with integrated functions such as ticketing and payment adhering to a standard (complementarity in production), and in which seamless mobility is provided through mobility packages (complementarity in consumption) (Jacobides et al., 2018). Subsequently, value elements of the ecosystem necessary to provide these complementarities must be identified, including the set of ecosystem partners customers, transportation service providers (e.g. sharing and on-demand services) and public transportation operators, and the orchestrator (Hensher et al., 2020). The subscriptions sold to customers, volume discounts from the transportation service providers, and new income for the transportation service providers concerning their ratios of earnings before interest and taxes to revenue are value inflow elements. Costs for personnel, IT infrastructure, and services such as payment integration and insurance are outflow elements. The value created jointly in a privately orchestrated MaaS ecosystem depends directly on the discount provided by the transportation service providers in the agency operating model (2%, 5%, or 10%). This is not the case in a publicly orchestrated MaaS ecosystem, where the orchestrator passes on the discounts directly to the customer. Furthermore, private MaaS orchestrators create additional value through data sold (to municipalities) and advertising. However, using market simulations, the results presented in Chapter D showed that in none of the settings joint value could be generated.

To answer RQ3: In the public setting, including the value elements mentioned, there are monthly losses of €180,640, mostly caused by public transportation, compared to €138,264 (2% discount setting), €168,275 (5% discount setting) and €168,880 (10% discount setting) loss in privately orchestrated MaaS ecosystems. Consequently, in the setting with a 2% discount for the private orchestrator, the least value is destroyed: This ecosystem setting causes 23.5% less loss than the public one. In all settings, less value is destroyed in a privately orchestrated MaaS ecosystem compared to a public one.

However, as for RO3, none of the investigated settings could create profit. Hence, it is important to find out where the losses are made. Surprisingly, the setting with the most newly generated revenue is the public one, even though it causes the highest loss. However, among all public transportation operators and transportation service providers, only car sharing has a positive net income and therefore is the only service generating profits in the analysis. Among the transportation service providers, the proportion of value generated through car sharing is only 14.3% (10% setting) to 19.3% (2% setting). Furthermore, the platform costs for the orchestrator surpass the additional value in all settings (€37,808 costs in the 2% setting up to €48,254 in the 10% setting). Consequently, the MaaS ecosystem can only be offered profitably if it includes transportation service providers who can cover their operating costs, increases the orchestrator's value inflow by creating higher WTP, attracts new customer groups, and offers value-adding services, e.g., through cross-selling. Artificial intelligence could further help to also decrease the orchestrator's, transportation service providers', and public transportation operators' operating costs, such as vehicle capacity utilisation (Schulz et al., 2021a). In addition, subsidies are necessary for the operation of the platform, at least for the set-up (Wong and Hensher, 2021).

1.4. Interaction of the results

To summarise the results presented in Chapters B, C, and D regarding the RQs and ROs formulated in Section A.2, Table E-1 gives a brief overview.

The presented answers and achievements are relevant to the initial design phase in building an ecosystem. Hence, to illustrate the interconnection of the results, Figure E-1 shows that the results of the Chapters B, C, and D can be considered as input for the building blocks of the minimum viable ecosystem (Adner, 2021; Dattée et al., 2018; Jaspers et al., 2023; Lewrick et al., 2018). Building blocks are defined as the key factors of the ecosystem necessary to create value in the initial stage (Lewrick et al., 2018). They are explained briefly as follows.

Table E-1: Answers and achievements regarding the formulated research questions and objectives in this thesis (own elaboration)

Code RQ/ RO	Question/Objective	Answer/Achievement
RQ1	Which is the most sustainable transportation service in the Ruhr area?	Public transportation (tramways [φ = 0.3185] and buses [φ = 0.1962])
RO1	to evaluate mobility service providers according to their sustainability impact	Application of ISM-P as objective weighting method in PROMETHEE and GAIA webs to show the strengths and weaknesses of each transportation service
RQ2	How should MaaS offers be designed for university students?	Emphasis on high price sensitivity (69.9%) and low relative importance for e-scooters (4.64%); paying attention to high heterogeneity (SD for price sensitivity = 12.34) by applying benefit segmentation using k-means clustering
RO2	to develop a MaaS offer appealing to promising customer segments	Identification of three segments with significant differences in transportation choice variables and offering specific packages: • generous multimodal flexibles: e-shuttles among the universities, car sharing and e-scooter sharing as PAYG options, and bike sharing as e-bike rental • frugal bike users: e-shuttles at one university, car sharing up to 3 h/100 km, bike sharing as e-bike rental and e-scooter sharing up to 10 trips/50 min • car users: e-shuttles among the universities, car sharing up to 6 h/200 km, bike sharing with normal bikes, and e-scooter sharing as PAYG option
RQ3	How does the joint value created differ in private MaaS ecosystems from a public MaaS ecosystem?	Monthly loss of €180,640 for a publicly orchestrated MaaS ecosystem compared to €138,264 (2% discount setting) up to €168,880 (10% discount setting) loss for a private ecosystem
RO3	to discover how the MaaS ecosystem can be offered profitably	Formulation of six leverages for increased profit: • only including transportation service providers that can cover their operating costs • creating higher WTP • addressing new customer groups • offering value-adding services • decreasing operating costs through artificial intelligence • providing subsidies for the platform operation

The customer information generated in this thesis via conjoint analysis served to find the focal value proposition using customer-centricity at the core of MaaS. It is defined in large part by the value offer made to the customer (Lusch and Vargo, 2006). This value offer was analysed in depth in Chapter C by finding out which MaaS bundles create customer utility. The operating model was largely composed according to the sustainability analysis of potential transportation service providers and public transportation operators for MaaS (Chapter B). Hence, the necessary partners to deliver a sustainable MaaS value were identified. This is important because the operating model highlights the strengths and weaknesses of potential ecosystem partners in general (Lewrick et al., 2018; Lewrick, 2022) but so far, research has not explicitly stated how the sustainability assessment could be conducted at this stage. By incorporating this assessment, it is possible to identify which partners are necessary to deliver sustainable MaaS value. The platform is the central part of the ecosystem as it can enhance joint value creation and value capture (Cusumano et al., 2019; Kapoor, 2018; Kraus and Proff, 2023b). The effects are called value drivers and include modularisation, supply-side economies of scope, and demand-side economies of scale (Chen et al., 2022; Dyer et al., 2018; Kraus and Proff, 2023a). However, rules and regulations, knowledge-sharing practices relation-specific assets are needed which the orchestrator demands as governance mechanisms (Cusumano et al., 2021; Dyer et al., 2018). This way, access to the platform and incentives for joining are defined (Adner, 2017). More information is provided in Section D.2.1. In a final step, information from Chapters B and C was used to create the blueprint for joint value creation and value capture. Calculations were performed to find out if the current ecosystem built under specific settings will scale in the future or if the ecosystem building blocks need to be readjusted (Dattée et al., 2018). Hence, Chapter D served to estimate how much joint value can be created in the MaaS ecosystem under certain settings. As the results showed, a reconfiguration of the previous building blocks is necessary for the next step to create joint value and not destroy it for the selected service providers and customer groups.

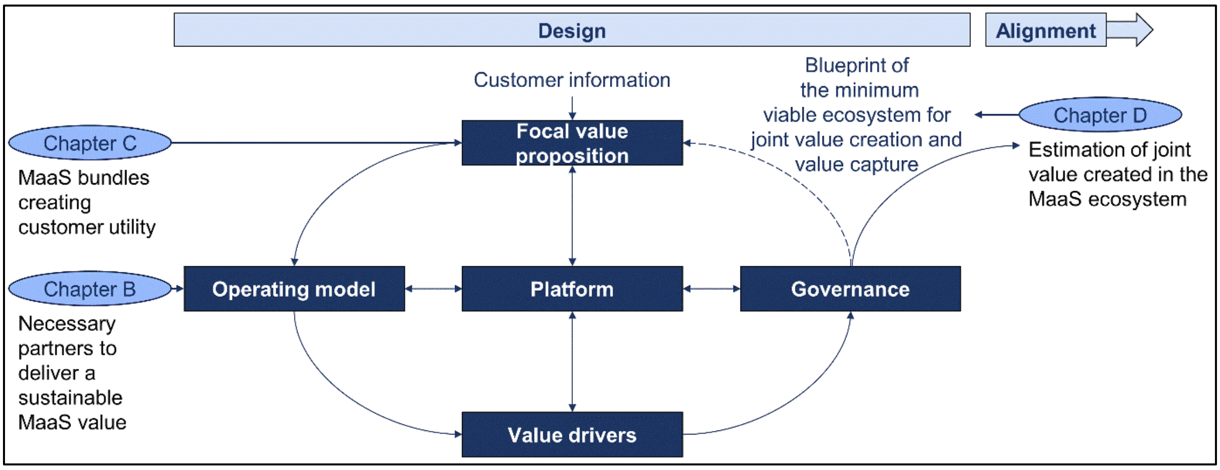


Figure E-1: Input from Chapters A, B and C for MaaS as an ecosystem for sustainable mobility (own elaboration based on Adner, 2021 and Lewrick et al., 2018)

2. Implications for research and practice

2.1. Implications for research

The findings of this thesis regarding the sustainability of transportation services potentially integrated into MaaS, the need for integration and individualisation of a MaaS offer for university students as customers, and the differing value formed in publicly and privately orchestrated MaaS ecosystems with different bargaining power contribute to existing research in a variety of ways.

The first implication for enhancing MaaS regarding sustainability is the deeper focus on the sustainability level of the mobility services included. So far, the topic of sustainability in MaaS has been addressed regarding car dependence and whether a behavioural change is feasible (Alyavina et al., 2020; Hensher et al., 2023; Strömberg et al., 2018). However, the topic has only been discussed on a superficial level, e.g. by mentioning the need to provide sustainable transportation options (Kamargianni and Matyas, 2017). It is not explained which options these are and why.

Therefore, a thorough analysis of the available modes for MaaS was needed based on the tripartite concept of sustainability. It implements the demand from prescriptive decision theory to include criteria relations and hierarchies in the decision models. The combination of ISM complemented by MICMAC and PROMETHEE extends previous research on hybrid MCDA methods that also incorporate conflict (e.g. van Huylenbroeck, 1995; Wu et al., 2020) in the growing field of hybrid MCDA applications (Abdel-Basset et al., 2021; Amirshenava and Osanloo, 2018). The implementation of a graphical representation of ISM-P and the GAIA web also contributes to the field of prescriptive decision theory given its requirement to make the decision process more transparent and comprehensible (Keeney and Winterfeldt, 2012). The inclusion of the criteria interrelations resulting from MICMAC in the weighting in MCDA, with the three sustainability dimensions weighted equally, did not show differences in the results compared to equal weighting of all criteria in the sensitivity analysis. Therefore, although this weighting method provides more objectivity compared to others and sensitivity analysis proved model robustness, its impact is relatively small. However, ISM-P proved to discover conflict between criteria: The conflict was also visible in diverging performance scores of alternatives on these criteria pairs. Incorporating polarity is hence a solid extension and should be validated in future research with statistical methods, such as structural equation modelling.

The method provided new information on the sustainability alternatives: These results underline the importance of public transportation as the backbone of any transportation system (Banister, 2008; Canzler and Wittowsky, 2016; Maas, 2022). More importantly, the sustainability performance of all alternatives on all criteria is transparently shown and more detailed insights are provided in the GAIA web. The web shows that, for instance, while car sharing has the lowest overall sustainability score (-0.2940), it scores highest on travel speed (28.75). Regarding polarity, a goal conflict is visible for tramways: the higher the demand, the higher the operating cost. Tramways should be improved regarding operating cost, occupancy, and travel speed. Increased efficiency levels could assist. They are stated in the literature to be a benefit of MaaS (Strömberg et al., 2018). It remains an area for future research to discover how this can be reached through the MaaS platform.

A newly gained insight into MaaS and customer centricity is the in-depth analysis of university students regarding their psychological factors of transportation choice and reflecting the differences in benefit segments based on relative transportation attribute importance. The results support the claim for individualised, segment-specific MaaS offers (Alonso-González et al., 2020; Jittrapirom et al., 2017; Jovic, 2022; Vij et al., 2020). Thereby, the individualisation and integration axiom of the service-dominant logic could be first proven statistically. This complements previous research on mobility using the service-dominant logic as an explanation for customer utility but without empirical analysis (Frey et al., 2019; Schulz et al., 2021b)

Furthermore, although originally used by McFadden (2001) to explain the black box of the individual choice process, the variables previous mode choice, car and bike availability, speed, price, environmental friendliness, enjoyment, and comfort as priorities for commuting, perceptions of the car and the bike, social norm for cars, bikes, and public transportation, and environmental awareness could also sow significant differences among the segments. Previous studies have found the importance of a single variable or a set of these types of variables (Liljamo et al., 2020; Ruhrort et al., 2014), but a more comprehensive study on the variables influencing choice has not yet been conducted. Previous studies on MaaS commonly used latent class analysis as a cluster method mainly based on socioeconomic variables (see e.g. Alonso-González et al., 2020; Chen et al., 2023; van 't Veer et al., 2023). The results of the present study prove the importance of benefit segmentation (Wind, 1973) because apart from income, none of the socioeconomic variables showed significant differences between the segments, compared to almost all psychological variables. Therefore, the importance of choice theory could be confirmed.

Future research could use the psychological factors in choice theory as explanatory variables, e.g., in regression analysis, as factors for explaining the utility of MaaS offers. It could also use variables and models from other theories relevant for new mobility technologies, such as the theory of planned behaviour to explain the mobility behaviour regarding MaaS (Ajzen, 1991). As a customer group belonging to the same life event was analysed (Proff, 2019), another research stream to be used in future studies on MaaS is life events (Günthner, 2022; Lanzendorf, 2010).

Regarding the supply-side profitability of MaaS, the requirements for MaaS as an ecosystem derived from ecosystem strategy research were clarified in this work (Adner, 2017; Jacobides et al., 2018) by combining previous research on individual definitional elements of MaaS ecosystems with the requirements of strategy research (Karinsalo and Halunen, 2018; Sochor et al., 2018). So far, only Hensher et al. (2020) have mentioned all ecosystem building blocks without further explanations.

This is the first research using calculations based on real market data for the profitability assessment. Only van den Berg et al. (2022) performed research on the economic potential of MaaS before but in a generalised manner. The standardised value elements used in the present study create a common understanding for following studies on the economic potential of MaaS. Contrary to general statements about superior value in an ecosystem (PwC, 2022), this study showed that value is jointly destroyed in MaaS ecosystems (similarly see Schulz et al., 2021a). It was possible to explain why MaaS ecosystems have so far failed to scale, and to uncover opportunities for improvement to increase the profitability of MaaS for all ecosystem partners involved – another novelty on which future research can build. One important aspect is that the transportation services incur high operating costs for the necessary fleet. Hence, scaling in the network as one value driver of ecosystems is not possible at no cost. This challenges previous research stating that industry boundaries will disappear and that the new structure will be given by ecosystems (Adner, 2021), especially for the automotive and mobility industry.

This thesis showed the importance for future MaaS research of a focus on each player's business and operating model (Hensher et al., 2023; Jittrapirom et al., 2020; Stopka et al., 2018). As the joint value destruction is caused by the participating firm's individual losses, a single case study of successful service providers, such as car sharing in this analysis, should deduce key success factors and guidelines on how other services should proceed to reach them. This can also enhance theory building regarding ecosystems in industries heavily based on assets. Another avenue for future research is calculating the impact of other platform effects as value drivers on joint value creation, such as data-based learning and cross-subsidisation (Iansiti and Lakhani, 2020; Petricevic and Teece, 2019). Furthermore, this dissertation is the first contribution to the debate for and against public and private MaaS ecosystem orchestrators (Kamargianni and Matyas, 2017; König et al., 2016; Mukhtar-Landgren and Smith, 2019; Polydoropoulou et al., 2020b; Wong et al., 2020), which is based on a numerical comparison of potential joint value creation. By performing the calculations, the study highlights the superiority of a privately orchestrated MaaS ecosystem for all bargaining power settings (6.5% up to 23.5% less loss), which contributes to current studies (Jittrapirom et al., 2020; Orozco-Fontalvo and Moura, 2023). Hence, governance as access to the platform for a certain discount provided is an important aspect of MaaS research (Murati, 2020) and must be discussed in more depth in future studies. It is even more crucial for the private orchestrator to find the right price for the customer by focussing on a combination of profit and market share because, controversially, in the setting with less discount provided less loss is made. Table E-2 condenses the theoretical implications regarding enhancing MaaS sustainability, customer centricity, and supply-side profitability presented in this section.

Table E-2: Theoretical implications for enhancing MaaS sustainability, customer centricity, and supply-side profitability (own elaboration)

Aspect	Newly gained insight	Advances in MaaS research	Opportunities for further research
Sustainability (Chapter B)	• Visibility of criteria conflicts in ISM-P also in differing performance scores of mobility services (e.g. for tramways between demand and operating cost) • Transparency about areas of improvement (regarding tramways e.g. operating cost, occupancy and travel speed)	• First study to analyse mobility services commonly offered in MaaS regarding the sustainability impact based on social, economic and environmental criteria • Proof for public transportation being the backbone of a sustainable MaaS offer	• Validation of relations between criteria using structural equation modelling • Increase in energy efficiency of transportation modes through the MaaS platform
Customer centricity (Chapter C)	• Statistical proof of the individualisation and integration value derived from the service-dominant logic regarding MaaS offers • Superiority of psychological factors (e.g. social norm) of transportation choice over classical (e.g. sociodemographic) in dividing customer segments	Compared to latent class analysis (commonly used in MaaS) more thorough analysis of dividing psychological factors using benefit segmentation and choice theory	• Regression analysis to explain the utility of MaaS offers based on psychological factors of choice theory • Application of theory of planned behaviour and life events for MaaS research regarding students
Profitability (Chapter D)	Difficulty for scaling in the network as ecosystem value driver due to high operating costs for the fleets of the service providers	• Moderate importance of bargaining power of the orchestrator (in terms of ecosystem governance) • High importance of determining the right price for the MaaS offer for the customer	• Single case studies on the service providers‘ business and operating models to deduce recommendations • Quantification of platform effects as value drivers, such as data-based learning and cross-subsidisation

2.2. Implications for practice

The results of the dissertation provide a framework for how to design an enhanced MaaS offer as an orchestrator. First, attention must be paid to the composition of the partners for the MaaS offer. As shown in Chapter B, the overall scores of sustainability of mobility services vary. To offer a sustainable MaaS solution, it is recommended to assess the sustainability of the available mobility service providers for the region to be served. Data must be collected for the city-specific criteria demand, affordability, reachability, and equality. Only those providers for the MaaS platform that achieve a certain minimum sustainability score defined before (e.g., a positive φ) should be considered. Among the providers that achieve this score, a wider range of mobility service providers should also be included in the MaaS offer, so that the disadvantages of one provider in some sustainability criteria can be outweighed by the advantages of the others. For instance, while bike sharing causes low air pollution, it is slower than car sharing. Smart algorithms are necessary for this step. For instance, in cases where a customer prefers speed for specific routes, car sharing should be displayed higher in the list of options; in other cases, public transportation could preferably be displayed in the app. Furthermore, it is important to continuously track the sustainability criteria and the outcome of each mode in a sustainability index, also after MaaS initialisation. This could happen on a monthly basis. This way, conflicting criteria should further be tracked and service improvements like technological innovations of the drive unit should be considered in novel ways to resolve the conflict.

Second, the design of the MaaS bundle should start with the collection of customer information about the utility of the different attributes, i.e., the transportation services. This will ensure sufficient customer utility to design an attractive value proposition via the offered MaaS bundles. Therefore, a survey as presented in Chapter C for conjoint analysis could be conducted before setting up the offer or during an initial pilot phase. Based on this data, customers should be segmented, and customised bundles as MaaS packages should be developed to address their specific desires. Benefit segmentation has proven to be a good method for this. It showed that at least three different packages should be offered: a low-cost, an intermediate, and a premium offer to exploit the highest WTP for each segment. Generally, it is recommended to integrate various providers into the app, but this should be verified with the customers' WTP. The integration of e-scooter sharing should be verified in any case, as this mode has the lowest relative importance.

Third, and most important for enhancing MaaS, the joint value created in the MaaS ecosystem should be estimated to make it scalable and economically viable for both public and private MaaS orchestrators as well as the specific service providers that could be integrated into the app. It is suggested to start the offer with a minimum viable product for which less personnel is necessary and to track the advances monthly. The orchestrator must design a business in accordance with the available WTP of the targeted customer group. The value proposition of MaaS needs to be extended to tap into further market opportunities (Hensher and Hietanen, 2023). Services apart from transportation providing value regarding WTP, such as cross-selling, the inclusion of a diversified service offer, or gamification through additional benefits for using the MaaS app should be considered. Nudging, i.e., soft pull measures to increase the use of the app could be implemented. Further examples to increase customer utility are pausing the subscription for one month, subscription transferability, taking one additional person in the transportation service, or included route planning (Maas, 2021; Orth et al., 2022). These ideas for added value should be discussed by the orchestrator with the target customers in focus groups and they should be tested in real-world labs. Apart from the user acceptance, the cost/benefit ratio should also be calculated and tracked monthly. These suggestions are summarised in Figure E-2 as steps to ensure that MaaS is a sustainable, customer-centric and economically viable element of the mobility shift.

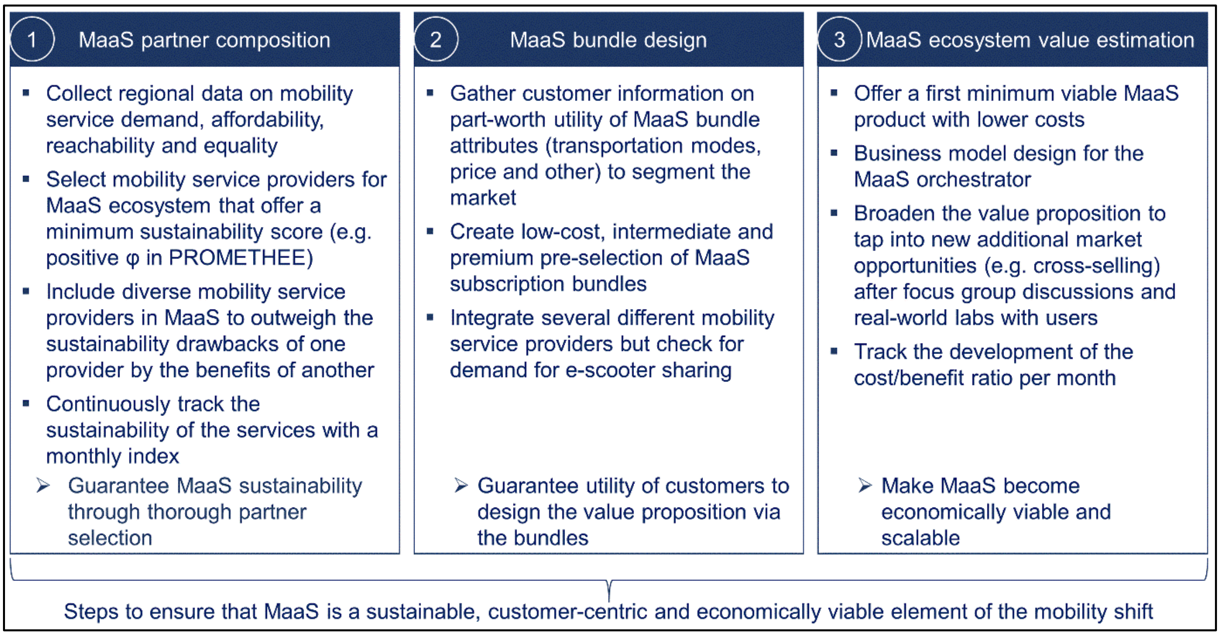


Figure E-2: Practical implications for enhancing MaaS sustainability, customer centricity, and supply-side profitability (own elaboration)

As for implications for policy-makers, the dissertation showed that no additional WTP is existent for the MaaS platform itself (Chapter C). However, the sustainability of the different mobility services is given (Chapter B) and can be enhanced when providing nudges to the customers for using the most sustainable transportation alternative. In order for MaaS to thrive, public funding is necessary, at least to cover the platform costs (Chapter D). This could be accompanied by new regulations for the distribution of taxes and the abolition of tax privileges for company cars, for example.

3. Limitations and Outlook

Despite its multifaceted outcomes on MaaS, this research is not without five limitations. First, the main limitation of the three articles in this thesis is their geographical and thematic scope. The transportation mode-specific data regarding one-third of the sustainability criteria in the sustainability assessment (Chapter B) stem from a regional assessment concerning the Ruhr area. Furthermore, the data gathered via conjoint analysis and the survey on mobility behaviour (Chapters C and D) are based on the responses of students and employees of the Research Alliance Ruhr. The results are hence neither entirely transferable to other regions or countries nor other MaaS customer groups.

Second, the three articles include different transportation services that are the subject of the research due to different data availability. For instance, the conjoint analysis for students did not include public transportation due to the mandatory subscription of the students to a semester ticket, whereas it was included in the analysis for employees in Chapter D. Furthermore, on-demand e-shuttles were included in the analysis in Chapter C but not in the other chapters due to missing market data caused by high market volatility during the span of the investigation.

Third, the data on mobility behaviour and preferences were collected when travel restrictions due to COVID-19 were still in place, which could have influenced response behaviour (Chapter B). The same applies to the data on profits and losses of the service providers (Chapter D).

Fourth, the utility and joint value estimations include only a narrow MaaS value proposition with transportation at its core due to the lack of available methodology. Therefore, hypothetical value inflows from cross-selling (e.g. discounts on other services) or other diversification methods as part of a holistic value proposition could not be estimated.

Fifth, the MaaS ecosystem platform, value drivers, and governance as further ecosystem building blocks are beyond the scope of the three articles. Value drivers such as economies of scale and governance mechanisms such as the creation of trust among the ecosystem actors are nonetheless critical for the uptake of MaaS, especially for the scaling phase of the ecosystem. This goes in line with the discussion about how to effectively coordinate public-private partnerships for MaaS.

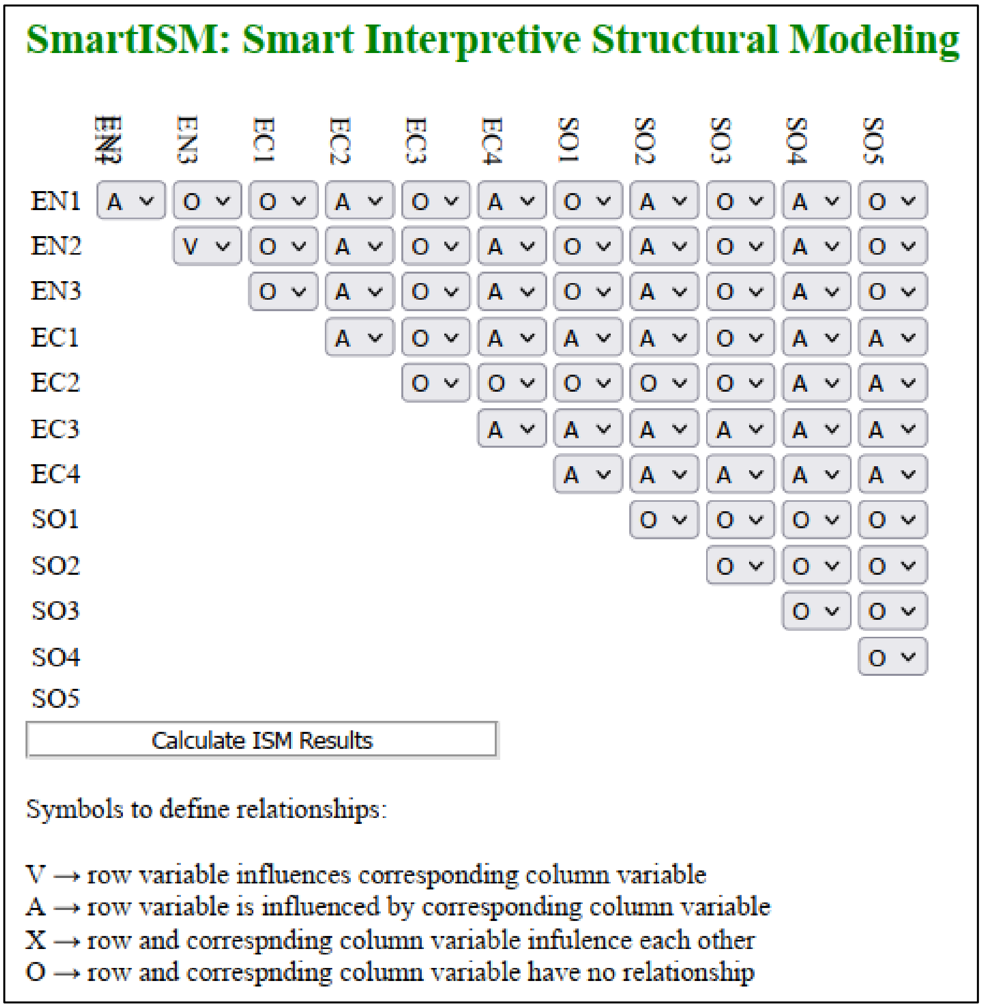
Therefore, future research should investigate MaaS for other German regions and other countries, especially in the Global South. A country comparison that allows statistical tests for differences, especially in terms of customer utility, can provide further insights into MaaS. Also, in future studies, the scope should be extended to other customer segments with presumably higher WTP, e.g., employees in private companies or MaaS for older people in aging societies like Germany. Further research should also consider novel mobility services relevant to MaaS, such as autonomous shuttles or other regionally relevant transportation modes. Available subscriptions, such as the “Deutschlandticket” should be included for all the customers investigated. A repetition of the survey on mobility behaviour after the removal of the COVID-19 protection measures for comparison with the results of this thesis is also recommended. This is of particular importance as mobility is a habitualised behaviour that can only be changed on a large scale by disruptive events such as travel restrictions. For a mobility shift, not only the available mobility services are relevant but also the customer acceptance of these services. An extension of the MaaS value proposition to also include leisure offers, e.g., shopping vouchers or discounts for local events should be undertaken for value estimations including additional value inflow. To include quantification of value drivers such as effective pricing over time, AI-based learning, or scaling in the network, more data on such effects should be gathered, for instance through case studies on similar research topics, and novel methodologies for forecasting such as statistical software based on expert judgment should be developed. This would not only improve research on MaaS as an exemplary mobility ecosystem, but on ecosystems in strategy research in general. A holistic study of the minimum viable MaaS ecosystem as a blueprint of its building blocks is necessary to gain an overview of all design elements. Semi-structured interviews to collect qualitative data complementing this quantitative study serve to gather this information.

Future studies can build on the outcomes of this thesis when it comes to the essential sustainable ecosystem partners, the determinants for the evaluation of MaaS bundles, and the necessary measures to make MaaS a lasting and scalable contribution to the mobility shift. The potential of MaaS in the context of sustainable transportation is undoubtedly great, though it must include the right mobility service providers, the right orchestrator, and target the right customers in order to be also profitable.

Appendix

1. Appendix to Chapter B

1.1. Data generated using smartISM



SmartISM: Smart Interpretive Structural Modeling

	EN2	EN3	EC1	EC2	EC3	EC4	SO1	SO2	SO3	SO4	SO5
EN1	A	O	O	A	O	A	O	A	O	A	O
EN2		V	O	A	O	A	O	A	O	A	O
EN3			O	A	O	A	O	A	O	A	O
EC1				A	O	A	A	A	O	A	A
EC2					O	O	O	O	O	A	A
EC3						A	A	A	A	A	A
EC4							A	A	A	A	A
SO1								O	O	O	O
SO2									O	O	O
SO3										O	O
SO4											O
SO5											

Calculate ISM Results

Symbols to define relationships:

V → row variable influences corresponding column variable
A → row variable is influenced by corresponding column variable
X → row and correspnding column variable infulence each other
O → row and correspnding column variable have no relationship

Figure 1-1: Data input for smartISM (SmartISM, 2023)

Structural Self-Interaction Matrix (SSIM)

Variables	1	2	3	4	5	6	7	8	9	10	11	12
EN1		A	O	O	A	O	A	O	A	O	A	O
EN2			V	O	A	O	A	O	A	O	A	O
EN3				O	A	O	A	O	A	O	A	O
EC1					A	O	A	A	A	O	A	A
EC2						O	O	O	O	O	A	A
EC3							A	A	A	A	A	A
EC4								A	A	A	A	A
SO1									O	O	O	O
SO2										O	O	O
SO3											O	O
SO4												O
SO5												

Figure 1-2: Data output SSIM (SmartISM, 2023)

Reachability Matrix(RM)

Variables	1	2	3	4	5	6	7	8	9	10	11	12	Driving Power
EN1	1	0	0	0	0	0	0	0	0	0	0	0	1
EN2	1	1	1	0	0	0	0	0	0	0	0	0	3
EN3	0	0	1	0	0	0	0	0	0	0	0	0	1
EC1	0	0	0	1	0	0	0	0	0	0	0	0	1
EC2	1	1	1	1	1	0	0	0	0	0	0	0	5
EC3	0	0	0	0	0	1	0	0	0	0	0	0	1
EC4	1	1	1	1	0	1	1	0	0	0	0	0	6
SO1	0	0	0	1	0	1	1	1	0	0	0	0	4
SO2	1	1	1	1	0	1	1	0	1	0	0	0	7
SO3	0	0	0	0	0	1	1	0	0	1	0	0	3
SO4	1	1	1	1	1	1	1	0	0	0	1	0	8
SO5	0	0	0	1	1	1	1	0	0	0	0	1	5
Dependence Power	6	5	6	7	3	7	6	1	1	1	1	1	

Figure 1-3: Data output RM (SmartISM, 2023)

Final Reachability Matrix(FRM)

Variables	1	2	3	4	5	6	7	8	9	10	11	12	Driving Power
EN1	1	0	0	0	0	0	0	0	0	0	0	0	1
EN2	1	1	1	0	0	0	0	0	0	0	0	0	3
EN3	0	0	1	0	0	0	0	0	0	0	0	0	1
EC1	0	0	0	1	0	0	0	0	0	0	0	0	1
EC2	1	1	1	1	1	0	0	0	0	0	0	0	5
EC3	0	0	0	0	0	1	0	0	0	0	0	0	1
EC4	1	1	1	1	0	1	1	0	0	0	0	0	6
SO1	1*	1*	1*	1	0	1	1	1	0	0	0	0	7
SO2	1	1	1	1	0	1	1	0	1	0	0	0	7
SO3	1*	1*	1*	1*	0	1	1	0	0	1	0	0	7
SO4	1	1	1	1	1	1	1	0	0	0	1	0	8
SO5	1*	1*	1*	1	1	1	1	0	0	0	0	1	8
Dependence Power	9	8	9	8	3	7	6	1	1	1	1	1	

Figure 1-4: Data output FRM (SmartISM, 2023)

Level Partitioning(LP)

Elements(Mi)	Reachability Set R(Mi)	Antecedent Set A(Ni)	Intersection Set R(Mi)∩A(Ni)	Level
1	1,	1, 2, 5, 7, 8, 9, 10, 11, 12,	1,	1
2	2,	2, 5, 7, 8, 9, 10, 11, 12,	2,	2
3	3,	2, 3, 5, 7, 8, 9, 10, 11, 12,	3,	1
4	4,	4, 5, 7, 8, 9, 10, 11, 12,	4,	1
5	5,	5, 11, 12,	5,	3
6	6,	6, 7, 8, 9, 10, 11, 12,	6,	1
7	7,	7, 8, 9, 10, 11, 12,	7,	3
8	8,	8,	8,	4
9	9,	9,	9,	4
10	10,	10,	10,	4
11	11,	11,	11,	4
12	12,	12,	12,	4

Figure 1-5: Data output level partitioning (SmartISM, 2023)

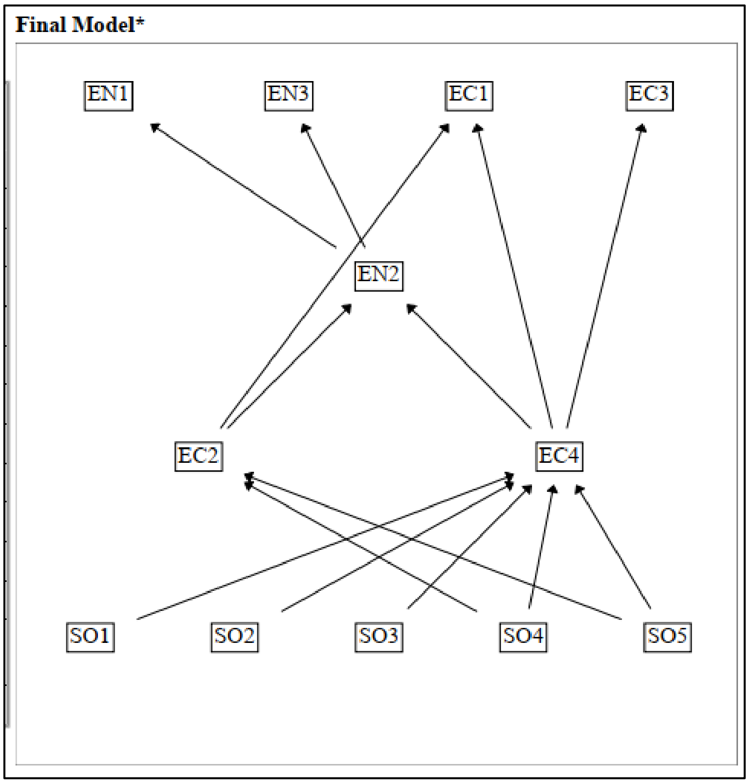


Figure 1-6: Data output digraph (SmartISM, 2023)

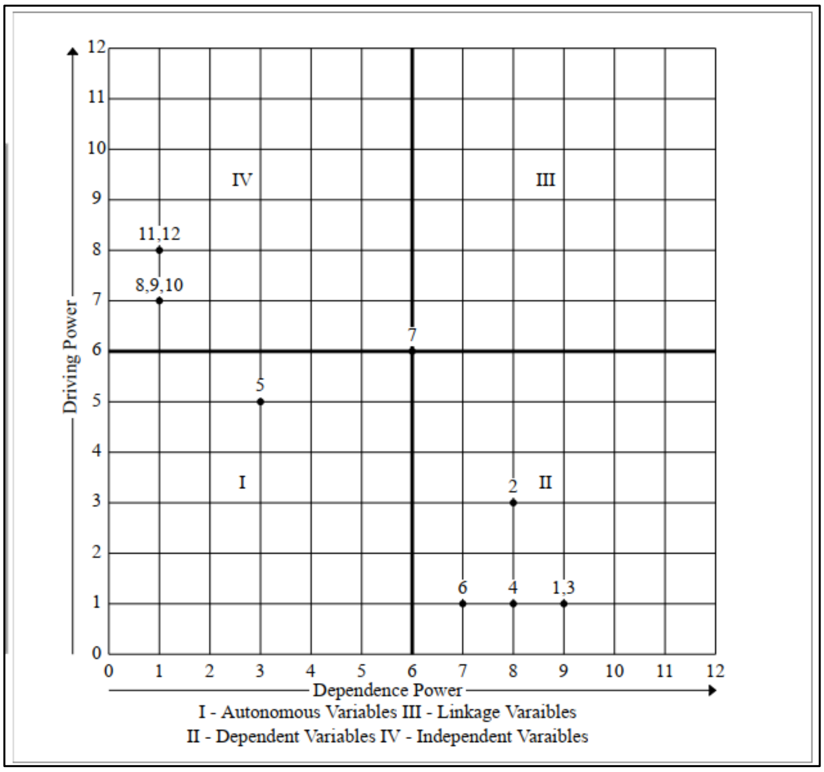


Figure 1-7: Data output MICMAC (SmartISM, 2023)

1.2. Data generated using Visual PROMETHEE

Table 1-1: Data input and output Visual PROMETHEE (Visual PROMETHEE, 2023)

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13
Szenario	Szenario1											
Evaluationen	Air pollution	Energy consumption	Greenhouse gas emissions	Operating cost	Occupancy	Revenue	Demand	Safety	Travel speed	Affordability	Reachability	Equality
action1	0,42	0,93	65,00	3,00	3,00	4,00	19,11	0,19	11,70	0,06	74,49	98,93
action2	0,09	0,91	64,58	1,00	3,00	4,00	44,21	0,00	11,80	0,06	74,49	98,93
action3	0,53	2,91	207,08	4,00	5,00	1,00	0,05	1,27	28,75	9,73	6,74	98,33
action4	0,03	1,25	106,25	2,00	2,00	3,00	0,11	27,40	18,70	8,63	5,06	98,14
action5	0,02	0,69	58,33	5,00	1,00	2,00	0,97	9,10	11,63	0,14	27,75	98,14
Präferenzen	Air pollution	Energy consumption	Greenhouse gas emissions	Operating cost	Occupancy	Revenue	Demand	Safety	Travel speed	Affordability	Reachability	Equality
aktiv	ja	ja	ja	ja	ja	ja	ja	ja	ja	ja	ja	ja
Min/Max	min	min	min	max	max	max	max	min	max	min	max	max
Gewicht	8,77	15,79	8,77	3,60	13,51	4,50	11,71	5,30	6,82	6,82	7,20	7,20
Präferenzfunktion	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear
Grenzwerte	absolut	absolut	absolut	absolut	absolut	absolut	absolut	absolut	absolut	absolut	absolut	absolut
q	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
p	0,52	2,20	148,75	4,00	4,00	3,00	44,17	27,40	17,13	9,68	69,43	0,79
s	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00	3,00
Monokriterielle Flüsse	Air pollution	Energy consumption	Greenhouse gas emissions	Operating cost	Occupancy	Revenue	Demand	Safety	Travel speed	Affordability	Reachability	Equality
action1	-0,4856	0,2318	0,2962	0,0000	0,0625	0,5000	0,1760	0,3377	-0,3514	0,4731	0,6622	0,6899
action2	0,3077	0,2432	0,2997	-0,6250	0,0625	0,5000	0,8863	0,3464	-0,3441	0,4731	0,6622	0,6899
action3	-0,7500	-0,8909	-0,8977	0,3125	0,6875	-0,7500	-0,3634	0,2884	0,8927	-0,7756	-0,5575	-0,2595
action4	0,4519	0,0500	-0,0504	-0,3125	-0,2500	0,0833	-0,3617	-0,9036	0,1594	-0,6335	-0,5878	-0,5601
action5	0,4760	0,3659	0,3523	0,6250	-0,5625	-0,3333	-0,3373	-0,0688	-0,3565	0,4628	-0,1792	-0,5601
Multikriterielle Flüsse	Phi	Phi+	Phi-									
action2	0,3284	0,4019	0,0735									
action1	0,1951	0,3125	0,1173									
action5	-0,0272	0,2099	0,2371									
action4	-0,2034	0,1295	0,3329									
action3	-0,2929	0,1928	0,4857									

Note: action1 = public buses; action2 = tramways, action3 = car sharing, action4 = e-scooter sharing, action5= bike sharing

2. Appendix to Chapter C

Table 2-1: Kruskal-Wallis test for differences between segments (own elaboration)

Variable	Segment	N	Mean rank	H	df	P
Socioeconomic						
Household size				0.37	2	0.83
	Car users	257	578.08			
	Frugal bike users	750	577.67			
	Generous multimodal flexibles	152	594.72			
Age				1.09	2	0.58
	Car users	257	568.82			
	Frugal bike users	755	583.33			
	Generous multimodal flexibles	152	601.5			
Income				6.96	2	0.03*
	Car users	249	604.18			
	Frugal bike users	723	542.84			
	Generous multimodal flexibles	143	554.22			
Priorities for commuting						
Speed				9.84	2	0.01*
	Car users	257	630.49			
	Frugal bike users	756	602.87			
	Generous multimodal flexibles	152	573.34			
Price				11.15	2	<0.01**
	Car users	257	530.27			
	Frugal bike users	756	602.87			
	Generous multimodal flexibles	152	573.34			
Environment				19.82	2	<0.001**
	Car users	257	521.59			
	Frugal bike users	756	612.53			
	Generous multimodal flexibles	152	539.98			
Comfort				25.84	2	<0.001**
	Car users	257	657.09			
	Frugal bike users	756	551.21			
	Generous multimodal flexibles	152	615.85			
Reliability				1.29	2	0.53
	Car users	257	591.93			
	Frugal bike users	756	576.8			
	Generous multimodal flexibles	152	598.75			
Enjoyment				6.06	2	0.05*
	Car users	245	585.5			
	Frugal bike users	730	545.9			
	Generous multimodal flexibles	147	598.98			

Notes: * Parameter is significant at the 0.05 level (two-tailed).
** Parameter is significant at the 0.01 level (two-tailed).
Fluctuations in segment sizes due to missing values (non-mandatory answers).

Table 2-1: Kruskal-Wallis test for differences between segments (continued)

Variable	Segment	N	Mean rank	H	df	P
Perceptions						
Attitudes modes						
Car				7.70	2	0.02*
	Car users	257	603.41			
	Frugal bike users	756	574.26			
	Generous multimodal flexibles	152	591.98			
Public transportation				2.89	2	0.24
	Car users	257	569.45			
	Frugal bike users	756	588.67			
	Generous multimodal flexibles	152	577.72			
Bike				10.17	2	0.01*
	Car users	257	571.64			
	Frugal bike users	756	595.1			
	Generous multimodal flexibles	152	542.02			
Social norms						
Public transportation				9.14	2	0.01*
	Car users	255	541.03			
	Frugal bike users	751	600.51			
	Generous multimodal flexibles	152	540.23			
Car				14.77	2	<0.001**
	Car users	255	639.24			
	Frugal bike users	756	557.8			
	Generous multimodal flexibles	151	602.64			
Bike				7.11	2	0.03*
	Car users	255	533.69			
	Frugal bike users	748	594.82			
	Generous multimodal flexibles	151	565.67			

Notes: * Parameter is significant at the 0.05 level (two-tailed).
** Parameter is significant at the 0.01 level (two-tailed).
Fluctuations in segment sizes due to missing values (non-mandatory answers).

3. Appendix to Chapter D

3.1. MaaS package attribute costs

Table 3-1: Prices for MaaS package attribute levels in €/month (own elaboration)

Attribute (level)	Full price standalone		Public		2% discount		5% discount		10% discount	
	Stud	Emp	Stud	Emp	Stud	Emp	Stud	Emp	Stud	Emp
PT 1	N.A.	0.00	N.A.	0.00	N.A.	0.00	N.A.	0.00	N.A.	0.00
PT 2	N.A.	63.70	N.A.	62.45	N.A.	62.45	N.A.	62.45	N.A.	62.45
PT 3	N.A.	**155.17**	N.A.	**152.07**	N.A.	**152.07**	N.A.	**152.07**	N.A.	**152.07**
CS 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CS 2	13.25	15.00	13.25	15.13	12.99	14.83	12.59	14.37	11.93	13.62
CS 3	31.00	**53.63**	31.00	**53.63**	30.38	**52.56**	29.45	**50.95**	27.90	**48.27**
BS 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BS 2	0.00	10	0.00	0.00	0.00	9.80	0.00	9.50	0.00	9.00
BS 3	15	**15**	12	**12**	11.76	**14.70**	11.40	**14.25**	10.80	**13.50**
ES 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ES 2	19.50	19.50	19.50	19.50	19.11	19.11	18.53	18.53	17.55	17.55
ES 3	39	39	39	39	38.22	38.22	37.05	37.05	35.10	35.10
Summed price P1$_{Emp}$ (example)	**223.80**		**217.70**		**219.33**		**217.27**		**213.84**	

Notes: * PT in all settings 10% discount.
* CS only with discount in private settings.

3.2. Prices for resulting MaaS packages per setting

Table 3-2: Prices for packages resulting from market analysis (public) and market simulations (private, Table 3.2) in €/month (own elaboration)

Package name	Public	2% discount	5% discount	10% discount
P1$_{Stud}$	62.50	62.50	59.38	62.50
P2$_{Stud}$	70.00	70.00	66.50	70.00
P3$_{Stud}$	82.00	80.36	77.90	82.00
P4$_{Stud}$	31.00	31.00	31.00	31.00
P5$_{Stud}$	50.50	50.50	47.98	50.50
P6$_{Stud}$	64.25	64.25	61.04	64.25
P7$_{Stud}$	44.75	44.75	42.51	40.28
P1$_{Emp}$	217.70	223.80	223.80	223.80
P2$_{Emp}$	128.10	131.00	129.15	128.70
P3$_{Emp}$	164.05	170.05	166.30	165.55
P4$_{Emp}$	205.70	208.70	208.80	208.80

3.3. Equations and data for the joint value calculations

Table 3-3: Extrapolated numbers of MaaS adopters per package and MaaS setting from market simulation (own elaboration)

Package name	Public		2% discount		5% discount		10% discount	
	%	N	%	N	%	N	%	N
N_{Stud} = 103210								
$P4_{Stud}$	6.18	6378	6.18	6378	6.18	6378	6.18	6378
$P6_{Stud}$	0.00	0	0.00	0	0.09	88	0.00	0
Sum	**6.18**	**6378**	**6.18**	**6378**	**6.26**	**6466**	6.18	**6378**
N_{Emp} = 12988								
$P1_{Emp}$	0.40	51	0.40	51	0.39	51	0.40	51
$P2_{Emp}$	0.40	51	0.40	51	0.39	51	0.40	51
$P3_{Emp}$	26.19	3401	20.83	2705	24.01	3118	24.20	3143
$P4_{Emp}$	2.77	360	2.38	309	2.38	309	0.02	309
Sum	**29.75**	**3863**	**24.01**	**3116**	**27.17**	**3529**	**27.36**	**3554**

Note: Deviations from total shares due to rounding of data.
* Resulting of the simulation, students only selected $P4_{Stud}$ and $P6_{Stud.}$
* N as an integer.

Table 3-4: BV_O per package and setting in €/month (own elaboration)

Package name	Public	2% discount	5% discount	10% discount
$P4_{Stud}$	0.00	3954.36	9885.90	19771.80
$P6_{Stud}$	0.00	0.00	0.22	0.00
$P1_{Emp}$	0.17	228.28	333.28	508.29
$P2_{Emp}$	0.74	65.65	76.30	228.36
$P3_{Emp}$	-56.46	8881.60	-51.76	-52.17
$P4_{Emp}$	1.22	1259.48	1787.53	2616.12
Sum	**-54.31**	**14389.36**	**12031.48**	**23072.39**

Note: Rounded values. For the input data $n_{Adopters}$ see C.1.

Table 3-5: Price $PK_{i,j}$ for users, discounted prices from TSPs and differences for each package and setting in € (own elaboration)

Package name	Public			2% discount			5% discount			10% discount		
	Price users	Disc. costs TSPs	Diff.	Price users	Disc. costs TSPs	Diff.	Price users	Disc. costs TSPs	Diff.	Price users	Disc. costs TSPs	Diff.
$P4_{Stud}$	31.00	31.00	**0.00**	31.00	30.38	**0.62**	31.00	29.45	**1.55**	31.00	27.90	**3.01**
$P6_{Stud}$	64.25	64.25	**0.00**	64.25	62.97	**1.29**	61.04	61.04	***0.003***	64.25	57.83	**6.43**
$P1_{Emp}$	217.70	217.70	**0.00**	223.80	219.32	**4.48**	223.80	217.27	**6.53**	223.80	213.83	**9.97**
$P2_{Emp}$	128.10	128.09	**0.01**	131.00	129.71	**1.29**	129.15	127.65	**1.50**	128.70	124.22	**4.48**
$P3_{Emp}$	164.05	164.07	**-0.02**	170.05	166.77	**3.28**	166.30	166.32	**-0.02**	165.55	165.57	**-0.02**
$P4_{Emp}$	205.70	205.70	**0.00**	208.70	204.62	**4.08**	208.80	203.02	**5.78**	208.80	200.33	**8.47**

Note: Rounded values

Table 3-6: AV_O from advertisements and data in €/month (own elaboration)

Type of AV_O	Package name	Public	2% discount	5% discount	10% discount
Ads	$P4_{Stud}$	0.00	622.92	622.92	622.92
	$P6_{Stud}$	0.00	0.00	8.60	0.00
	$P1_{Emp}$	0.00	4.98	4.98	4.98
	$P2_{Emp}$	0.00	4.98	4.98	4.98
	$P3_{Emp}$	0.00	264.19	304.52	306.97
	$P4_{Emp}$	0.00	30.18	30.18	30.18
	Sum	**0.00**	**927.25**	**976.18**	**970.03**
Data		0.00	3333.33	3333.33	3333.33
Sum		**0.00**	**4260.58**	**4309.51**	**4303.36**

Note: Rounded values. For the input data $n_{Adopters}$ see Table D.1.

Table 3-7: VO_O calculation per setting in €/month (own elaboration)

Type of costs	Public	2% discount	5% discount	10% discount
Payment	16946.80	14805.73	16082.65	20028.91
insurance	16946.80	14805.73	16082.65	20028.91
Employee (computer scientist)	5000.00	5000.00	5000.00	5000.00
Employee (service)	2500.00	2500.00	2500.00	2500.00
Server	696.67	696.67	696.67	696.67
Sum costs	**42090.26**	**37808.12**	**40361.97**	**48254.48**

Note: Rounded values.

Table 3-8: Input data value outflow of the orchestrator (VO_O) (own elaboration)

VO_O element	Amount
Payment integration ($C\ var_{pay}$)	2% of ER (Table D.8)
Insurance ($C\ var_{ins}$)	2% of ER (Table D.8)
Costs Wage IT expert ($C\ fixed_{computer\ scientist}$)	€60000.00/12 = €5000.00
Costs Wage Service (Part-time) ($C\ fixed_{service}$)	€30000.00/12 = €2500.00
Costs Server, data access, etc. ($C\ fixed_{IT}$)	€696.67

Note: Sources: personal confidential interviews.

Table 3-9: Ecosystem revenue (ER) for each package and setting in €/month (own elaboration)

Package name	Ecosystem revenue [€]			
	Public	2% discount	5% discount	10% discount
$P4_{Stud}$	197718.00	197718.00	197718.00	398625.00
$P6_{Stud}$	0.00	0.00	5371.52	0.00
$P1_{Emp}$	11102.70	11413.80	11413.80	11413.80
$P2_{Emp}$	6533.10	6681.00	6586.65	6563.70
$P3_{Emp}$	557934.05	459985.25	518523.40	520323.65
$P4_{Emp}$	74052.00	64488.30	64519.20	64519.20
Sum	**847339.85**	**740286.40**	**804132.60**	**1001445.40**

Note: For the input data price $PK_{i,j}$ in €/month see Table C.3, for the input data $n_{Adopters}$ see Table C.1.

Table 3-10: VA_O per setting in €/month (own elaboration)

VA_O	Public	2% discount	5% discount	10% discount
Value inflow (BV_O + AV_O)	-54.31	18649.94	16340.99	27375.75
Value outflow (VO_O)	42090.26	37808.12	40361.97	48254.48
Difference	**-42144.58**	**-19158.18**	**-24020.98**	**-20878.73**

Table 3-11: NRM_{TSP} per setting in €/month (own elaboration)

TSP	Public	2% discount	5% discount	10% discount
PT	187193.99	157541.00	181415.45	200271.71
CS	212103.86	205233.91	200058.94	188480.12
BS	42024.00	39538.10	44555.95	41593.50
ES	0.00	0.00	3260.40	0.00

Note: Rounded values. For input data see Table A and Table C.10.

Table 3-12: Extrapolated numbers of new subscriptions for the TSPs per package and MaaS setting (own elaboration)

Package name	Public		2% discount		5% discount		10% discount	
	%	N	%	N	%	N	%	N
N_{Stud} = 103210								
$P4_{Stud}CS$	0.06	6112	0.06	6112	0.06	6112	0.06	6112
$P4_{Stud}BS$	0.00	0	0.00	0	0.00	0	0.00	0
$P6_{Stud}CS$	0.00	0	0.00	0	0.0009	88	0.00	0
$P6_{Stud}BS$	0.00	0	0.00	0	0.0009	88	0.00	0
$P6_{Stud}ES$	0.00	0	0.00	0	0.0009	88	0.00	0
Sum		**6112**		**6112**		**6376**		**6112**
N_{Emp} = 12988								
$P1_{Emp}PT$	0.00	0	0.00	0	0.00	0	0.00	0
$P1_{Emp}CS$	0.004	51	0.004	51	0.004	51	0.004	51
$P1_{Emp}BS$	0.004	51	0.004	51	0.004	51	0.004	51
$P2_{Emp}PT$	0.00	0	0.00	0	0.00	0	0.00	0
$P2_{Emp}CS$	0.004	51	0.004	51	0.004	51	0.004	51
$P2_{Emp}BS$	0.004	51	0.004	51	0.004	51	0.004	51
$P3_{Emp}PT$	0.09	1231	0.07	882	0.08	1039	0.08	1047
$P3_{Emp}BS$	0.23	3049	0.19	2529	0.22	2873	0.22	2897
$P4_{Emp}PT$	0.00	0	0.01	154	0.01	154	0.02	270
$P4_{Emp}CS$	0.02	320	0.02	270	0.02	270	0.02	270
Sum		**4804**		**4039**		**4540**		**4688**

Table 3-13: VA_{TSP} per setting in €/month (own elaboration)

TSP	Ratio EBIT/ Rev.	Public		2% discount		5% discount		10% discount	
		New Rev. (MaaS)	VA_{TSP}	New Rev. (MaaS)	VA_{TSP}	New Rev. (MaaS)	VA_{TSP}	New Rev. (MaaS)	VA_{TSP}
PT	-0.57	187193.99	**-106413.54**	157541.00	**-89556.81**	181415.45	**-103128.64**	200271.71	**-113847.80**
CS	0.11	212103.86	**23740.06**	205233.91	**22971.13**	200058.94	**22391.91**	188480.12	**21095.93**
BS	-1.33	42024.00	**-55821.88**	39538.10	**-52519.78**	44555.95	**-59185.15**	41593.50	**-55250.03**
ES	-1.33	0.00	**0.00**	0.00	**0.00**	3260.40	**-4330.90**	0.00	**0.00**

Note: Rounded values. Rev. = Revenue. Confidential data used.

Table 3-14: Market data on the ratio of EBIT to revenue (own elaboration)

TSP	Revenue p.a.	EBIT p.a.	Ratio EBIT/Revenue	Source
PT	84671478.99	-35934415.59	-0.57	(BOGESTRA, 2022; DVG, 2022)
CS	5040813.43	564200.94	0.11	(stadtmobil carsharing, 2021)
BS	60000000.00	-79700000.00	-1.33	(North Data, 2020)
ES	60000000.00	-79700000.00	-1.33	(North Data, 2020)

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