MASTER THESIS

# Inner Join Privacy:
# Incorporating Functionality-Privacy Trade-Offs in Mobility-as-a-Service Solution Design Methods


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# PREFACE

Today's world is one where agility and swiftness are rewarded, whereas careful contemplation and reflection are commonly compared to stagnation. Nevertheless, to address key challenges in the mobility infrastructure for the next decade, it is important to reflect and contemplate on the challenges and implications of mobility innovations, specifically regarding Mobility-as-a-Service.

As part of this master's thesis, I therefore set out to explore the domain of Mobility-as-a-Service and challenge its conceptual rigidity by cross-referencing definitions and conceptualisations used in both academic and grey literature. In the process, it was found that only a limited amount of research was performed on the privacy implications of innovative mobility services, even though newly enacted personal data protection legislation has already had a considerable impact on the software industry at large. As such, this research explores the privacy implications of Mobility-as-a-Service in an attempt to provide design guidelines and process recommendations that balance the needs and expectations of individual customers, whilst also taking into account the various data requirements for the implementation of functionality expected from mobility applications.

Over the course of this master's thesis, I have been fortunate enough to have the amazing feedback and support of both Hans Moonen and Marten van Sinderen, my supervisors from the University of Twente. It is because of their feedback that I have been able to constantly challenge my presumptions and beliefs, resulting in a master's thesis that I am more than proud of. Moreover, I am grateful for having been able to write this master's thesis at CGI Rotterdam, as part of their Transport & Logistics department. Throughout the duration of this research, I have been graciously supported by the members of the department whilst faced challenges that arose during the year, including access to industry experts and resources, the impact of the Covid-19 pandemic on society and the industry, and even personal illness. I am more than grateful with the support received from everyone at the department, however I would like to personally, and specifically, express my gratitude to Sebastiaan Bracke, Melvin Spooren and Samuel de Groot. Their experience, guidance and patience are highly appreciated, and this cannot be understated.

Finally, I would like to extend my appreciation to the participants of the user study, my friends, and my family, all of whom supported me throughout this master's thesis. Specifically, I would like to take a moment to express my profound gratitude to my parents, without whom I would not have been able to pursue my interests and an exciting career.

Have a great time scrutinising this research and its underlying concepts, and feel free to reach out to me in case you have any questions.

Peter Bastiaan den Boer

# ABSTRACT


Whether the reason is congested road infrastructure, environmental concerns, or limited access to public transport, it is evident that personal mobility is having an identity crisis. Combined with the rise of internet services, these challenges in the transport and logistics domain created an atmosphere in which a novel mobility concept was quickly devised: Mobility-as-a-Service (MaaS). The MaaS concept leverages the subscription-based economy enabled by internet technology to provide personalised mobility service packages to consumers, eventually reducing the need for ownership of transport modalities and relieving the stress to the road infrastructure.

However, whilst the promise of service-based mobility might seem promising, the concept faces various challenges in the realms of fundamental platform design and personal data protection as a result of newly enacted legislation following introduced directives on personal data protection (PDP), such as the European Union's (EU) General Data Protection Directive (GDPR). Moreover, although the concept does not suffer from a lack of ambitious goals and equally novel enablers, it does however suffer from an identity crisis. One of the major challenges in the field of MaaS is to arrive at a consensus with regards to its characteristics, associated concepts and, therefore, a common definition for the term.

This research therefore set out to both derive a clear definition for MaaS as the semantic product of its core characteristics and concepts, determine the implications of novel privacy legislation on MaaS solutions, and accordingly recommend privacy-focused process improvements for use in the development of MaaS solutions in order to minimise their privacy impact.

First, identifying characteristics and concepts associated with MaaS was achieved by performing literature studies on academic and grey publications, resulting in a comprehensive definition and conceptualisation of MaaS. Subsequently, existing studies related to the MaaS domain were mapped to the selected concepts, and notable research gaps were pointed out.

Second, privacy-focused process improvements were established by first analysing capabilities and personal data requirements (PDRs) of existing mobility applications and performing a user study to assert whether the implemented features match consumer expectations. Respondents were also asked to rate their level of concern with these PDRs in order to assess their sentiment on the prospective use of these PDRs in support of application functionality. These findings were then combined to provide grounded design recommendations with respect to privacy in mobility solutions, and a method was developed by which varying levels of privacy assortments can be considered and incorporated in the design methods of mobility solutions. To validate whether these recommendations could be used in practice, two methods were evaluated for suitability: Disciplined Agile Delivery (DAD) and The Open Group Architecture Framework (TOGAF). Both were found to support the recommendations, albeit with certain considerations regarding the lack of substantial documentation in Agile methods.

Fundamentally, this research provides a comprehensive perspective of the MaaS research field, whilst producing novel methods to address personal data protection challenges in the design and development of practical MaaS solutions. Therefore, its findings not only establish a foundation for future research, but also promote 'privacy-by-design' principles in practice.

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# INTRODUCTION

*In this chapter, the primary research topic and its context are discussed. Subsequently, the research setting is introduced, and the topics covered in this study are outlined.*

## 1.1 Research Context

“Our” current mobility infrastructure no longer meets the demands of our fast-paced and ever-growing interconnected world. In fact, one could argue that “our infrastructure” no longer serves “us”, but rather our owned modalities. The cars that once provided us with the freedom to travel anywhere our hearts desired have become sources of frustration, increased commuting/ travel times and a substantial share of global carbon emissions, not to mention the heavy congestion and (in)frequent gridlocks encountered in metropolitan areas around the world.

Various efforts to change this reality have been undertaken, amongst which the development of global ride-sharing and car-hailing services (e.g. Lyft and Uber), integrated mobility payment systems (e.g. OV-Chipkaart and Oyster Card) as well as bike-sharing schemes (e.g. Bicing and OV-Fiets). Whilst these initiatives often share common goals, such as the systematic reduction in metropolitan carbon emissions, incentivising or improving the accessibility and easy-of-use of public transport services, they are often implemented as fully separate and isolated mobility services (Petzer et al., 2019), consequently limiting their potential overall impact on the transport network (MaaS Alliance, 2018b). Mobility-as-a-Service (MaaS), otherwise known as the manifestation of truly unconstrained and subscription-based personal freedom in mobility, is believed by many to be the one-size-fits-all solution to various problems faced in the transport industry, including the lack of integration between mobility services (Hietanen, 2014; Jittrapirom et al., 2017; Kováčiková et al., 2018; Willing et al., 2017).

The MaaS concept was supposedly first introduced in a Master’s thesis by Hietanen (2014), even though supportive concepts such as Combined Mobility (UITP, 2011), were already heavily researched prior to its appearance in academic literature. Since its 2014 debut, several researchers have attempted to conceptualise MaaS in terms of its associated characteristics (Giesecke et al., 2016; Jittrapirom et al., 2017; Wong et al., 2019). While these studies have provided valuable insight into the various aspects of the mobility concept, there remains substantial debate on whether the concept should even be conceptualised as a physical artefact, such as a Mobility Service Platform (MSP), or a grand societal vision attempting to meet various mobility-related policy goals.

However, while the promise of unconstrained mobility might seem appealing, the concept faces various challenges in the realms of fundamental platform design and personal data protection as a result of newly enacted legislation following introduced directives on personal data protection (PDP), such as the European Union’s (EU) General Data Protection Directive (GDPR). This development has resulted in various questions being raised with respect to data-ownership and data-sharing practices by stakeholders interfaced with MaaS platforms (MaaS Alliance, 2018a). As a result, some researchers have attempted to assess the impact of these PDP directives on MaaS platforms, often by means of a case study (e.g. Cottrill, 2019) or by highlighting their potential effects on meeting MaaS objectives (e.g. Jittrapirom et al., 2017).

With MaaS pilots actively being ran in (regions of) various EU countries, the question arises to what extent these projects and their associated mobility services abide by the 'Privacy by Design' design principle as stated in the GDPR. Furthermore, reason would suggest that intended design variations between the implementation of these mobility services would result in substantially different data requirements and collection practices. As these variations in data requirements for MaaS platforms should be reflected by the set of applicable PDP constraints, it is possible to assess the privacy impact of individual MaaS pilots. Whilst such a privacy assessment of MaaS pilots could provide much-needed insight into best practices for the design and development processes of MaaS projects, there remains an absence of research studies on this topic.

### 1.2 Research Outline

This research therefore set out to deliver clarity on two key points of debate within the Mobility-as-a-Service domain. First, a clear definition for MaaS is provided as the semantic product of its core characteristics and concepts. Second, the manner in which MSPs are impacted by privacy legislation, including the collection and processing of personal data, is assessed with respect to the functionality offered as part of their mobility service.

This paper is structured as follows. First, contextual and background information as well as core definitions used within the discipline are provided in Chapter 2. The problem statement, research scope and objectives as well as the research questions are provided in Chapter 3. The used methodology to address these research questions is discussed in-depth throughout Chapter 4 with the results split between the next four chapters. Chapter 5 concerns the conceptualisation of MaaS and addresses the research gaps within the MaaS research field. During Chapter 6, a comprehensive assessment of existing MaaS solutions is provided in terms of their functionality offered as well as the personal data requirements requested from the mobile device user. Chapter 7 presents the results of a user survey on user expectations with regards to expected MaaS application functionality and personal data requirements. These results are then reflected upon in Chapter 8, during which the obtained knowledge is incorporated in established (project) management and design methods. Finally, the study is concluded by reflecting on the results and placing them in a broader societal and research context in Chapter 9.

# 2 BACKGROUND

*In this chapter, the conceptual framework for this study is devised on the basis of background literature analysis. First, an overview of recent developments in the research domain of Mobility-as-a-Service is presented. Subsequently, various concepts with regards to privacy and personal data protection are discussed.*

## 2.1 Mobility-as-a-Service

Whereas the internet has mostly alleviated the transportation of information from the physical world, other physical objects such as goods and people remain restricted to the physical world in their mobility. However, increased human mobility, partially due to improving socio-economic factors, has resulted in measurable increased pressure on national transportation infrastructure (Kennisinstituut voor Mobiliteitsbeleid, 2018). In The Netherlands, this pressure on the national transportation infrastructure network has manifested itself through record-high road traffic in both 2017 (Statistics Netherlands, 2018) and 2018 (Statistics Netherlands, 2019), whilst an increase in train passenger growth from an average of 2.2% per year (2014-2018) to 4.6% was also reported in the first half of 2019 (Nederlandse Spoorwegen, 2019a). At the current rate of train passenger growth, it is projected that the maximum rail capacity of the Netherlands will have been reached in 2025 (Nederlandse Spoorwegen, 2019a). In this context, maximum rail capacity is defined as the total capacity of the rail network required for both cargo and passenger services, the latter of which is derived from seat opportunity metrics during peak hours in congested areas (Ministerie van Infrastructuur en Waterstaat, 2019a).

Although these figures seem to suggest the need for immediate capacity expansion of various Dutch transportation networks, such action would not be proportionate. Whilst expanding on existing transportation infrastructure in high-congestion areas can alleviate pressure and expand the capacity of the network, there exist genuine concerns about the environmental impact of personal mobility, which arguably should first be explored.

As it stands, private vehicles are the dominant modality in the transportation sector and account for the majority of greenhouse gas emissions (Hodges, 2010), the environmental impact of which has major effects on human health (Levy et al., 2010). As increasing road capacity can result in the continued build-up of private vehicles (Noland, 2001), their impact on public health and the environment will continue to increase without alleviating network pressure. Instead, expanding on the network capacity of shared modalities can have a positive impact on the environment as their respective energy input requirements are shared among the modality's occupants. This effect strengthens when we consider that shared modalities such as trains, trams, buses, and bikes can easily be converted to make use of renewable energy. For instance, trains from Dutch operator NS, have been running on renewable energy since 2018 (NS, 2019) and consequently mitigated the modality's impact on the environment. However, whilst expanding on the capacity of these transport networks could alleviate congestion during busy peak hours, their respective capacities are far from being utilised efficiently in off-peak hours. As such, it is evident that there is no more need for additional capacity than there is a need to use this capacity efficiently.

As such, governments have started to encourage their citizens to forgo the use of their personal cars (Foresight & Government Office for Science, 2018) and have adopted policies to integrate shared mobility services and new modalities (e.g. electric bikes) in their current transportation infrastructure (Van Audenhove et al., 2018). As part of this process, there is an increased focus on developing alternative safe, efficient, accessible and sustainable transport systems (Ministry of Infrastructure and Climate Policy, 2016). So far, these initiatives have seen moderate success, as an increasing number of people have started to prefer the use of shared modalities (e.g. cars and bikes) for their mobility rather than private alternatives (Cohen & Kietzmann, 2014; C. J. Martin, 2016; E. Martin et al., 2010).

Conversely, peer-to-peer ride sharing platforms such as Uber and Lyft have become well-established organisations by offering flexible taxi-like mobility using a fleet of registered vehicles to those forgoing the tradition of car ownership. In the near future, these registered vehicles might be replaced by a fleet of autonomous taxis, providing on-demand transport services to individuals with a temporary need for mobility (Lu et al., 2018; Moreno et al., 2018).

Another method of utilising the capacity of transport systems is to reduce the space required to transport an individual. As such, bike sharing services have not only established themselves as a sustainable alternative to cars-based transportation, but also a highly efficient one – especially for short distance travel – and have been found to reduce traffic congestion in urbanised areas by 2 to 3% (Hamilton & Wichman, 2015). Whilst bike-sharing mobility services have become quite popular, they have also been faced with legal challenges for not adhering to established legislation in some cases (Cohen & Kietzmann, 2014). Nevertheless, The Netherlands and other countries have seen an explosive increase in the use of bike-sharing services (Petzer et al., 2019; van Waes et al., 2018). This is most evident in the immediate vicinity of train stations with long-standing programs such as OV-Fiets – a bike-sharing service operated by the Dutch railways – noting 5.3 million trips in 2019: a 179% increase compared to 2015 (NS, 2020).

A common factor of these alternative transport methods, is the desire to deliver door-to-door transit (Potter & Skinner, 2000). Traditional transportation networks lack such capability due to unappealing travel times and predictability (Van Audenhove et al., 2018). Attempts were made to increase the predictability of these travel times by means of more accurate and real-time measurements of the transportation network. These measurements were originally taken using roadside systems, however call detail records (CDRs) have also shown to be capable of inferring traveller mobility behaviour on a larger scale (Schneider et al., 2013; Song et al., 2010). Although both CDRs and traditional roadside systems can provide insights into transportation network usage, internet-connected hand-held devices have allowed for real-time location telemetry from mobile applications, such as Google Maps and HERE Navigation, to be integrated with existing databases and routing services (Boriboonsomsin et al., 2012; Luxen & Vetter, 2011).

Consequently, there has been an increasing desire to leverage both the real-time mobility data as well as the increasing variety in transport modalities (e.g. shared cars and bikes) to improve the efficiency of the personal transportation network. One such initiative is Mobility-as-a-Service (MaaS) and seemingly aims to transform mobility from an ownership model to a subscription model by offering personal mobility as an integrated service.

## 2.2 Personal Data Protection (PDP)

Key to Information Systems (IS) is the systematic (and automated) aggregation and processing of data sets. Whilst these data sets do not exclusively refer to personal data, practices regarding the collection and processing of personal data have endured additional scrutiny due to the sensitive nature of personal data. In fact, in response to the ever-increasing scope of personal data collection practices, the Organisation for Economic Co-operation and Development (OECD) introduced their Guidelines on the Protection of Privacy and Transborder Flows of Personal Data in 1980 (Organisation for Economic Co-operation and Development, 2020). These guidelines have paved the way for many international privacy regulations with respect to personal data protection, amongst which the European Union's General Data Protection Regulation (*Regulation (EU) 2018/1725*, 2018).

Within the context of this study, rather than referring to the practice of personal data protection in terms of the physical security of (personal) data, it is instead understood as the practice by which the privacy of individuals is protected by means of securing data in both a physical and digital manner as well as through developing and enforcing legislative requirements and guidelines. This interpretation of PDP is in line with other (grey) literature on the topic (Cottrill, 2019; Urban Transport Group, 2019; Van Audenhove et al., 2018) and puts more emphasis on design principles such 'Privacy by Design' (Section 2.6.3).

## 2.3 General Data Protection Regulation (GDPR)

The stance of the European Union on the protection of personal privacy is clearly outlined in the first paragraph of its directive on the processing of personal data, stating that: "The protection of natural persons in relation to the processing of personal data is a fundamental right." (*Regulation (EU) 2018/1725*, 2018). One could argue that the GDPR not only forms the backbone of modern privacy legislation in the EU, but that its pan-European nature is also essential in providing cross-border mobility solutions which are also integrated in the national mobility network.

## 2.4 Personal Data

While it could be argued that 'personal data' refers to any data that can directly or indirectly be related or traced back to a natural person, this research follows the definition of 'personal data' listed in Article 3 (1) of the GDPR, as it provides a clear, specific, and legally enforced definition of what constitutes personal data. In the GDPR, the term 'personal data' is defined as:

> *"'personal data' means any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person;"*
>
> (Article 3, Paragraph 1, *Regulation (EU) 2018/1725*, 2018)

As can be inferred from this definition, 'personal data' is not only considered as data containing an identifier, but also as the combination of specific other data types that are descriptive to the living context of a natural person. This is especially important within the context of MaaS, as the person's context can be used to derive preferences for personalised multimodal travel services.

### 2.5 Data Processing

The EU's legislative framework provides a clear, yet very broad, definition for 'personal data'. The document treats 'processing' of personal data in a similar fashion.

> *"'processing' means any operation or set of operations which is performed on personal data or on sets of personal data, whether or not by automated means, such as collection, recording, organisation, structuring, storage, adaptation or alteration, retrieval, consultation, use, disclosure by transmission, dissemination or otherwise making available, alignment or combination, restriction, erasure or destruction;"*
>
> (Article 3, Paragraph 3, *Regulation (EU) 2018/1725*, 2018)

Based on this excerpt, 'processing' can be considered to be even more nondeterministic than the definition of 'personal data', as it encompasses any set of operations involving personal data, including those related to its destruction. In order to provide an accurate and representative privacy impact assessment of existing MaaS solutions and the development of personal data processing guidelines for future MaaS solutions, this research follows the GDPR definition of 'processing' when addressing data processing activities by MaaS stakeholders.

### 2.6 'Privacy by Design' and 'Privacy by Default'

Due to the nature of software development, design decisions with regards to data architecture and the default behaviour of data processing activities determine the extent of the required data. As such, design principles such as 'Privacy by Design' and 'Privacy by Default' have emerged that seek to design information systems so that its personal data requirements are reduced to a minimum and that measures are taken to ensure the protection of personal information.

These design principles, including the appropriate organisational and technical measures used for each, are listed in Paragraphs 1 and 2 of Article 27 of the GDPR (Article 27, *Regulation (EU) 2018/1725*, 2018). These paragraphs specifically note measures such as pseudonymisation, data minimisation and limiting organisational access as primary means of addressing these design principles. As such, this study leverages the measures listed in Paragraphs 1 and 2 of Article 27 in the GDPR as a reference framework for any 'Privacy by Design' assessments.

### 2.7 Software Features

What constitutes a 'feature' is highly dependent on your field of research. In this study, features are in reference to software features as defined in Quirchmayr et al. (2017): "Software features describe and bundle low level capabilities logically on an abstract level and thus provide a structured and comprehensive overview of the entire capabilities of a software system." As such, each software feature is understood on a conceptual level, allowing for multiple implementations of a single software capability to exist in different software systems. In addition, it is implied that each implementation of a certain software feature is served by one or more data requirements.

### 2.8 Personal Data Requirements

The notion of requirements is well-developed within the software industry with software features often being defined on the basis of its functional and non-functional requirements. Considering the focus of this research on privacy design principles, requirements are instead understood in terms of their personal data components, i.e. personal data requirements (PDRs). Within the context of the developed conceptual framework, personal data requirements specify the types of personal data required for the implementation of features incorporated in software solutions.

## 2.9 Relationship Entity Diagram

The concepts introduced in the previous sections of this chapter can relate to each other in many ways, dependent on the specific context in which they are examined. Within the context of this research study, the concepts are examined from the perspective of allowing for the analysis and comparison of individual implementations of MaaS-specific software features. Therefore, the conceptual framework developed in this study should serve that goal, consequently impacting the relations between the concepts in this chapter. A brief overview is provided in the form of a compact relationship entity diagram (Figure 1), developed in accordance with the interpretation of the concepts and their relations in the context of this research study.

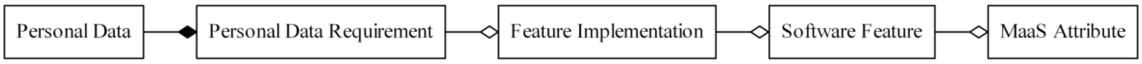


**FIGURE 1: CONCEPTUAL FRAMEWORK: RELATIONSHIP ENTITY DIAGRAM**

# 3 RESEARCH PROBLEM

*In this chapter, the research design of this study is constructed on the basis of its problem statement, its primary and secondary objectives and associated research questions, all of which limited by a specified research scope.*

## 3.1 Problem Statement

While the concept of combining different transport modes was by no means novel (UITP, 2011), the first definition of MaaS only appeared in 2014 (Esztergár-Kiss & Kerényi, 2019a). Since then, several publications on MaaS have seen the light of day. Most of these publications seem to be in agreement that MaaS should refer to the consolidation or integration of transport modes (Foresight & Government Office for Science, 2018; Goodall et al., 2017; MaaS Alliance, 2018b; Transport Systems Catapult, 2016), yet there seems to be diverging opinions on whether MaaS should incorporate travel information, payment systems, or both (Polis, 2017). In fact, there seems to be no consensus on what constitutes MaaS as "[…] there is no one definition of MaaS" (Polis, 2017, p. 4) and has even been described as a "nascent phenomenon" Smith et al. (2018).

Several studies have therefore attempted to scope MaaS and explore its potential uses. Because the MaaS research area is relatively immature (Esztergár-Kiss & Kerényi, 2019a), researchers often rely on their academic experience to identify research gaps. While relying on this academic experience can sometimes introduce a form of bias to the research, the various considerations, and conceptualisations of the concept by these studies have also contributed to establishing a definition for MaaS. As such, most of these studies are thought-pieces and would therefore be considered "grey literature" by Smith et al. (2018) and often do not consider empirical evidence as there is a lack of analysed MaaS pilots (Smith et al., 2018). Analyses of MaaS' characteristics are therefore predominantly based on literature review (Jittrapirom et al., 2017) and often do not include empirical evidence to support their findings.

Failure to provide a clear, stable, and concise conceptualisation of Mobility-as-a-Service has prevented directed research into the development of the mobility concept and its associated characteristics. Moreover, the introduction of personal data protection directives, such as the EU's GDPR, has introduced several early design considerations and constraints into the design and development processes of Mobility Service Platforms and other MaaS solutions.

Consequently, this has resulted in serious mayhem in the MaaS research field, with technologies such as blockchain both being presented as the ultimate use-case for MaaS platforms as well as being designated inherently and technologically incompatible with PDPs such as the GDPR. Several studies have attempted to assess the impact of PDP directives on the concept of MaaS, however few seem to have extended their assessment to include existing MaaS pilots, much less discuss their functional differences or design principles. This lack of empirical knowledge on the architectural differences between MaaS pilots, specifically with respect to their data requirements and data processing practices, can seriously hinder the development of future MaaS projects.

### 3.2 Objectives

Over the past few years, several MaaS pilots have been conducted and subsequently analysed by industry and government. This yields an opportunity to assess whether conceptualisations of MaaS have changed over time or differ from deployed pilot projects. As such, this research study sets out to define what constitutes MaaS through combining novel empirical industry findings with a systematic review of academic literature, subsequently providing an indication of which MaaS research areas (i.e. MaaS-associated characteristics) require additional scrutinizing.

Additionally, this research study primarily addresses the design principle of 'Privacy by Design' and the extent to which it is incorporated in the design of MaaS pilots. This is considered in order to assess the impact of MaaS solutions on user privacy and how this can be minimised.

In summary, the primary research goal, as written in the style of Wieringa (2014), is as follows:

> *The primary goal of this research is to* ***improve*** *personal data protection practices in MaaS solutions* ***by developing*** *privacy-focused process improvements* ***which consider*** *the relations between common features of MaaS solutions and their associated personal data requirements* ***in order to*** *minimise the privacy implications of MaaS solutions.*

This primary research objective is served by five secondary research objectives:

(1) the identification of characteristics associated with MaaS in academic and grey literature;

(2) the conceptualisation of MaaS on the basis of its identified characteristics;

(3) the exploration of research gaps and opportunities in the MaaS domain;

(4) the identification of MaaS features and PDRs in MaaS solutions;

(5) the development of a comprehensive user sentiment analysis with respect to offered functionality and PDRs in MaaS solutions;

(6) embedding grounded recommendations on personal data protection and privacy in popular design methods with respect to designing MaaS solutions.

### 3.3 Scope

The research objectives listed in Section 3.2 serve the purpose of providing clear guidelines on personal data protection and user privacy to organisations seeking to design or implement (new) features for (mobile) MaaS solutions. These research objectives should therefore only be considered in the afore-mentioned context, especially considering the diverging effect of lacking a commonly-accepted definition for MaaS has had on research papers published in this field.

As such, while the results of this research are intended to be reproducible and cover most conceptual interpretations of MaaS and its associated attributes, they might not be applicable to all MaaS projects. Specifically, the applicability of the developed construct in the context of another Maas project mostly depends on that project's conceptual framework. Verifying whether the results of this research, and derivatives thereof, are transferable to another MaaS project can therefore be achieved by comparing its underlying concepts with those discussed in the MaaS Conceptual Framework (Section 2.1), as it forms the basis of this study's conceptual framework.

### 3.4 Research Questions

To meet the research objectives (Section 3.2), each objective is addressed by a single research question. The following research questions are considered:

1. Which characteristics are associated with Mobility-as-a-Service?
    a. in academic literature?
    b. in industry and government publications?

Throughout both academic as well as grey literature, various concepts are often associated with Mobility-as-a-Service. However, there seems to be no consensus on the concept's definition, nor which core characteristics should be associated with it (CUBIC Transportation Systems, 2018, p. 6; Polis, 2017, p. 4). Thus, it is imperative that relevant literature is closely examined to identify which facets are associated with MaaS. The first research question serves that goal. Answering this research question relies on the inclusion of both theoretical and empirical evidence. However, as the MaaS research field remains relatively small and most empirical evidence can mostly be found in grey literature, both forms of literature are considered.

2. What definition for MaaS can be derived based on the overlap of its characteristics between academic and non-academic literature?

To provide a clear definition of MaaS, it must first be established which facets are inherent to it. The second research question serves to classify which of the identified facets are inherent to MaaS by assessing the overlap between the characteristics discovered in academic literature and those facets found in non-academic publications, such as whitepapers or position papers. As the overlap of facets between sources can be understood as the consensus between academia and industry, the obtained results can be used to draft a formal conceptual definition of MaaS.

3. Which research gaps and challenges can be found in literature for each of the MaaS characteristics, specifically with regards to personal data protection?

Before addressing the challenges with respect to personal data protection, literature on each of MaaS' characteristics is first consulted to identify key research challenges and opportunities for the entire MaaS research domain. The results obtained from this brief literature scan will not only yield insight into the challenges facing MaaS within the context of this research, but it will also provide a jumping-off point for future research in this domain, as these results will highlight how literature is distributed across the research field in addition to indicating specific fields of interest.

4. How do existing MaaS solutions compare on the basis of their personal data requirements in relation to their implemented MaaS features and characteristics?
    a. Which characteristics of MaaS are implemented by existing MaaS solutions?
    b. What personal data requirements can be identified for each MaaS solution?

This research question directly addresses the fourth secondary research objective, as it attempts to identify which features and PDRs exist for MaaS solutions in two steps. First, characteristics of MaaS solutions are catalogued by means of feature identification. Second, the MaaS solutions are analysed to assess which PDRs can be attributed to their use. The obtained results provide both the basis for a comparison based on 'Privacy-by-Design' principles and the information necessary to evaluate user sentiment on MaaS functionality and privacy aspects.

5. What are user-expected levels of service for MaaS solutions?
    a. Which user expectations exist with regards to the functionality offered by existing MaaS solutions?
    b. What is the user sentiment with regards to the personal data requirements of existing MaaS solutions?

The scientific and practical contribution of developing a comprehensive privacy assessment is believed to be limited by the assessment framework's ability to accurately reflect not only the inherent personal data processing differences between MaaS solutions, but also the user sentiment towards the use of personal data for MaaS features, as well as the expected functionality of these solutions. As such, this research question was drafted in such a manner that it both provides insight into user expectations with regards to the capabilities of MaaS solutions, and their associated personal data requirements. The combined results of this research question provide a ranking by which the various PDRs and features can be listed alongside user sentiments. This can be used in improvement of decision-making processes with regards to the design and implementation of specific MaaS capabilities.

6. How can MaaS solutions be designed to achieve user-expected levels of service whilst adhering to 'Privacy by Design' and 'Privacy by Default' principles?
    a. What recommendations can be given with regards to the role of personal data protection principles in the design process of MaaS solutions?
    b. What steps can be taken to embed these recommendations in popular design methods for (the enterprise architecture of) software solutions?

Based on the results obtained from the previous research question, it is possible to (re)design solution design processes to better integrate privacy constructs, whilst remaining to deliver on user expectations with regards to the levels of service and expected capabilities of MaaS solutions. The intent behind this research question is to provide a 'balanced approach' between privacy and user expectations with regards to design process of MaaS solutions. As such, it addresses the final secondary research goal.

# 4 METHODOLOGY

*In this chapter, the research methods used in this research are described. This research builds on various research methods proven to yield reproducible results. First, the methods used for the purposes of an extensive literature analysis are discussed in-depth. Subsequently, the methods used to address the remainder of the research questions are presented. Whilst these methods are comprehensive, some limitations for each method still apply, which can be found in their respective sections.*

## 4.1 Overview of Methodological Approach

Before any steps can be taken to assess the PDRs of MaaS solutions, an assessment of which facets are directly associated with the concept must be devised, as reflected by the first research question. Because the scope of a research field can be approximated by examining its associations with other concepts and phenomena, and the extent of research activity can be determined by a scoping search (Arksey & O'Malley, 2005), it therefore follows that the discovery of the characteristics associated with MaaS is also enabled by a scoping study. Anderson et al. (Anderson et al., 2008) have also described scoping studies that scope the nature of a research area as mapping reviews.

However, because MaaS is a relatively immature concept, it is imperative that any such mapping study would not only follow a rigorous and systematic approach, but that it would also be comprehensive. For that reason, studies concerning the creation, analysis and/or comparison of different strategies for performing literature reviews and mapping studies were consulted to ensure method suitability for research areas with a limited body of knowledge (Beckers et al., 2012; B. Kitchenham & Charters, 2007; Paré et al., 2015). From this analysis, it followed that a Systematic Literature Review (SLR), performed according to Kitchenham and Charters' guidelines (B. Kitchenham & Charters, 2007), is the most suitable approach for a literature review conducted in immature research areas (B. A. Kitchenham et al., 2011), specifically benefiting from its systematic and explicit approach to literature inclusion and exclusion.

Despite the suitability of SLRs for immature research areas, the aim of this research is not to extract a selection of studies to address a specific research question, but rather to identify MaaS research gaps from a broader sample. Considering Kitchenham and Charters' guidelines on performing literature reviews, it follows that this literature review should therefore be conducted as a Systematic Mapping Study (SMS) – specifically the Gap Study – in conjuncture with a SLR (Beckers et al., 2012; B. Kitchenham & Charters, 2007).

This research therefore utilizes a SMS to create a mapping of MaaS studies and their associated research fields, including the research gaps mentioned therein, served by a SLR to identify the characteristics given to MaaS by academic literature. While this approach would have been sufficient for a literature study that only considers academic literature in order to address the research questions, the absence of an extensive body of academic empirical knowledge on the topic necessitates the inclusion of industry and government publications in order to achieve the intended research goals (i.e. identify challenges in MaaS).

As these publications are often distributed without any method of accessing these resources in a structured manner, a Semi-Structured Literature Review (SSLR) is used in addition to a SMS and a SLR to address the first three research questions. Specifically, the SSLR is used to identify the characteristics attributed to MaaS from an industry perspective. In order to assert whether there is a consensus between industry and academia on the definition of MaaS, the overlap between characteristics identified in academic literature and industry publications is analysed. These characteristics are subsequently used in the development of a 'MaaS Conceptual Framework' and as the dimensions used in the Systematic Mapping Study.

The primary means of identifying implemented MaaS capabilities and PDRs in MaaS solutions is by means of a literature scan and by using an adapted version of the APPA (Automated aPp Privacy Assessment) method developed by Wefflaufer & Simo (2020). To identify MaaS features, the scan considers generally available documents and assets associated to each MaaS solution.

The identified features are subsequently subjected to a user survey, which should provide insight into the user expectations of MaaS solutions as well as their sentiment with regards to personal data collection and processing for the purposes of offering said functionality. The survey utilizes customer segmentations found in other studies to provide insight into the needs of MaaS customers on the basis of their access to (shared) multimodal transportation.

Following the results from the user survey, grounded recommendations were made by means of developing a privacy-functionality trade-off and challenging the status-quo with regards to the role of personal data protection and privacy within the MaaS ecosystem. Two design methods used in the software development and enterprise architecture domains were then evaluated to determine to what degree these methods were suitable for the incorporation of privacy guidelines and best practice recommendations because of the prior results evaluation. The considered methods concern Disciplined Agile Delivery (DAD) and The Open Group Architecture Framework (TOGAF). Both were selected based on the mechanisms used to manage requirements and the notion that they are representative of other methods used in their respective fields. With respect to TOGAF, the performed analysis is focused on embedding the privacy guidelines on an architectural level, whereas the analysis performed in the context of DAD is more generic due to the method's more versatile nature with respect to the types of projects that it supports.

An overview of the leveraged research methods and their relations to the secondary research goals and research questions can be found in Table 1. In the following sections, the used research methods are worked out in more detail.

**TABLE 1: RESEARCH QUESTIONS, GOALS AND USED METHODS**

| Secondary Research Goal | Research Question | Used (Research) Methods |
|---|---|---|
| the identification of characteristics associated with MaaS in academic and grey literature | RQ1 | Systematic Literature Review (academic literature); Semi-Structured Literature Review (grey literature) |
| the conceptualisation of MaaS on the basis of its identified characteristics | RQ2 | Overlap analysis |
| the exploration of research gaps and opportunities in the MaaS domain | RQ3 | Systematic Mapping Study; Semi-Structured Literature Review |
| the identification of MaaS features and PDRs in MaaS solutions | RQ4 | Automated aPp Privacy Assessment; Semi-Structured Literature Review |
| the development of a comprehensive user sentiment analysis with respect to offered functionality and PDRs in MaaS solutions | RQ5 | Quantitative Analysis (i.e. User Survey) |
| embedding grounded recommendations on personal data protection and privacy in popular design methods with respect to designing MaaS solutions | RQ6 | Disciplined Agile Delivery; TOGAF ADM |

## 4.2 Systematic Literature Review

A Systematic Literature Review (SLR) is used to identify the characteristics of MaaS in academic literature, and therefore addresses part of the first research question. In accordance with the guidelines set forth in Kitchenham and Charters (2007), an SLR follows a certain set or inclusion and exclusion criteria. In the following sections, these criteria are defined and the database selection along with the search strategy and material selection process are presented.

### 4.2.1 *Inclusion criteria*

Any journal article or conference proceeding published before December 2019 that concerns conceptualisation of Mobility-as-a-Service was included in this SLR.

### 4.2.2 *Exclusion criteria*

Materials excluded from the literature review:

- Other types of publications (e.g. conference reviews)
- Articles published in languages other than English
- Older versions of duplicate articles
- Materials that are inaccessible due to limitations imposed by the leveraged academic license

### 4.2.3 *Database selection*

The scientific literature databases and academic search engines utilised in this SLR were selected based on their relevance or prominence in the field, indexing reach and functional capabilities (e.g. complex queries and filtering). While most notable literature search engines were included in the selection, there is one omission: Google Scholar. This service was explicitly mentioned in literature on scientific databases as yielding resources that either overlap with Scopus and Web of Science, or are predominantly non-academic (Martín-Martín et al., 2018).

As such, the following databases were selected and accessed:

- ACM Digital Library (https://dl.acm.org/)
- IEEE Explore Digital Library (https://ieeexplore.ieee.org/)
- ScienceDirect (https://www.sciencedirect.com/)
- Web of Science (https://apps.webofknowledge.com/)
- Scopus (https://www.scopus.com/)
- SpringerLink (https://link.springer.com/)
- TRID (https://trid.trb.org/)

### 4.2.4 *Search strategy*

In order to produce reproducible results as part of this literature research, the criteria for inclusion and exclusion from Sections 4.2.1 and 4.2.2 were to be formalised. As such, the following search queries were derived and subsequently performed on the title, author-defined keywords, and abstract of listed materials, in order to query the selected databases for relevant materials:

- “Mobility-as-a-Service” AND Conceptuali*
- “Mobility-as-a-Service” AND Characteristic* AND Concept*

Filtering was then performed according to the specified date range (i.e. only materials published before December 4th, 2019), type of publication (i.e. only journal articles and conference proceedings) and language used (i.e. only English). At this stage, any (older) duplicates were removed from the result set, resulting in an initial set of 34 journal articles and conference proceedings. One document was misidentified as a conference proceeding instead of a report and was therefore excluded from the SLR, bringing the total down to 33 articles. Based on a brief analysis of each paper's research focus, the number of selected materials discussing the characteristics of MaaS was reduced to 13. Finally, the definitions used to characterise and describe MaaS from each of these papers were aggregated and examined (see Section 5.1).

## 4.3 Semi-Structured Literature Review

The Semi-Structured Literature Review (SSLR) performed in this study has two goals: identify which characteristics are associated with MaaS by industry and government; and discover MaaS research gaps based on industry and government publications. However, as established in the introduction of this section, these materials are often not accessible in a structured manner. As such, while this SSLR derives from Kitchenham and Charters' (2007) guidelines for SLRs by listing various criteria for inclusion and exclusion, it is understood that the associated results are by no means comprehensive due to the inherently complex nature of indexing internet resources.

### 4.3.1 *Inclusion criteria*

Any newspaper article, editorial, review, reflection, whitepaper, position paper and other documents published before December 2019 describing the conceptualisation, implementation, or general characteristics of MaaS were included in this SSLR.

### 4.3.2 *Exclusion criteria*

Materials excluded from the literature review:

- Materials in languages other than English or Dutch
- Materials derived from/ referencing the original publication without providing either additional insights or otherwise relevant information
- Duplicates of published materials
- Materials that are inaccessible due to limitations imposed by the leveraged available academic license
- Forum or social media posts

Due to the nature of this SSLR, it is expected that a large set of publications are unintentionally excluded. Dutch was added as a secondary language to increase the scope of the SSLR.

### 4.3.3 *Database selection*

In Section 4.2.3, it was determined that Google Scholar often yields literature that either overlaps between Scopus and Web of Science or is inherently non-academic in origin. As such, this literature search engine would seem to suit itself for use in this SSLR. However, Google Scholar does not provide a reproducible method to programmatically access the results without the use of web scraping methods, which are explicitly prohibited in the Terms of Service of Google Scholar. Therefore, while this SSLR does utilise the search capability of Google Scholar for discovering industry and government publications on MaaS, there is no means by which the search query can be repeated to validate search result reproducibility.

#### 4.3.4 *Search strategy and selection process*

The SSLR has been conducted during the period September-December 2019 and included activities such as monitoring news outlets, indexing government and industry publications, identifying relevant legislation and consulting Mobility-as-a-Service experts and mobility service providers (MSPs). Several documents have been catalogued as a result of these activities, of which a random selection is discussed in the result Section of the SSLR.

### 4.4 Systematic Mapping Study

The Systematic Mapping Study performed in this study is used to map a selection of studies performed on the topic of MaaS to a set of MaaS characteristics. This set of MaaS characteristics is derived from combining the characteristics identified during the SLR and the SSLR. The goal of the SMS is to both assess the scope and state of academic MaaS research as well as identify any research gaps within the Mobility-as-a-Service domain. However, as the state of MaaS research changes over time, the associated research gaps are also expected to change. As such, to avoid pointlessly repeating prior research on this topic and to increase the relevance of the results presented in this literature review, this mapping study utilizes the submission date of the paper by Jittrapirom et al. (2017) as a coarse reference point for the lower boundary of the search date parameter and thus only considers journal articles and conference proceedings published between February 2017 and December 2019, the latter of which is in line with the upper boundary search date of the SLR.

#### 4.4.1 *Inclusion criteria*

Any journal article or conference proceeding published between February 2017 and December 2019 that directly addresses Mobility-as-a-Service was included in the SMS.

#### 4.4.2 *Exclusion criteria*

Materials excluded from the literature review:

- Other types of publications (e.g. conference reviews)
- Materials published in languages other than English
- Duplicate (older) versions of materials
- Materials that are inaccessible due to limitations imposed by the used academic license

#### 4.4.3 *Database selection*

Because the SMS considers a subset of the literature found as part of the SLR, the validity of the SMS results is dependent on consistency within the accessed body of knowledge between the SLR and SMS. As such, the databases accessed as part of this SMS are equivalent to the databases listed in Section 4.2.3.

#### 4.4.4 *Search strategy and selection process*

Based on the overlap of MaaS characteristics between academic and non-academic literature identified in the SLR and SSLR respectively, an inter-disciplinary definition and conceptual map of MaaS is derived (see Section 5.3). Subsequently, this definition of MaaS and its associated characteristics are used as a reference framework in mapping a subset of MaaS-focused studies – 28 studies were selected by applying the inclusion and exclusion criteria of this SMS to the 33 MaaS studies identified in the SLR – based on their research focuses (see Section 5.4). The conceptual map is then leveraged to identify MaaS research gaps (see Section 5.5).

## 4.5 Features and Data Requirements in Existing MaaS Solutions

Whilst the concept of MaaS is arguably quite novel, there already exist a plethora of multimodal travel aids available to consumers. However, it could be argued that the availability of multimodal planning alone does not qualify a product as a “MaaS solution”. Regardless, there exists various products that are described as “MaaS products”. As such, a rigorous method was required to control and limit the scope of the selected MaaS solutions. Due to the explicit nature by which inclusion and exclusion criteria are defined in Kitchenham & Charters (2007), this analysis adopts this method and its guidelines in a similar fashion to its usage in the SLR (Section 4.2).

### 4.5.1 *Inclusion and Exclusion Criteria*

As access to MaaS solutions can be limited – corporate-exclusive applications were out of reach within the study constraints –, only publicly accessible offerings were included in this analysis. Whilst geographic service coverage was initially considered as a potential constraint to be used in the selection process, this factor was found to have no effect on the extent to which a MaaS solution could be analysed. Instead, ‘a minimum threshold of 1000 installations’ and ‘geographic service coverage of at least one area where GDPR applies’ were defined as selection criteria. Furthermore, only materials available in English or Dutch were assessed as part of this research.

### 4.5.2 *Database selection*

Due to restrictions imposed by the APPA framework, the ‘databases’ of MaaS software solutions available to this research was limited to (mobile) applications distributed through the Google Play store. Though it was briefly considered to expand the used methods to include other application distribution channels, as it is believed that different privacy cultures exist for different application distribution methods, expanding on this model was eventually deemed to fall outside the scope of this research.

### 4.5.3 *Search strategy and selection process*

Due to the closed and proprietary nature of Google Play search, the results obtained from each search in the Google Play store can differ between queries based on “[…] a combination of ratings, reviews, downloads, and other factors.” (Google, 2020). As such, the search strategy cannot be defined in such a manner that the results could be reproduced easily in the future.

Instead, the search functionality offered by the Google Play store was leveraged by means of first defining a shortlist of natural language search terms and keywords encountered in selected academic publications on the topic of MaaS. Search terms on this shortlist were then used independently as input for Google Play search on a Google account with no prior usage of the distribution platform or other Google services. The search was performed in July 2020.

The following search terms were used: *‘mobility’, ‘mobility-as-a-service’, ‘MaaS’, ‘multimodal’, ‘travel planner’, ‘on-demand mobility’*.

From the result set of mobile applications returned by Google Play search, the title, description, and screenshots were first assessed on the basis of the functionality offered by the software package, in order to consider whether each of these applications could be considered a ‘MaaS-type’ application within the context of the MaaS conceptual framework. Specifically, it was looked at whether multiple types of modalities were offered, whether payment and ticketing options were integrated alongside planning features, and whether customisation or personalisation of journeys was addressed in any capacity.

Based on these criteria, the following mobile applications were selected for feature identification:

- Google Maps
- Here WeGo
- Moovit
- NS Lab[1]
- REACH NOW[2]
- TripGo
- Turnn
- Urbi
- Whim

### 4.5.4 *Feature Identification*

The primary method used in the feature identification process is a scan of generally available descriptive materials on the behaviour and implemented software capabilities of MaaS solutions. Materials considered in this literature scan are those published online by its proprietor, or on the proprietor's behalf, those listed on the product's web page and app store listings (i.e. application descriptions, screenshots, and videos). The results obtained from this analysis provide an overview of each MaaS solution, its implemented features and the associated MaaS concepts.

### 4.5.5 *PDR Identification*

Pending the results of the feature identification process, each MaaS solution is then subjected to an adapted version of the APPA (Automated aPp Privacy Assessment) framework, originally developed by Wettlaufer & Simo (2020). The original framework leverages app store metadata (i.e. permissions and privacy policy) to devise a comprehensive privacy assessment for mobile applications published on the Google Play store.

Whereas the original version of the APPA method would suffice for an automated coarse-grained analysis of MaaS solutions' personal data collection and processing practices, the adapted method does not utilise the automated features of the APPA method – the scope of this research segment does not necessitate the use of automated analyses – and instead performs the process manually with additional contextual information to yield more accurate results than those otherwise obtained from an automated assessment. As such, the functionality-to-privacy trade-off metric is not incorporated as this is studied using the methods listed in Section 4.6.

The discovered PDRs and privacy score for each MaaS solution are subsequently mapped to the identified MaaS features (see Section 4.5.4). The resulting mapping between PDRs and MaaS features can then be leveraged in assessing consumer sentiment with regards to personal data collection and processing for the purposes of offering said capabilities.

## 4.6 Customer Survey on MaaS Privacy Considerations

To provide insight into the consumer expectations of MaaS solutions and assess the user sentiment towards personal data collection and processing practices by these solutions, the identified features, and PDRs of MaaS solutions were incorporated into a user survey.

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[1] As the NS Lab application can only be used in combination with the non-experimental NS application, features from both are considered in the performed analysis.

[2] As MOBI is the business-to-business (B2B) variant of REACH NOW, the former is not included separately.

#### 4.6.1 *Survey Design*

Respondents of this survey were first asked to provide information on their personal travel and trip planning behaviour, e.g. which modes of transport are used and by what means trips are planned, in addition to several socio-demographic questions used to compare the results of this survey with concepts found as part of earlier survey studies, e.g. Alonso-González et al. (2020).

Considering that the scope of this research is constrained to identifying privacy considerations for MaaS software solutions, the research population for this survey was limited to individuals that:

- used a mobile application in the past at any stage of their journey;
- have the intent of using such a mobile application in the future;
- their reasons for not using such a mobile application include privacy concerns.

There was no requirement drafted on whether respondents should have any familiarity with the MaaS concept. This was deliberately kept undefined as users might have different ideas about the usefulness of certain typical MaaS features, therefore changing their perception on whether there exist any privacy concerns for the feature's personal data requirements.

After information required for the class cluster mapping had been provided, the survey was continued by respondents indicating their expectations of MaaS applications. This assessment was carried out by providing respondents with statements structured according to a 5-point Likert-scale (i.e. not at all important, not important, somewhat important, important, very important) on each of the identified MaaS features.

Respondents were subsequently asked about their privacy concerns with respect to the personal data requirements associated with MaaS-type applications. For each of the PDRs, respondents were asked to indicate their level of concern by means of a 3-point Likert-scale (i.e. not concerned/ somewhat concerned/ very concerned), thus indicating their stance towards the use of these PDRs in MaaS solutions.

#### 4.6.2 *Research Population & Sample Size*

In order to reach a representative sample size for this research, the research population first has to be established. Whilst it could be argued that the research population of this survey could encompass any person with a need or desire for mobility, there were practical limitations to the maximum reach of a survey with such a research population.

First, although a target population can be established for the research setting/ country (i.e. the Netherlands) using publicly available statistics – the population of the Netherlands was recorded at 17.440.679 in August 2020 (Statistics Netherlands, 2020) –, there is no means by which the intent or desire for mobility can be estimated for this population[3]. As such, there is no clear benefit to the representativeness of this research to limit the research population to the country in which the research study was performed.

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[3] While there are statistics available on indicators such as modality use and access to mobility, there did not exist data sets which had recorded the intent or desire for personal mobility. As such, it was reasoned that establishing the research population using one of the previously mentioned available statistics would solely include those which already use modalities available to them, and therefore skew the overall results of this questionnaire, subsequently making them less valuable for the development of (future) MaaS solutions.

Second, whilst random sampling methods would yield more representative and scientifically generalisable results, the limitations imposed by scope and the available resources for this research, as well as the enforced health and safety measures in response to the SARS-Cov-19 Coronavirus in mid-2020 substantially hindered the distribution of this questionnaire. As such, the survey was distributed using opportunity and voluntary sampling methods, e.g. leveraging easily accessible existing global online networks. Whilst this introduced self-selection bias in the sample set, it was deemed acceptable under the circumstances and for the purposes of this research. Moreover, due to the unknown reach achieved by online mediums, an estimated response rate could therefore not be determined beforehand.

Third, despite a global reach of this questionnaire is believed to be beneficial to understanding the privacy considerations with regards to MaaS solutions from consumers in different markets (with varying privacy values and legislation), it would ultimately result in the research population still being left unable to be quantified.

As such, whilst generalisable results and a representative sample size of the research population remain desired outcomes of this research, it was instead reasoned that the representativeness offered by presumed diversity in privacy views due to the global outreach offered by leveraging online outreach channels and voluntary sampling methods would substantially outweigh the representativeness offered by extensively controlling the research population to a set geographic area. Furthermore, as the scientific value offered by this thesis results from providing insight into privacy considerations of consumers in MaaS solutions and subsequently embedding those into the design and development processes of these solutions, it comes to reason that more diversity in privacy considerations yields more value than a higher degree of accuracy with respect to any specific research population. Instead, a target value of 100 was set for the research population.

#### 4.6.3 *Survey Distribution*

Due to opting for (mostly online) opportunity and voluntary sampling methods, the survey was created and distributed using the Microsoft Forms application[4]. This online survey tool is used to create online user surveys, including those aimed towards scientific research, and provides both a rich feature set and means to adhere to applicable privacy regulations.

As the survey included questions regarding socio-demographic characteristics of respondents, the survey was sent out alongside a data consent form, asking respondents for their consent with regards to the processing of their personal data for the purposes of this research.

Paper variants of both the questionnaire and consent form were also available to participants, if this was their preferred method of participation and the logistical challenges as a consequence to providing paper versions were deemed acceptable. Received responses by paper were collected and digitalised post-completion, after which the physical copies were destroyed.

[4] https://forms.office.com/

### 4.6.4 *Results Analysis*

The results from this survey were used to compare the attitude of respondents towards personal data protection with their willingness to compromise PDP for specific MaaS functionalities based on their perceived importance. As such, the data set was analysed according to two indicators:

- user-perceived importance of feature presence;
- and personal data requirement acceptance rate.

First, the features identified in the feature and PDR identification process (see Section 4.5) were ranked according to the importance (5-point Likert-scale) given by respondents and expressed as the ratio of respondents with an expectation for the presence of each MaaS feature. Similarly, the PDR-acceptance rate is ranked according to the concern (3-point Likert-scale) given by respondents and expressed as the ratio of respondents with a positive view towards these PDRs. These rankings can then be leveraged to prioritise MaaS features and limit highly-controversial PDRs in MaaS solutions.

## 4.7 Incorporating Privacy Recommendations in Design Methods

Following the results from the user survey, this segment of the research attempts to both develop privacy recommendations for MaaS solutions and embed these recommendations in the management and design processes of these solutions.

Considering that privacy recommendations can be perceived as design-specific requirements – this especially holds true within the context of the 'privacy-by-design' and 'privacy-by-default' design philosophies –, it was reasoned that methods providing reoccurring mechanisms by which to control project requirements throughout its lifecycle would likely be most suitable.

As such, two (project) management methods were selected from the software development and enterprise architecture domains that were believed to adhere to these selection criteria and be representative of methods used in practice. The methods and frameworks selected and adapted for the purposes of this research are:

- Disciplined Agile Delivery (DAD);
- The Open Group Architecture Framework (TOGAF).

Each of the methods will be analysed within the context of its use, i.e. privacy recommendations made in the context of TOGAF will be considered from a (higher) architectural level compared with DAD, which is more versatile in terms of the types of projects that it supports and therefore requires a different approach to privacy recommendations.

Finally, the incorporation of privacy constructs and guidelines in methods used for the design and development of MaaS solutions was thoroughly reviewed and lessons-learnt were documented. Subsequently, grounded recommendations are made by developing a privacy-functionality trade-off debate and challenging the status-quo with regards to the role of personal data protection and privacy within the MaaS ecosystem.

# 5 MAAS CONCEPTUALISATION & GAP ANALYSIS

*This chapter concerns the conceptualisation of MaaS and therefore addresses the first three research questions of this study. Definitions of MaaS encountered in academic literature (Section 3.1) and non-academic publications (Section 3.2) are first outlined and subsequently discussed. Identified characteristics are observed and an overlap assessment is performed to conceptualise the MaaS ecosystem (Section 3.3). This conceptualisation is then leveraged in mapping studies in the research field to individual MaaS concepts (Section 3.4). Finally, an extensive gap analysis is performed on the MaaS research field to pinpoint areas lacking research (Section 3.5).*

## 5.1 MaaS in Academic Literature

Using the methods listed in Section 4.2, 13 journal articles and conference proceedings were identified (Appendix A: Materials included in the SLR) that concern either the conceptualisation of MaaS, or the discussion of its characteristics. In this section, the focus of each paper and their conceptualisations of MaaS are discussed first, after which they are aggregated, and a synthesis of these findings is presented.

### 5.1.1 *Literature Review*

While conceptualising Mobility-as-a-Service is not the focus of Melis, Prandini, Sartori and Callegati (2016), it is an integral part of their research in determining the technical and social implications of IoT in an urban public transportation setting. For this, the authors derive their definition of MaaS from Hietanen (2014) as an "[…] innovative approach to the integration of public and private transport" (Melis et al., 2016, p. 320). As such, there is no further effort to systematically define MaaS in their research, however some of the concept's characteristics are elaborated upon. For instance, key to their interpretation of MaaS is the inclusion of real-time demand and supply information on transportation services. Other characteristics that are mentioned in relation to MaaS are: route planning; payment integration; availability of alternative transport modes/ freedom of (modality) choice; route constraints (comfort and timing); and tracking (timing, position, and asset availability). The authors of this paper also consider the privacy implications of collecting these datasets by both public administrations as well as private companies. They argue that citizens' privacy is respected more when the role of MaaS operator is assigned to a public administration rather than private organisations considering the potential for malevolent data collection (Melis et al., 2016).

These privacy concerns are shared by Cottrill (2019) in their journal article titled 'MaaS surveillance: Privacy considerations in mobility as a service'. While this paper considers various interpretations of MaaS, it does so in order to fully examine all associated privacy considerations. This not only includes the various conceptualisations of MaaS by academic literature and industry – this paper explicitly mentions a definition of MaaS by the MaaS Alliance –, but also the various business models and actor roles. However, based on their explicit citation, it is clear that the authors of this paper primarily consider the MaaS characteristics presented in Jittrapirom et al. (2017) in their impact analysis of GDPR on MaaS solutions. In fact, this paper by Jittrapirom et al. (2017) has been cited by a large number of the analysed papers in their endeavours to conceptualise MaaS for their own research purposes. This is not without reason, as Jittrapirom et al. (2017) perform a comprehensive literature review on the various interpretations of MaaS and subsequently define its characteristics based on this academic literature.

Specifically, the MaaS characteristics listed by Jittrapirom et al. (2017) are:

- Integration of transport modes
- Tariff option
- One platform
- Multiple actors
- Use of technologies
- Demand orientation
- Registration requirement
- Personalisation
- Customisation (Jittrapirom et al., 2017, p. 16)

Jittrapirom et al. (2017) also acknowledge the privacy concerns expressed by many authors, but mainly restrict their judgement to the various smart payment methods suitable public transport, such as (virtual) smart cards (Jittrapirom et al., 2017, p. 21). Instead, the authors follow up on their concern by expressing the vital importance of aggregating and integrating various data sources (Jittrapirom et al., 2017, p. 21).

Integrating various data sources and modalities is a common theme in MaaS literature. It is also key to the definition of MaaS used by Wong, Hensher and Mulley (2019). However, instead of considering the integration challenge from a technical perspective, Wong et al. (2019) propose that the challenges of MaaS are to be considered from a model efficiency perspective. They argue that "Spatial and temporal integration constitute key components of our MaaS vision where MaaS is an enabler of an efficient transport network." (Wong et al., 2019, p. 8). They also state that MaaS can act as a supporting mobility tool, mostly limited to first and last mile use cases, in areas with rail-centric high-volume mobility systems (Wong et al., 2019, p. 7). Although their approach – to consider both demand-over-time as well as the spatial footprint of transport modes as part of the conceptual basis for MaaS – is quite novel, the desire to meet mobility demand more effectively has already been researched extensively.

For instance, the paper by Pangbourne, Mladenović, Stead and Milakis (2019) explores both the efficiency and equity aspects of Mobility-as-a-Service in their endeavour to determine the societal and governance effects of the concept. In their analysis, the authors are aware of the various MaaS conceptualisations and their characteristics. For that reason, this paper adopts a broader definition of MaaS where users can purchase a variety of mobility services. In line with the aforementioned privacy implications of MaaS, the authors of this paper also discuss how various governance structures can affect personal mobility. They especially highlight that when primarily considered as a private-sector business opportunity, the impact of MaaS might not be limited to mobility (Pangbourne et al., 2019, p. 13). Specifically, with regards to the access to transport, they note: "the threat of potential enclosure of our mobility systems by allowing private entities to control the products that enable people to access to transport through integrated platforms as well as through data monetisation, is just one element that leads us to conclude that urban governance is considerably challenged by MaaS" (Pangbourne et al., 2019, p. 13). They also advise caution with respect to the pricing structure of MaaS, as the bundling of various modalities and their respective pricing can result in the obfuscation of individual journey cost (Pangbourne et al., 2019, p. 13).

Conversely, Willing, Brandt and Neumann (2017) do not seem concerned with the obfuscation of individual journey cost. In fact, they claim that the transparency of Multimodal Mobility Platforms (MMPs), which is mentioned by them as the basis for MaaS initiatives, can lower journey prices overall (Willing et al., 2017, p. 271). It is therefore worthwhile to examine their interpretation of MaaS and its relation to MMPs. Willing et al. (2017) describe MMPs as advanced route planning tools, which aim to find the best route for the user by comparing multiple modes of transportation along certain parameters (e.g. fast, short, clean, comfort) and real-time (traffic) data, while sometimes also enabling payment services for the journey. In their own words, “MMPs represent an increase in convenience as they provide a one-stop shop and make it unnecessary to collect and combine information from different sources.” (Willing et al., 2017, p. 271). This is strikingly similar to the definition given to MaaS by Mukhtar-Landgren et al. (as cited in Mukhtar-Landgren & Smith, 2019, p. 1), describing it as a service that integrates a range of mobility services and provides access to these services through a single interface.

However, Willing et al. (2017) also note that such integration of different mobility services is a key challenge in MMPs, along with data standardisation and the incorporation of real-time data as mentioned by Aditjandra, Nelson and Wright (as cited in Willing et al., 2017, p. 270). The integration of services between mobility providers is described by Beutel el al. (as cited in Willing et al., 2017, p. 270) as a key architectural challenge with regards to MMPs and therefore they also stress the importance of an independent mobility platform provider. In another paper published by Beutel et al. (2018) the research into the integration of these mobility provider information services is developed further. In their research, the authors reflect on the degree according to which mobility platforms implement a set of characteristics identified in literature pre-dating Mobility-as-a-Service (Beutel et al., 2018, p. 160).

Whereas some of the characteristics identified by Beutel et al. (2018) can solely be used to evaluate implemented mobility platforms (i.e. the structure and business model of the service), other characteristics (i.e. pricing policy and transaction phase characteristics) can also be related to the abstract concept of mobility platforms or, in this case, the concept of Mobility-as-a-Service. Whilst Beutel et al. (2018) do not explicitly mention Mobility-as-a-Service as a term in the contents of their paper, the authors do imply that it is relatable to the concepts discussed within their research by referring to it as a relevant keyword. Considering that the main contribution of Beutel et al. (2018) is the characterisation and conceptualisation of different mobility service platforms, it can be assumed that, from the perception of these authors, MaaS should be designed as a centralised mobility service platform with a singular purpose: to deliver mobility service interoperability.

The notion that MaaS should be implemented as a broker platform seems to be the status quo in academic literature. It stands to reason that this is due to the multi-faceted nature of MaaS. Tura et al. (2018) conceptualise MaaS as a multi-sided market and – following the inverse of Gawer’s description of platforms being multi-sided markets (as cited in Tura et al., 2018, p. 881) – a platform. As such, the focus of Tura et al. (2018) is to develop a design framework and subsequently apply it to DORA, which can be described as a mobility information integrator in a MaaS ecosystem (Tura et al., 2018, p. 886). Most case studies seem to follow this ‘platform-approach’ to integrate mobility service providers, however Giesecke, Surakka & Hakonen (2016) consider MaaS on a higher conceptual level and provide it with the following definition: “MaaS currently aims at transporting persons (and sometimes goods) over a predefined distance, often by combining different means, by making intelligent use of ICT (and, less often, ITS) in a way that is distinctly more sustainable than the use of a private car.” (Giesecke et al., 2016, p. 9).

Therefore, the ‘platform-approach’ to MaaS as seen in Tura et al. (2018) can be considered as one of many possible solutions to the interoperability challenges of MaaS. Giesecke et al. (2016) themselves stress the need for mobility data interface standardisation as a requirement for interoperability.

Whilst the interoperability of MSPs’ information systems is evidently important to the success of MaaS ecosystems, another key success factor of MaaS can be found in the end-user of any MaaS solution. Not only does Giesecke et al. (2016) include a strong focus on end-users in their listing of key MaaS issues, its user-oriented nature is underlined by Sakai (2019) and end-user needs are also the focus of the research performed by Lamberth-Cocca and Meiren (2017). Although the definition given to Mobility-as-a-Service by Lamberth-Cocca and Meiren (2017) is slightly different from other MaaS definitions discussed so far – MaaS is considered in the context of both travellers as well as physical goods, which could be argued to be an attempt to intersect the domains of MaaS and the Physical Internet (PI) –, it continues the trend of referring to the concept as a complex ecosystem.

Lamberth-Cocca and Meiren (2017) furthermore argue that understanding the needs of travellers and other customers of MaaS platforms, as well as including these actors into the development process of MaaS solutions, are necessary to provide seamless personal mobility. Where Giesecke et al. (2016) refer to the importance of identifying user group segments, attitudes and behaviours for the success of MaaS, Lamberth-Cocca and Meiren (2017) consider user needs in the process of development a method for providing interactive and personal MaaS offerings. A user-centric approach to Mobility-as-a-Service therefore seems to be vital to its success, not only in terms of freedom of route choice (Sakai, 2019), but also with regards to the associated method of payment. MaaS services currently provide one or more of the following payment methods: pay-as-you-go; monthly tariffs; mobility packages (Esztergár-Kiss & Kerényi, 2019a, p. 3).

Though any of the above-mentioned payment methods would suffice for offering Mobility-as-a-Service, Esztergár-Kiss & Kerényi (2019a) specifically take an interest in the creation of (personal) mobility packages based a number of city parameters and elaborate on payment options such as pay-as-you-go. While their research is centred around dynamic payment methods, a broader definition of MaaS is provided: “Mobility-as-a-Service (MaaS) is a solution that combines a number of services and provides a platform, where multimodal journey planning, booking, payment and ticketing are integrated.” (Esztergár-Kiss & Kerényi, 2019a, p. 1). Their definition of MaaS is derived from Kamargianni et al. (2018), who describe MaaS as an intermodal journey planner integrated with payment services.

It then becomes clear that the MaaS concept is directly supported by internet-services and other applications of ICT. In fact, “The goal of the concept of MaaS conceived in Finland is to improve productivity in the transportation sector through the use of ICT.” according to Sakai (2019, p. 3). This expression by Sakai (2019) must be taken in the context of its related definition of MaaS, which includes all modes of transport other than private cars (Sakai, 2019, p. 1). The used definition of MaaS is itself based off a description of the MaaS concept given by Sedlik, who describes it as a “digital platform with integrated services, including journey planning involving all modes of transport, booking, e-ticketing, and payment, from the starting location up to the destination.” (as cited in Sakai, 2019, p. 1). While the two definitions are different in the included modes of transport – contrary to the definition of MaaS used by Sakai, the referenced work of Sedlik does not explicitly exclude private vehicles from MaaS – their views are aligned when it concerns the need for integrated planning, booking, ticketing and payment in mobility services.

### 5.1.2 *Synthesis of MaaS Characteristics in Academic Publications*

The aggregated characteristics (Table 2) are mostly in line with those presented in Jittrapirom et al. (2017), however leave out three characteristics (i.e. one platform; registration requirement; personalisation). Whereas there does seem to be a consensus on the need for a centralised application to handle user requests, either in the form of a multimodal mobility platform (MMP) or mobility service platform (MSP), there is some debate over whether such platforms should act as brokers, aggregators, or integrators. While the differences between these service types are negligible from a service offering perspective – eventually, the same mobility service is ideally offered to the customer, albeit under different terms –, their architectural differences result in certain privacy implications and other challenges with regards to the method by which customer and mobility data is stored and managed, as discussed extensively by Cottrill (2019).

Moreover, the specific implementation of MaaS characteristics, such as ticketing, booking and payment, differs substantially between each type of platform due to the system's particular role in the transaction process (i.e. broker or payment handler). Especially considering that publications before Jittrapirom et al. (2017) and Hietanen (2014) mostly did not consider mobility packages, but rather referred to pay-as-you-go or smart card options, it is therefore entirely possible to imagine other types of MaaS platforms. For instance, it would be possible to design a platform that implements ticketing, booking and payment functionality without the need for mobility subscriptions and user registration.

In fact, it was found that while modality choice is considered a core characteristic of MaaS, personalisation was not as widely mentioned in the papers analysed. While most publications that followed the definition of MaaS from Jittrapirom et al. (2017) consider personalisation an important aspect of MaaS by means of inheritance – it even forms the backbone for the privacy considerations presented by Cottrill (2019) –, it seems that this sentiment is not shared at large.

**TABLE 2: MAAS CONCEPT CHARACTERISTICS IN ACADEMIC PUBLICATIONS**

| | |
|---|---|
| **MaaS Characteristics** | MaaS is the consolidated offering of various mobility options and modes (i.e. modality choice). |
| | Route planning is dynamic and customisable through internal (e.g. network) and external (e.g. contextual/ environmental) parameters. |
| | Ticketing, booking, and payment services are exposed to the end-user through a centralised application. |
| | Tariff options provide dynamic access to diverse and potentially incentivised modes of transport. |
| | The effectiveness of MaaS solutions is measured through their ability to increase the transportation network's (spatial) efficiency by improving the methods by which supply and demand are matched. |
| | Collaboration between multiple actors, among which PT operators, government entities and third-party organisations is required for operation. |
| | MaaS solutions depend heavily on the use of telecommunications (e.g. real-time tracking) and information technology. |

## 5.2 MaaS in Industry and Government

Using the methods presented in Section 4.3, a total of 17 documents were selected for further analysis (Appendix B: Materials included in the SSLR). These documents discuss either the conceptualisation, implementation, or characteristics of MaaS. In this section, the general premise of each document and the presented perspectives on MaaS and its characteristics are discussed first. Subsequently, an overview of MaaS characteristics from the perspective of industry and government is derived.

### 5.2.1 *Literature Review*

Connekt[5], an organisation in the Netherlands focused on collaboration between organisations in mobility innovation, presented their perspective on Mobility-as-a-Service in a report drafted by their 'Taskforce MaaS'. In this report, the definition, characteristics, and challenges of MaaS are discussed. For their analysis, they use the definition of MaaS given by Hietanen (2014) and rely heavily on resources and information from organisations such as UbiGo[6], Smile[7] and MaaS Global[8]. In this report, they specifically mention characteristics they believe are key to MaaS:

- Accessibility;
- Speed;
- Reliability;
- Affordability;
- Comfort;
- Ease-of-use;
- Flexibility (Connekt, 2017).

Additionally, the report reveals that their vision of MaaS is that of a single platform combining all types of modalities (Connekt, 2017, p. 6). Through this platform, the geo-location data of the customer and modalities as well as traffic data should be readily available and exchangeable, as they argue that MaaS solutions depend on such data to match customer demand with the capacity of the transportation network (Connekt, 2017, p. 7). The report concludes by highlighting core challenges to be overcome before the implementation of a nation-wide (or international) MaaS platform can be achieved, with those relevant to the conceptualisation or implementation of MaaS listed in Table 3.

These challenges not only reflect the ambitions of Connekt, but also to some extent the priorities of the Dutch government. Especially for those MaaS challenges that are inherently social in nature, (i.e. monitoring accessibility and environmental impact; transport concessions; as well as privacy and security), the Dutch government has set specific policy goals that it wants to attain. These include mandating that all PT in government-granted transport concessions are accessible through MaaS services, fiscal barriers are removed where possible and that data about PT processes and facilities are of sufficient quality and based on open standards (van Nieuwenhuizen Wijbenga & van Veldhoven - Van der Meer, 2019, p. 2). In fact, open data is of such high priority within the Dutch government's MaaS policy that it even aims to make it a prerequisite for being granted a transport concession (Ministerie van Infrastructuur en Waterstaat, 2019b, p. 19).

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[5] https://www.connekt.nl/en/home/

[6] https://www.ubigo.me/en/home

[7] http://smile-einfachmobil.at/index_en.html

[8] https://whimapp.com/

**TABLE 3: MAAS CONCEPTUALISATION CHALLENGES DERIVED FROM (CONNEKT, 2017, PP. 10–13)**

| | |
|---|---|
| **MaaS Platform Challenges** | Measurement instruments for (government) monitoring and validation of accessibility and environmental criteria. |
| | Development and application of (dynamic) pricing schemes (e.g. parking tariffs, road pricing/ mileage toll). |
| | Development of a dynamic and robust customer segmentation (i.e. motivations and situational context). |
| | Introduce MaaS to public transport concessions to allow for a level-playing field with new mobility providers. |
| | Setup protocols for real-time sharing of (travel) data. |
| | Develop a framework with best-practices regarding privacy, data-ownership and data security in the context of MaaS, while adhering to the GDPR and protecting the interest of all involved stakeholders. |
| | Test and validate techniques that can potentially be used to develop a production-level MaaS system. |
| | Incentivise consumers and organisations fiscally to pay for personal mobility rather than the ownership of individual modalities. |

Moreover, privacy and data protection are key to the MaaS policy of the Dutch government. In their publications and letters, it has made itself clear by stating that (1) it does not want a closed platform for MaaS, but rather an open ecosystem that allows for a level-playing field (van Nieuwenhuizen Wijbenga & van Veldhoven - Van der Meer, 2019, p. 2) and (2) that while open data should be a priority, it should not outweigh citizens' right to privacy (Ministerie van Infrastructuur en Waterstaat, 2019b, p. 19). As such, it could be argued that the Dutch government is opting for a very data-centric approach to MaaS policy. This is not unlike the Finnish approach to facilitating Mobility-as-a-Service in their cities, where the introduction of the 2018 Transport Service Act mandated that mobility service providers publicly expose their travel data (Dooley, 2018). Not only did this legislative change allow for the sustained growth and expansion of MaaS Global services (Dooley, 2018, p. 8), but also brought ride-sharing service Uber back to its capital: Helsinki (Dooley, 2018, p. 15).

Considering MaaS Global's dominance in the MaaS ecosystem in Finland, it is unsurprising that the characteristics of MaaS considered by the Finnish government closely resembles those offered by MaaS Global and their Chief Executive: Hietanen (2014). As such, their definition of MaaS is broad. It includes all modes of public and private transport offered through a single user-oriented service, often a mobile application, and paid for using (predefined) mobility packages. Whereas some European countries, like Switzerland have opted for a similar approach, some other European countries, among which Austria, have instead adopted the approach of providing centralised mobility and routing services in conjuncture with payment through smart cards (European Parliamentary Technology Assessment, 2017).

**TABLE 4: MAAS CHARACTERISTICS DERIVED FROM POLIS (2017)**

| Opportunity | Characteristics mentioned |
|---|---|
| "Promote sustainable travel" (Polis, 2017, sec. 4.1) | Easier access; reduction in modality ownership; customisation; affordability; convenience; comfort. |
| "Improve efficiency of existing transport services and public resources" (Polis, 2017, sec. 4.2) | Demand-responsive; modality choice; increased efficiency. |
| "Take advantage of the personalised approach to develop an inclusive transport system" (Polis, 2017, sec. 4.3) | Personalised services; easing access to door-to-door transport. |
| "Enhance access to transport services" (Polis, 2017, sec. 4.4) | Integrated travel information; public and private partnerships; policy-fit. |
| "Offer choice to users" (Polis, 2017, sec. 4.5) | Modality choice; affordability; reduction of environmental impact; customised mobility; accessibility; inclusivity. |

Even though it might therefore seem like European countries are divided on the definition and implementation of MaaS, this does not mean that there are no efforts to unify efforts. A report by the Polis Traffic Efficiency & Mobility Working Group (Polis, 2017) addresses the state of MaaS in Europe, both in definition and in implementation. While their report states that "[…] there is no one definition of MaaS" (Polis, 2017, p. 4), their suggested path forward for partner cities and regions with respect to MaaS is one where traditional public transport is combined with new mobility services (Polis, 2017, p. 5). As such, it can be derived that modality choice is inherent to their perspective on MaaS. Moreover, based on their enumeration of opportunities that could potentially come with MaaS, it is possible to extract MaaS characteristics resembling their perspective on the concept (Table 4).

Accounting for duplicates, this mapping between these MaaS opportunities listed in Polis (2017) and the associated MaaS characteristics can be reduced to a set of 15 concepts:

- Accessibility;
- Affordability;
- Comfort;
- Convenience;
- Customisation;
- Demand-responsiveness;
- Efficiency;
- Inclusivity;
- Integrated travel information;
- Modality choice;
- Personalised services;
- Policy-fit;
- Public and private partnerships;
- Reduction of environmental impact;
- Reduction in modality ownership.

The challenges listed in the Polis report associated with MaaS are predominantly concerned with its business model (Polis, 2017, sec. 6.6), the roles of public and private actors (Polis, 2017, secs. 6.1, 6.2, 6.5) as well as the uncertainty of its future (societal) impact (Polis, 2017, secs. 6.3, 6.4, 6.7). Specifically, the need for a legislative framework around MaaS is called for (Polis, 2017, pp. 9–10), acknowledging the legislative barriers experienced during MaaS tests in Sweden (European Parliamentary Technology Assessment, 2017). Some initiatives have attempted to deliver a collaborative workspace/ platform in which these challenges can be overcome. One such initiative is the MaaS Alliance, which encourages participation of all interested actors in their efforts to develop a MaaS market enabled by "Open IT architecture and standardised sub-element features, such as payment, ticketing, authentication and security, […]" (MaaS Alliance, 2017, p. 2). Furthermore, characteristics previously seen in other industry publications, such as access, accessibility, customisation and personalisation, are re-iterated in their recommendations (MaaS Alliance, 2017).

One particular PT organisation in the Netherlands has taken it upon themselves to illustrate what freedom in mobility might look like from both traveller and operator perspectives. In their report titled 'Journey to the Future', Dutch Railways (NS) take a customer-centric approach to mobility, stressing the importance of customisation, personalisation, modality choice and comfort to individual travellers. Similarly, the report also highlights other perceived benefits of MaaS, like sustainability and the ability to better meet mobility demand. In addition to these characteristics, NS also specifically considers the spatial impact of modalities (Nederlandse Spoorwegen, 2019b, pp. 26, 42–47) and present several design elements to be used for redesigning mobility hubs in order to prepare for large-scale MaaS adoption (Nederlandse Spoorwegen, 2019b, pp. 28–30).

From this, one could argue that Dutch Railways (NS) clearly desires to become a true multimodal transport provider. However, it is not necessarily new behaviour for their organisation, as they have been at the forefront of mobility innovation for quite some time, implementing the concept of Combined Mobility through projects like OV-Fiets[9] and NS-Zonetaxi[10]. This concept was discussed at length in UITP (2011) and can be summarised as a precursor to MaaS, yet solely focused on the integration of mobility services from a modality choice perspective.

Meanwhile in the UK, various groups and organisations have been working on investigating the dimensions of various MaaS concepts and assessing their potential impact on the transport network. A report by Transport Systems Catapult continues to place modality diversity front and centre, while simultaneously presenting the consumer-centric nature of MaaS (Transport Systems Catapult, 2016). Besides conceptualising MaaS, their publication also discusses the contextualisation of the concept in present-day. Their argument that services related to MaaS are already being used in certain parts of the UK implies that the functionality offered by these services resembles their view of the MaaS concept. Specifically, they note that these services are "[…] associated with navigation, journey information, cashless payment as well as managed access to transport services including taxi, bus, rail and shared transport journeys." (Transport Systems Catapult, 2016, p. 10).

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[9] https://www.ns.nl/en/door-to-door/ov-fiets

[10] https://www.ns.nl/en/door-to-door/consumers/ns-zonetaxi.html

In addition to these characteristics, the authors note that features such as personalisation, real-time/ dynamic journey management and customised journey planning are relevant to MaaS (Transport Systems Catapult, 2016, p. 12). Moreover, the authors explicitly define MaaS in their concluding remarks as “using a digital interface to source and manage the provision of transport related service(s) which meets the mobility requirements of a customer” (Transport Systems Catapult, 2016, p. 48). Not only does this statement reflect their view that MaaS should be inherently demand-oriented, but also that MaaS ought to be considered as data and service aggregation actors rather than refer to the interfaces between mobility services. Furthermore, this would seem to suggest that the term ‘MaaS’ is often used as shorthand to describe MaaS Providers in their analysis, especially considering their role interpretation of MaaS Providers as data aggregators and mobility service providers (Transport Systems Catapult, 2016, p. 15).

Another interpretation of this particular definition of MaaS by Transport Systems Catapult is provided to us in a publication by Foresight and the Government Office for Science in the UK, which considers MaaS as a ‘one-stop online ICT interface’ for intermodal journey planning, ticketing and payment (Foresight & Government Office for Science, 2018, p. 2). In their analysis, the authors envision this interface being one of Digital Service Platforms (DSPs). While it could be argued that these DSPs are in essence MaaS Providers, as described by Transport Systems Catapult, the term ‘provider’ is used interchangeably with ‘operator’ in sections of this document and therefore makes such reasoning unsound. However, it does become clear from this report that both the demand-orientation and customer-focus of MaaS remain unchanged in their interpretation and remain a key characteristic of MaaS initiatives in their view (Foresight & Government Office for Science, 2018, pp. 4–5).

In a report on Londoners’ attitude towards car-ownership and Mobility-as-a-Service by UCL Energy Institute’s MaaS Lab describes MaaS as a model covering several (mobility) concepts (Kamargianni et al., 2018, p. 3). While the report highlights several interpretations of MaaS, their main interpretation of MaaS states that the mobility concept should be implemented as a single integrated platform through which the interconnected services of co-operating mobility operators provide seamless, sustainable and personalised transport services (Kamargianni et al., 2018, pp. 3, 10–11). Furthermore, while public transport is the backbone in their definition of MaaS (Kamargianni et al., 2018, p. 5), taxis, shared bikes/cars and other modalities are also considered (Kamargianni et al., 2018, p. 38). In addition to conceptual insights, this report also provides insight into key concerns of potential MaaS users, such as exceeding the limits of their mobility subscription packages, through user research statistics (Kamargianni et al., 2018, p. 29).

The Urban Transportation Group based their definition of MaaS on those of other organisations. They specifically state that the MaaS concept should be defined as it was originally presented by MaaS Global and Hietanen (2014). As such, their vision for MaaS is based of its service component: to offer personalised mobility subscription services, facilitating ticketing, payments and journey planning (Urban Transport Group, 2019, p. 6). Similar to Kamargianni (2018), these mobility services ought to be implemented by means of a single platform (Urban Transport Group, 2019, p. 6). Other characteristics of MaaS solutions listed in this publication include: insight into mobility behaviour; demand-orientation; customer-focus; real-time and accurate mobility information; social factors (i.e. public health; social inclusion; air quality; congestion; carbon emissions); ticketing innovations; cost reduction; and a reduction of private car ownership (Urban Transport Group, 2019, p. 7).

While the reduction of car ownership is also the premise of Goodall et al. (2017), their analysis explicitly describes the emergence of MaaS as "[…] a natural evolution of two key trends" (Goodall et al., 2017, p. 115). Specifically, resolving infrastructure congestion and the emergence of mobility sharing schemes are pointed to as the key trends leading to the 'need' for MaaS (Goodall et al., 2017, p. 116). As such, their conceptualisation of MaaS shows a strong focus on the efficiency of the transport system, attributing descriptive characteristics such as 'fast', 'seamless', 'real-time', 'integrated', 'accessible' (Goodall et al., 2017). In addition, the whitepaper denotes the importance of both matching supply and demand (Goodall et al., 2017, p. 121) as well as public-private partnerships (Goodall et al., 2017, p. 127). Whilst payment and ticketing options included in their analysis are limited to the pay-as-you-go and subscription schemes, the authors consider ticketless travel a key component of MaaS (Goodall et al., 2017, p. 120).

In the whitepaper by Van Audenhove et al., MaaS is described as an element of 'Mobility 4.0' driven by 'the 4th industrial revolution' (Van Audenhove et al., 2018, p. 10). Ergo, their definition of MaaS is built from the perspective of digitalisation, highlighting ecosystem integration through mobility platforms providing "[…] integrated, flexible, efficient and user-oriented mobility services" by "[…] combining transportation services from public- and private transportation providers" (Van Audenhove et al., 2018, p. 59). Other characteristics essential to their view of MaaS are the need for integrated planning and payment services, a focus on real-time network optimisation and the goal to reduce car-ownership (Van Audenhove et al., 2018, p. 59). Additionally, they stress that data sharing and availability is imperative to the deployment of MaaS solutions (2018, p. 59).

Alternatively, rather than describing MaaS in terms of a specific set of service components, it can also be defined more broadly. Specifically, Falconer et al. (2018, p. 11) consider MaaS as "[…] both a physical service provision and a medium for accessing this service.". In their view, MaaS constitutes not only an ecosystem consisting of various mobility components, but instead refers to the physical and digital mobility services. While their terminology and conceptualisation could therefore be considered somewhat confusing to someone unfamiliar with the subject, their view on MaaS still encompasses the usual suspects in the domain: multimodality; service-orientation; focus on last-mile solutions. In addition, in an interview conducted with MaaS stakeholders, they found that MaaS is often considered as a single platform that provides both integrated planning and payment solutions, with a focus on cost savings for all parties (Falconer et al., 2018, p. 47).

This perspective, i.e. where integrated planning and payment form the backbone of MaaS solutions, is shared by CUBIC Transportation Systems, as their definition of MaaS – as stated in their 2018 analysis of the public transport domain – is described as follows: "Mobility as a Service is a combination of public and private transportation services within a given regional environment that provides holistic, optimal and people-centred travel options, to enable end-to-end journeys paid for by the user as a single charge, and which aims to achieve key public equity objectives." (CUBIC Transportation Systems, 2018, p. 6). The report furthermore notes that this interpretation of MaaS is one of many, even pointing out that the lack of a uniform interpretation of MaaS and its immediate context is derailing innovations in the transportation and public transit industries.

Interpretations of MaaS have also been found to deviate based on the stakeholder role within the ecosystem. In a study by Falconer et al. (2018), four MaaS stakeholders (i.e. academia, vendors, platform providers and government/ transit authorities) were consulted on their interpretation of MaaS. While common characteristics were found between some of the stakeholders, those being 'single platform' and 'integrated planning/ payment', other characteristics such as 'demand-orientation', 'multimodality' and 'personalisation' were not shared (Falconer et al., 2018, p. 47).

### 5.2.2 *Synthesis of MaaS Characteristics in Industry and Government*

While it could be argued, based on the breadth of non-academic MaaS conceptualisations seen in Section 5.2.1, that MaaS in industry and government is considered to be a 'catch-all' solution for mobility bottlenecks and other problems encountered in the transport sector, such a statement only remains valid when one doesn't consider the functionally-centric views presented in whitepapers such as Goodall et al. (2017) and Van Audenhove et al. (2018). Even then, the conceptualisations of MaaS have also been found to be dependent on stakeholders' roles within the ecosystem, as seen in Falconer et al. (2018). Instead, the various MaaS conceptualisations encountered in both industry and government publications related to the topic (Table 5) can be generalised as falling into either one of the following two categories:

- **MaaS as a broad and societal vision**: often considered as a 'catch-all' for mobility, public transit, policy, and infrastructure problems (e.g. congestion, environmental, policy fit, inclusivity);
- **MaaS as a mobility service platform**: providing a variety of mobility services for people (and sometimes goods) by means of a 'one-stop shop', i.e. integrating routing and payment services for the purposes of multi-modal transportation;

Regardless of which category any MaaS conceptualisation in government and industry falls within, their external motivators show great overlap. External factors often mentioned in the analysed whitepapers are environmental impact, affordability, and accessibility of personal transportation. In addition, both interpretations of MaaS build on the concepts of demand-orientation, multimodality, personalisation, and the integration of transportation data sources as well as routing, ticketing, and payment services. Not surprising, considering that most industry or government papers at the very least refer to the publication by Hietanen (2014). Furthermore, most publications considered in this review refer to the necessity of public-private partnerships for MaaS success, often stressing the importance of existing public transit infrastructure.

**TABLE 5: MAAS CONCEPT CHARACTERISTICS IN INDUSTRY AND GOVERNMENT**

| | |
|---|---|
| **MaaS Characteristics** | MaaS, in essence, is envisioned as the integrated offering of multi-modal transportation (e.g. modality choice and combined modality). |
| | Public-private partnerships (e.g. between public transit and private transportation companies) are central to any kind of MaaS solution. |
| | MaaS is inherently demand-orientated and focused on network and/ or spatial efficiency, regardless whether it is interpreted as a vision or a platform. |
| | Customer segmentation and personalisation through various parameters (e.g. comfort, convenience/ ease-of-use, dynamic pricing, and flexibility) are deemed as important focus areas for industry MaaS solutions. |
| | Reduction of the environmental impact resulting from personal mobility and other policy goals (e.g. speed, accessibility, affordability, reliability, and inclusivity) are often indicated as success metrics for MaaS. |
| | Integration in MaaS often exceeds the concept of integrated mobility, as it also requires addresses planning, ticketing, booking and payment services. |
| | Government policy on MaaS is primarily data-centric and includes references to, or requirements for, data sharing schemes between participating organisations. |

## 5.3 Conceptualising Mobility-as-a-Service

Building on the results presented in Sections 5.1.2 and 5.2.2 – respectively addressing the characteristics of MaaS as discussed in academic and industry/ government publications –, this section incorporates the obtained knowledge in the endeavour to derive a comprehensive and holistic conceptualisation of MaaS. As such, this section directly addresses the second research question as presented in Section 3.4.

### 5.3.1 *Overlap Analysis*

Based on initial readings of relevant literature, it was believed that deriving a uniform and formal definition of MaaS would be a challenging endeavour, however this turned out not to be the case. This is mostly the effect of MaaS conceptualisations used in most publications being derived from either Hietanen (2014) or Jittrapirom et al. (2017), with the latter reference not only being more prominent in academic materials, but also referring to the former. This results in publications often including MaaS characteristics such as multimodality, integration of public and private transportation assets and services, innovative ticketing and payment methods (e.g. mobility packages/ smart cards) and a focus on personalisation and ease-of-use (e.g. single customer interface), all of which are characteristic to the definition presented by Hietanen (2014).

While a disparity was found in industry and government literature with regards to whether MaaS conceptualisations ought to have a broad and societal focus, or whether it should refer to an evolution of the Mobility Service Platform concept, the majority of MaaS studies followed the same reasoning. Therefore, the following is believed to be comprehensive definition and conceptualisation of Mobility-as-a-Service, representing both academic and grey literature:

> *MaaS is an evolution of the traditional transport system, either conceptualised as a physical artefact or a vision, which should ultimately benefit society by improving the efficiency of the transport network, and optionally meet certain policy goals with respect to social welfare and the environment.*

Not only does this MaaS conceptualisation arguably represent the MaaS vision outlined in Hietanen (2014) and derived studies, it also encapsulates the MaaS characteristics defined in Jittrapirom et al. (2017) and derived studies. This definition can also be used to divide the MaaS ecosystem into three categories:

- Enablers
- Attributes
- Goals

By means of identifying the conceptual relationships between the listed characteristics in associated literature, it was possible to construct a conceptual framework of the entire ecosystem and its associated research fields: the MaaS Conceptual Framework (MCF) (Figure 2).

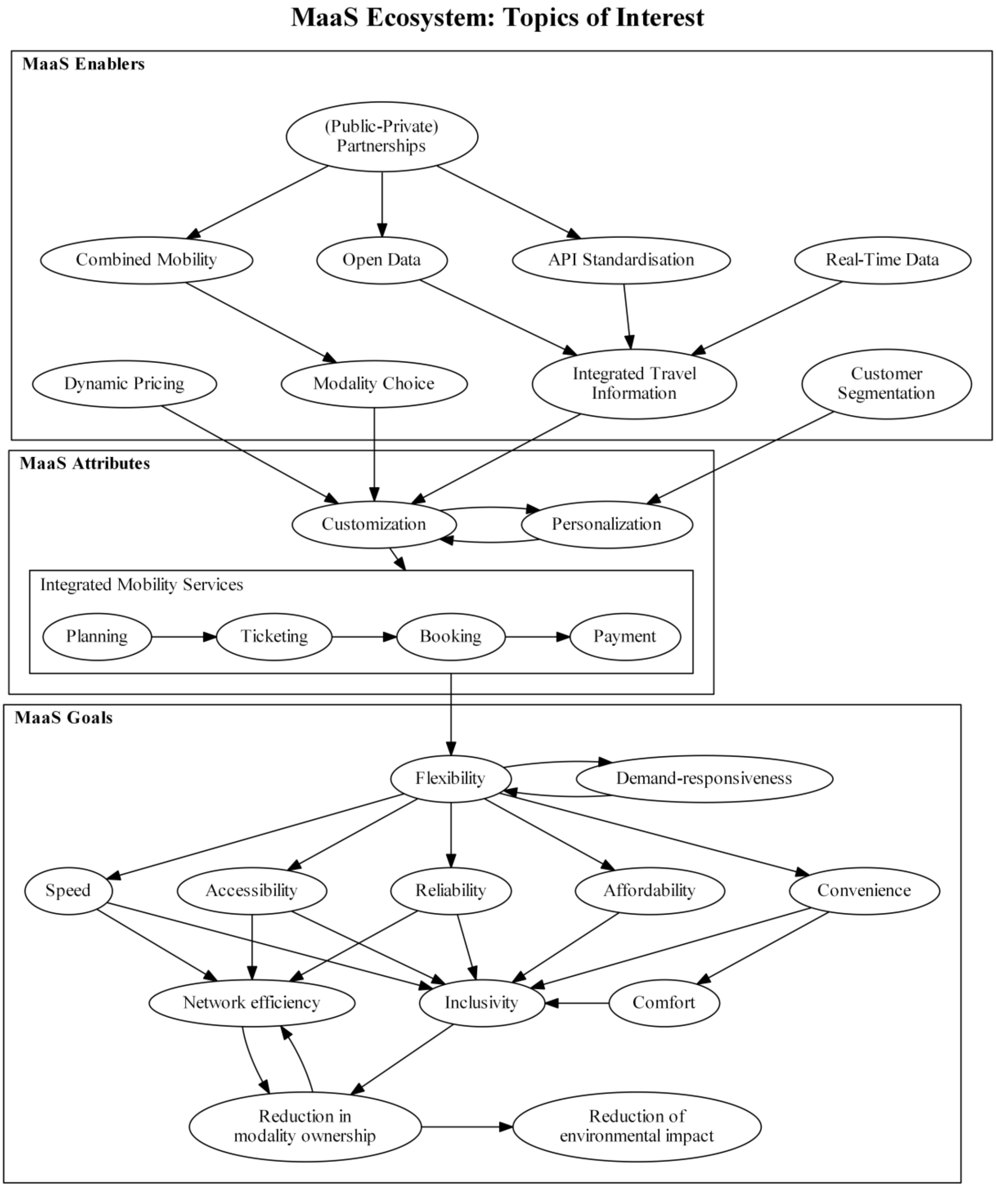


**FIGURE 2: MAAS CONCEPTUAL FRAMEWORK: RELATIONS BETWEEN IDENTIFIED MAAS CONCEPTS DIVIDED INTO ENABLERS, ATTRIBUTES AND GOALS**

A few explanatory notes with respect to this MaaS Conceptual Framework (Figure 2):

- Only concepts and relations found in the analysed literature are included. Those not represented can be used to expand the conceptual map.
- The concept of policy-fit within MaaS was often highlighted as an important characteristic of MaaS, as it allows for measuring its effectiveness in meeting key societal goals. While the concept of policy-fit is not represented directly in the conceptual map, it is understood as the degree to which (some of) the listed goals, as desired by society, are met by the core MaaS artefact and its associated attributes.
- The conceptual map attempts to avoid mentioning specific technical implementations of the associated characteristic. For example, whilst the MaaS enabler 'Customer Segmentation' is represented, specific methods to perform customer segmentation, including machine learning and surveys, are left out for the purpose of simplification.
- As part of the MaaS attributes, concepts such as planning, ticketing, booking and payment have been aggregated into a cluster titled 'Integrated Mobility Services'. This decision was made as these concepts were often discussed together in the analysed papers and are to some extent inter-dependent. In addition, these mobility service concepts were often already described in an integrated manner, specifically in the form of either MSPs or MMPs.
- The concept of '(Public-Private) Partnerships' only has relationships with 'MaaS enabling' concepts that were found to be highly dependent on collaboration between organisations. For instance, while 'Real-Time Data' as well as 'API Standardisation' projects often require an outside organisation responsible for the technical implementation of said project, it is only the latter which is in itself dependent on inter-organisational agreement on what constitutes a 'Standardised API' and what does not.
- Various concepts were named differently in the analysed publications. The included terms are those most accurately describing the concept as defined by the majority of the publications. For example, '(Dynamic) Pricing' can also be understood as 'Tariff options' (Jittrapirom et al., 2017), however can also include references to payment options. As this is a reference to another concept in the conceptual framework (i.e. 'Payment'), the concept describing dynamic changes in pricing for journey segments is hence described as '(Dynamic) Pricing'.
- Three bi-directional relationships were included: customisation ←→ personalisation; flexibility ←→ demand-responsiveness; network efficiency ←→ reduction in modality ownership. Whilst there might exist other relevant bi-directional relationships between concepts – a potential indirect bi-directional relationship between flexibility and network efficiency comes to mind –, only those bi-directional relationships found to be substantially re-enforcing were included. Specifically, the notion that more customisation leads to a higher degree of personalisation, and vice-versa was found to be a stronger re-enforcing relationship compared with, for example, network efficiency and flexibility.
- Whilst the reduction of environmental impact was mentioned as a policy goal in various studies across all types of literature, a relationship between itself and concepts such as 'Comfort' was intentionally avoided. The reasoning here is that the directional nature of the concept itself, i.e. the reduction rather than the increase of environmental impact, would suggest that the associated out-relationship is of the same nature. As not the measured environmental impact, but rather its perception is of relevance to traveller values, a direct relationship between these was omitted.

### 5.3.2 *Deriving a Definition for MaaS*

Based on the results presented in Section 5.3.1, this section presents various statements on the formal definition of MaaS. As it stands, it remains unclear whether MaaS should be referred to as either a digital product (i.e. MSP or MMP) or as the vision for the future of personal transport as outlined in Hietanen (2014). Regardless, some arguments can be made in support of the latter.

First, when considering the terminology used in the Software-as-a-Service (SaaS) domain, it can be argued that one does not refer to a single instance of a program as SaaS, but rather the vision under which it operates. Second, the aggregation of mobility services in a platform has already been defined in literature as an MSP. As such, unless MaaS specifically refers to the extent to which customisation and personalisation is possible in MSPs, its definition would see substantial overlap and therefore provide little added value. Third, publications on MaaS often consider various aspects of the concept that are inherently different – combined mobility (i.e. MaaS enabler) is often mentioned alongside journey customisation (i.e. MaaS attribute) – and are thus measured according to different metrics. For example, the degree to which policy goals are met is a more subjective analysis compared to the degree of customisation, which can be found by aggregating the rational number of dimensions by which the traveller can customise their journey. As such, it can be argued that MaaS itself, as generically referred to in all types of literature, should refer to the entire ecosystem of the associated MaaS concept.

Therefore, it is recommended that research studies should henceforth make note the difference between MaaS enablers, attribute, and goals, and treat them as separate conceptual categories when discussing MaaS concepts and entities. With respect to the conceptualisation of MaaS itself, this study finds that it should refer to the entire ecosystem of MaaS concepts, using the previously-mentioned three conceptual categories as its primary reference framework. Rather than using the already convoluted term of ‘MaaS’, this study proposes referring to the research construct of MaaS studies as the MaaS Artefact, provided that the study’s primary focus is the analysis of the MaaS ecosystem’s core attributes.

In the following paragraphs, a comprehensive taxonomy supported by literature is presented for each of the previously-discussed MaaS-related concepts and other associated terms.

**MOBILITY-AS-A-SERVICE (MAAS)**

Rather than there being consensus on the definition of Mobility-as-a-Service, the only consensus within the concept’s domain for both academia, industry and government alike is that there is no single method of conceptualising MaaS (CUBIC Transportation Systems, 2018, p. 6; Polis, 2017, p. 4). Whilst its original definition by Hietanen (2014) is often used in grey literature to describe the concept, a more recent study by Jittrapirom et al. (2017, p. 16) reduced the MaaS concept to nine characteristics. Whilst these nine characteristics could be used to construct any MaaS artefact, this research has shown that the diversity of MaaS conceptualisations prevents any such artefact to be considered representative of the research topic, as it was found that MaaS is often referred to as either a broad and societal vision on mobility, or as the evolution of MSPs.

Due to the incompatibility between these definitions, it is proposed that a distinction should be made between the MaaS ecosystem and its artefacts on the basis of classifying its associated characteristics as either MaaS enablers, attributes, or goals. These characteristics were then modelled in the MaaS Conceptual Framework (Figure 2), providing a comprehensive overview of the MaaS ecosystem, whilst additionally defining the MaaS artefact as the developed mobility service platform implementing the set of MaaS concepts classified as MaaS attributes.

### MAAS ARTEFACT

The MaaS artefact is defined as the MSP implementing concepts classified as MaaS attributes. By default, this includes any characteristics implemented by MSPs found in literature, such as 'planning', 'ticketing', 'booking' and 'payment'. In addition to implementing these traditional MSP concepts, the MaaS artefact is primarily characterised by the incorporation of 'Customisation' and 'Personalisation' concepts, often found to be key to MaaS conceptualisation in both academic (Beutel et al., 2018; Cottrill, 2019; Jittrapirom et al., 2017) and industry literature (Nederlandse Spoorwegen, 2019b; Polis, 2017; Transport Systems Catapult, 2016; Urban Transport Group, 2019). Furthermore, within the context of the MaaS Conceptual Framework, the MaaS artefact is served by concepts such as Integrated Travel Information, Modality Choice, Dynamic Pricing and Customer Segmentation, whereas itself represents the means by which MaaS goals are attained.

### CUSTOMISATION

Consulted literature provides two clear and distinct definitions for the act of customisation. Either, the method by which the journey experience is customised is centred around the customisation of a person's itinerary by means of altering involved modalities and/ or route (e.g. Jittrapirom et al., 2017; Willing et al., 2017; Wong et al., 2019), or on the basis of personal information (Jonietz & Bucher, 2018; Turetken et al., 2019; Xie et al., 2019).

As the latter interpretation of customisation closely resembles the concept of personalisation, this study considers customisation by means of personal information to fall within the concept of 'Personalisation'. Conversely, customisation is therefore understood as modifying the journey experience by means other than those making use of personal information.

### PERSONALISATION

From a high-level perspective, the act of personalisation can be defined as customisation of the journey experience by means of personal information. However, there exist multiple methods by which personalisation can be achieved. The seemingly most common method of personalisation encountered in literature is that of 'Customer Segmentation' (Giesecke et al., 2016; Kamargianni et al., 2018; Lugano et al., 2019; Yeboah et al., 2019), which itself can also be considered separate from personalisation or outside the MaaS Conceptual Framework.

Another method used for the purposes of customisation by means of personal information is already prevalent in the IT services industry: machine learning (e.g. Franzen et al., 2019; Lugano et al., 2019; Willing et al., 2017). Whilst machine learning is in essence no different from customer segmentation – and is therefore not included as a separate concept in the MaaS Conceptual Framework –, its automated nature does allow for efficient scaling of personalised mobility services. In this study, 'Personalisation' is simply understood as the product of 'Customer Segmentation', regardless of the applied customer segmentation method.

### MULTIMODAL MOBILITY PLATFORM

Multimodal Mobility Platforms (MMPs) are understood as one type of Mobility Service Platform, specifically integrating 'Combined Mobility' and 'Customisation' concepts in addition to core MSP concepts (Willing et al., 2017).

**MOBILITY SERVICE PLATFORM**

The primary component of the MaaS Artefact is the Mobility Service Platform, which includes four Integrated Mobility Services (ITS): 'Planning'; 'Ticketing'; 'Booking'; and 'Payment'. These four mobility services serve as the backbone for integrated mobility offerings, providing seamless and customisable mobility across the modality spectrum (Beutel et al., 2019).

*1. PLANNING*

Within the scope of Mobility Service Platforms, journey planning is understood as part of the trip context (Yeboah et al., 2019). In addition, within MaaS, journey planning is inherently multimodal (Esztergár-Kiss & Kerényi, 2019b; Willing et al., 2017) and provides travellers with mode choice (Willing et al., 2017). Within the scope of this study, the concept of 'Planning' is considered as a MaaS Attribute, incorporating both the aforementioned multimodality and mode choice aspects.

*2. TICKETING*

Ticketing is considered as the first step in the process by which physical or digital evidence of allowed access to a certain modality for a given time and location is completed. In this step, the details of the ticket (e.g. time, location, modality, class and fare) are selected (Beutel et al., 2018; Esztergár-Kiss & Kerényi, 2019b).

*3. BOOKING*

Booking is understood to be the second step in the process by which evidence for admittance to modalities is generated. It follows the ticketing process and confirms ticket booking (i.e. reserving modality use), rather than its specification (Beutel et al., 2018; Esztergár-Kiss & Kerényi, 2019b).

*4. PAYMENT*

Payment is the third and final step in the process by which evidence for admittance to modalities is generated. In key papers on MaaS, payment is often described in a subscription-centric manner: offering access to certain modes of transport on the basis of predefined mobility packages (Beutel et al., 2019; Esztergár-Kiss & Kerényi, 2019b; Hietanen, 2014; Jittrapirom et al., 2017). In addition to these mobility packages, smart cards and pay-as-you-go schemes are often described as inferior alternatives and precursors to subscription-based mobility packages (Esztergár-Kiss & Kerényi, 2019b). Interestingly, practices by public transport operators such as NS[11] and RET[12] show that these mobility packages can co-exist with prepaid and pay-as-you-go options, all of which are supported by smart card technology[13].

While there exist privacy concerns for both the subscription requirement for mobility packages as well as smart card use (Cottrill, 2019), both can be used to complement each other in order to provide MSP customers with method choice. As user choice with respect to payment methods is believed to potentially have an influence on privacy impact, this research considers the concept of 'Payment' to include all aforementioned payment options.

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[11] NS is a Dutch rail operator that has shown interest to offer multimodal mobility through programmes such as OV-Fiets, a subscription-based bike rental service. Source: https://www.ns.nl/en/door-to-door

[12] RET is the main PT operator in Rotterdam (Netherlands) and a number of its surrounding municipalities. Mobility is provided by bus, tram, metro, and ferries. Source: https://corporate.ret.nl/over-ret/organisatie

[13] The Dutch mobility smart card (i.e. OV-Chipkaart) provides travelers with the option to either use an anonymous smart card, which is limited to prepaid credit, or a personal smart card, which can be used in combination with both pay-as-you-go schemes and predefined mobility packages for multiple modes of transport. Source: https://www.ov-chipkaart.nl/everything-about-travelling/how-does-travelling-work-1.htm

## 5.4 Current State of MaaS Research

Based on the definition for MaaS provided in Section 5.3.2, it is possible to assess the current state and overall focus of the MaaS research field by mapping the papers selected for the Systematic Mapping Study (SMS) to the MaaS Conceptual Framework on the basis of their research focus and discussed concepts[14] (Table 6; Table 7). Not only can this mapping provide insight into researchers' perspective on MaaS, but it is also useful to identify research gaps in the MaaS research field. While the extent to which this mapping can be used to identify research gaps is limited due to not providing any indication to what degree concepts are discussed in the referenced publications, it provides a coarse-grained overview for future analysis.

## 5.5 Identified Research Gaps

At first glance, the mapping study (Section 5.4) appears to suggest that the reduction of environmental impact has been the main focus of MaaS research papers. Conversely, other aspects of MaaS (e.g. Open Data, API standardisation and dynamic pricing) seem to be discussed less frequently. However, as the coarse-grained nature of this mapping prevents its results from being used to directly infer research gaps with high confidence, the mapping study does not reflect the knowledge and research gaps in the associated fields. Instead, it was found that while MaaS research areas such as personalisation was discussed a total of 12 times, it was often discussed from a perspective of customer segmentation rather than one where its relationship with customisation options is explored. This holds true for many of the concepts included in the MaaS Conceptual Mapping. Notable examples include:

- Real-time tracking of PT assets results in high-value data sets that can be used in integrated travel information for the purposes of customisation. While several studies have looked into using tracking data of travel agents for the purposes of improving overall network efficiency, only few papers discuss its potential in the realm of personalisation through automated customer segmentation.
- Modality choice is frequently discussed in relation to the concepts of planning (i.e. itinerary customisation) and ticketing/payment (i.e. customisation of mobility packages), often in conjuncture with a high level of integrated travel information system involvement. However, due to the near endless stream of PT data, there remain a large number of research opportunities in the field of integrated travel information, such as:
    - automated customisation of trips on the basis of integrating demand-specific data sets, such as those generated by people-counting solutions in mobility hubs
    - longitudinal studies assessing MaaS pilots on the effectiveness of using centralised or decentralised travel information platforms
    - exploring the (customisation) potential of integrating non-PT (Open) Data with existing integrated travel information
- With respect to the personalisation aspects of customisation, while both have received ample interest from researchers, the effects of recently enforced personal data protection laws have resulted in an immediate need to explore the privacy aspects of integrated mobility services as well as customer segmentation practices.

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[14] Materials are not marked as 'discussing the concept' when one-off references are made to a concept. Whilst this does introduce a certain degree of subjectivity into the process of marking these publications, it is believed that marking a publication on the basis of one-off references would result in a convoluted and unnecessary complex data set, which itself would yield considerably less valuable results.

#### TABLE 6: MAAS PAPERS MAPPED TO THE MCF BASED ON DISCUSSED CONCEPTS

| | **MaaS Enablers** | | | | | | | | | **MaaS Attributes** | | | | | | **MaaS Goals** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Mobility Services | | | | | | | | | | | | | | | |
| | (Public-Private) Partnerships | Combined Mobility | Open Data | API Standardisation | Real-Time Data | (Dynamic) Pricing | Modality Choice | Integrated Travel Information | Customer Segmentation | Customisation | Personalisation | Planning | Ticketing | Booking | Payment | Flexibility | Demand-responsiveness | Speed | Accessibility | Reliability | Affordability | Convenience | Network efficiency | Inclusivity | Comfort | Reduction in modality ownership | Reduction of environmental impact |
| (Abotalebi et al., 2018) | | | | | | | | | X | | | | | | | | | | | | X | X | | | X | | X |
| (Acheampong & Siiba, 2019) | | X | | | | | X | | X | | | | | | | | | X | | | X | X | | | X | X | X |
| (Beutel et al., 2019) | | X | X | X | X | | X | X | | | | X | X | X | X | X | | | | | | | | | | | |
| (Beutel et al., 2018) | X | X | | | X | X | X | X | | X | | X | X | X | X | X | X | X | | | X | | X | | | | |
| (Bibri, 2019) | X | X | X | | X | | X | X | | X | | | | | | X | X | X | X | X | X | | X | X | | | X |
| (Chandrasekaran et al., 2017) | | | | | X | | | | | | | | | | | | X | | | | | | X | | | | |
| (Cottrill, 2019) | X | X | X | | X | | X | X | | X | X | X | X | X | X | X | | | | | X | X | X | | | X | X |
| (Esztergár-Kiss & Kerényi, 2019a) | | X | | | | X | X | | X | X | | | | | X | X | | X | | X | X | X | | | | | X |
| (Finger & Razaghi, 2017) | X | X | X | X | | X | | X | | | | | | | | | | | | | | | X | | | | X |
| (Franzen et al., 2019) | | | | | | | | | | | | | | | | X | | | | X | | | X | | | | |
| (Galatoulas et al., 2017) | | | | | | | | | X | | | | | | | X | | X | X | | X | | X | X | | | X |
| (Grieger & Ludwig, 2019) | | | | | X | | | X | | | | | | | | | X | X | | | | X | | | X | | X |
| (Jittrapirom et al., 2017) | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | | X | X |
| (Jonietz & Bucher, 2018) | | X | | | X | | | | X | | X | | | | | | | X | | | | | | | | | X |
| (Kováčiková et al., 2018) | | X | | | | | X | | X | X | X | | | | | X | | X | | X | X | X | | | X | | X |

#### TABLE 7: MAAS PAPERS MAPPED TO THE MCF BASED ON DISCUSSED CONCEPTS (CONTINUED)

| | **MaaS Enablers** | | | | | | | | | **MaaS Attributes** | | | | | | | **MaaS Goals** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Mobility Services | | | | | | | | | | | | | | | |
| | (Public-Private) Partnerships | Combined Mobility | Open Data | API Standardisation | Real-Time Data | (Dynamic) Pricing | Modality Choice | Integrated Travel Information | Customer Segmentation | Customisation | Personalisation | Planning | Ticketing | Booking | Payment | Flexibility | Demand-responsiveness | Speed | Accessibility | Reliability | Affordability | Convenience | Network efficiency | Inclusivity | Comfort | Reduction in modality ownership | Reduction of environmental impact |
| (Lamberth-Cocca & Meiren, 2017) | X | X | | | | | X | | X | X | X | | | | | X | X | | X | | | X | | | X | | |
| (Lugano et al., 2019) | | X | | | X | | X | X | X | X | X | X | | | | X | | X | X | X | X | X | X | | X | | X |
| (Mukhtar-Landgren & Smith, 2019) | X | X | X | X | X | | X | X | | X | X | | X | | | X | X | | X | X | X | | X | X | | | X |
| (Pangbourne et al., 2019) | X | X | | X | X | | X | X | | X | | | X | X | X | X | X | | X | | X | X | X | X | | X | X |
| (Pichler et al., 2019) | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| (Sakai, 2019) | X | X | X | X | | | X | X | | X | | X | X | X | X | X | | | | | | X | X | X | | X | X |
| (Sweet & Laidlaw, 2019) | | | | | | | | | | | | | | | | X | X | | | X | X | X | | X | X | X | X |
| (Tura et al., 2018) | X | X | | X | X | | | X | | | | X | X | | | | X | | | | | | X | X | | | X |
| (Turetken et al., 2019) | X | X | | | X | | X | X | X | | X | | | | | X | X | X | | X | | | X | | X | X | X |
| (Willing et al., 2017) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | X | X | | X | X | X |
| (Wong et al., 2019) | X | X | | | | X | X | X | | X | X | | X | | | X | X | | X | | X | | X | X | X | X | X |
| (Xie et al., 2019) | | X | | | X | | X | X | X | | X | X | X | X | X | X | X | X | | | | X | X | | | | X |
| (Yeboah et al., 2019) | | | | | X | | | X | X | X | X | X | | | X | | | | X | X | | | | | | | |

In addition to these research gaps related to the specific concepts included in the MaaS Conceptual Mapping, key sources also cite different challenges with respect to MaaS. Specifically, the Urban Transport Group (2019, p. 10) lists making a commercial return while providing travellers with MaaS packages that cover their transportation needs at all times. They furthermore denote that MaaS is at risk of becoming too focused on high-income urbanised areas, perhaps excluding other segments of society.

Furthermore, Jittrapirom et al. (2017, pp. 19–21) mention three types of challenges for MaaS: Demand-Side Modelling; Supply-Side Modelling; and Governance and Business Model to Match Supply and Demand. Specifically, the challenges with regards to value creation and the network effect (of mobility platforms) are highlighted (Jittrapirom et al., 2017, p. 21). In a paper by Beutel et al. (2019, p. 155), the need for interdisciplinary cooperation during the development of MaaS solutions is put forward as an important challenge for the development of the concept.

With regards to data concepts related to MaaS, Yeboah et al. (2019, p. 155) recommend focused research on the differences between on-demand and real-time public transit information as well as the different engagement mechanics for smartphone-based travel information searches. In addition, the Urban Transport Group cites a range of MaaS ecosystem challenges identified by the MaaS Alliance, including several data-related challenges, which include: poor quality or incomplete data; a lack of data standardisation; a lack of interoperability by design; a lack of data portability; and a lack of economic incentives (MaaS Alliance, 2018a).

On the topic of governance, Pangbourne et al. (2019, p. 13) recommend further studying the relations between the public and the private sector on MaaS development, including the rhetoric used to describe the concept, its financing as well as its strategic value for both stakeholders. They furthermore state that research into understanding user behaviours should be conducted to better tailor mobility packages. Wong et al. (2019, p. 13) also highlights the relationship between private and public actors, including their respective roles in the ecosystem, as a key research opportunity, amongst other topics such competition and the creation of a level playing field.

With respect to the demand-orientation of MaaS, Lugano et al. (2019, p. 443) specify that future research should elaborate on the concept of Time Horizons[15], specifically with regards to the means by which this concept can be incorporated in dynamic demand-prediction algorithms. In order to comprehensively understand the concept of predictability, Cuttone et al. (2018, p. 14) suggest to study the concept's likely relation with mobility patterns and traveller demographics.

[15] "Time Horizons describe fixed future periods defined by the time where the real demand may be realised" (Lugano et al., 2019, p. 443)

# 6 MAAS SOLUTION ANALYSIS

*In this chapter, the methods presented in Section 4.5 are used to discover features and PDRs for a set of existing MaaS solutions. First, these MaaS solutions are mapped to the MCF, after which their implementation of MaaS Attributes is assessed. Subsequently, a privacy assessment is performed using established methods.*

## 6.1 MCF Mapping of MaaS Solutions

Based on the analysis performed in line with the methods listed in Section 4.5, the selected MaaS solutions were first mapped to the MaaS concepts listed in the MaaS Conceptual Framework on the basis of their implemented features (Table 8).

Whereas MSP-type MaaS concepts (i.e. Planning, Ticketing, Booking and Payment) could easily be identified in these MaaS solutions on the basis of their well-established etymological and (non-)functional definitions, distinguishing features with regards to the concepts of customisation and personalisation was found to be more difficult due to their bi-directional and re-enforcing conceptual relationship. Therefore, these concepts were treated as composite attributes (Figure 3), modelled using first-degree related concepts – not including the MSP-type MaaS concepts or their re-enforcing relationship – from the MaaS Conceptual Framework.

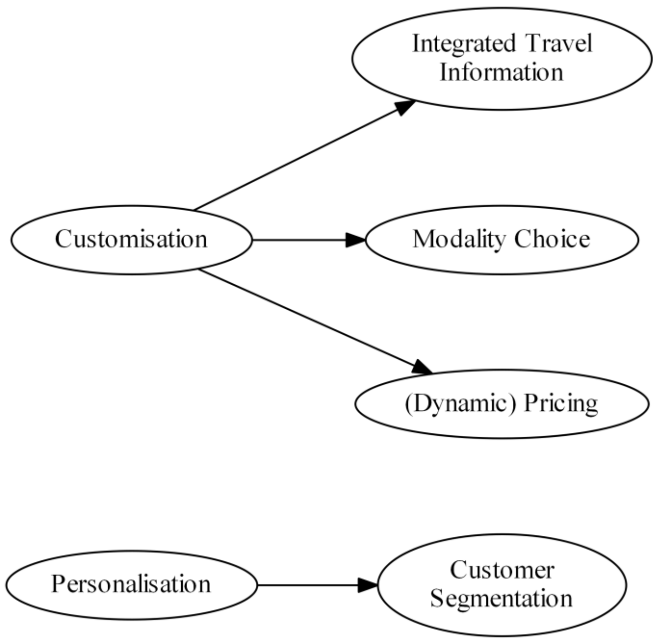


**FIGURE 3: COMPOSITE MAAS ATTRIBUTES**

**TABLE 8: MAPPING BETWEEN MOBILITY SOLUTIONS AND MAAS CHARACTERISTICS LISTED IN THE MCF**

| | MaaS Enablers | | | | | | | | | MaaS Attributes | | | | | | MaaS Goals | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Mobility Services | | | | | | | | | | | | | | | |
| | (Public-Private) Partnerships | Combined Mobility | Open Data[16] | API Standardisation | Real-Time Data | (Dynamic) Pricing | Modality Choice | Integrated Travel Information | Customer Segmentation | Customisation | Personalisation | Planning | Ticketing | Booking | Payment | Flexibility | Demand-responsiveness | Speed | Accessibility | Reliability | Affordability | Convenience | Network efficiency | Inclusivity | Comfort | Reduction in modality ownership | Reduction of environmental impact |
| Google Maps | X | X | | | X | | X | X | X | X | X | X | | | | X | | X | X | X | | X | | X | X | | |
| HERE WeGo | X | X | | | X | | X | X | | X | | X | | | | X | | X | X | X | | X | | X | X | | |
| Moovit | X | X | | | X | | X | X | | X | | X | | | | X | | X | X | X | | X | | X | | | |
| NS Lab | X | X | | X | X | | X | X | | X | | X | X | X | X | X | | X | X | X | | X | | X | X | | |
| Reach Now | X | X | | X | X | X | X | X | | X | | X | X | X | X | X | | X | X | X | X | X | | X | X | X | X |
| TripGo | X | X | | X | X | | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | | X | X | | X |
| Turnn | X | X | | | X | | X | X | | X | | X | X | X | X | X | X | X | X | | X | X | | X | X | X | X |
| Urbi | | X | | | X | | X | X | | X | | X | X | X | X | X | | X | X | | | X | | X | | | |
| Whim | X | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

16 No explicit mentions to “Open Data” were found in the materials, however, this is presumed to be the result of business strategy, i.e. not revealing data sources

### 6.1.1 *Core services*

The results indicate that all MaaS solutions analysed implement the planning concept as listed in the MCF. This is unsurprising, considering that MSP-type MaaS attributes such as ticketing and booking require the presence of the planning concept in these solutions, and that customisation and personalisation concepts can only be included in MaaS solutions in support to functionality offered by implementing these MSP-type concepts.

Additionally, it was found that from of the applications analysed, there is no subset of MaaS solutions that supports one or more, but not all, of either ‘ticketing’, ‘booking’ or ‘payment’ concepts, that does not also include ‘planning’ or any of the other listed MSP-type concepts. To clarify, the subset of applications analysed that integrate either ‘ticketing’, ‘booking’ or ‘payment’ concepts, also integrate all other MSP-type concepts.

It is believed that this can be explained by considering that payment functionality can only exist if a booking has been made for a specific ticket. In other words, the nature of functionality offered by the ‘payment’ concept makes it directly dependent on functionality offered by the ‘booking’ concept, which in turn is dependent in a similar fashion on ‘ticketing’.

As such, whilst functionality can be offered for each tier that came before the last supported tier (Figure 4), it is not feasible nor desirable from a business perspective to offer functionality for a tier that is at least two steps away from the last supported tier. Specifically, the organisation behind a MaaS solution has no reason nor incentive to financially and organisationally support the technical and business support processes of offering payment concept functionality in a scenario where no tickets are being provisioned or itineraries are provided. In fact, such MaaS solutions would not even exist, as they would be classified as third-party payment providers instead, considering that these solutions would only implement payment-specific functionality.

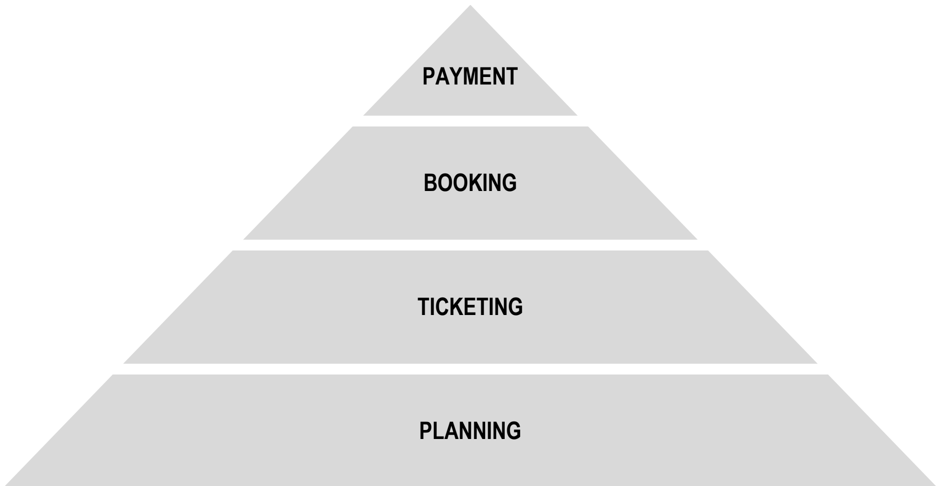


**FIGURE 4: INTERDEPENDENT FUNCTIONALITY TIERS OF MSP ARTEFACTS**

### 6.1.2 *Implemented functionality*

The features implemented in each of the MaaS solutions was aggregated with duplicates subsequently being removed and the abstracted functionality mapped to individual MSP concepts (Table 9; Table 10). Within the context of the implemented functionality, the remaining MaaS attributes (i.e. customisation and personalisation) are addressed in Section 6.1.3.

### 6.1.3 *Customisation and personalisation*

Customisation and personalisation, whilst being separate MaaS attributes, cannot be directly perceived in MaaS solutions. Instead, they are means by which the MSP concepts are brought forward and each MaaS solution is allowed to differentiate themselves. As such, it was found that MaaS solutions often include the option to customise intended journeys on the basis of various internal and external parameters (e.g. available or preferred modalities, service disruptions and weather forecasts), however, lacked any notable 'personalisation' features beyond saving predefined locations and modality preferences.

Moreover, the difficulty in this analysis was to identify what constitutes a 'personalisation' feature. Whereas one could argue that saving a user's favourite locations could be regarded as a personalisation feature, it could also be perceived as the pre-recorded customisation of one's itinerary based on the internal state of the transportation network. The latter reasoning also applies in the case of preferred modalities. Regardless, such customisations cannot exist without the preferences of customers being used in these MaaS solutions. Furthermore, knowing the user's frequently-visited addresses can yield considerable value to data-driven organisations. Not only can this type of data be used in the seamless provisioning of customised itineraries, but it can also be used for targeted marketing, user acquisition or the (re)distribution of mobility assets based on measures or projected demand.

As such, the types of customisation and personalisation within the offered functionality was believed to be divisible between four categories:

- Customer segmentation-based personalisation
    - e.g. utilise customer data and simple data analysis to provide group-wide recommendations based on prior travel patterns
- Non-hierarchical preference-based personalisation
    - e.g. users can select from available modalities or store frequently-used locations
- Hierarchical preference-based personalisation
    - e.g. users can indicate a preference for specific modalities over other modalities to be used in the process of planning itineraries
- Contextual or sensory-based personalisation
    - e.g. real-time tracking of both physical and digital (travel) behaviour provides dynamic recommendations based on the context of individual travellers

These types of customisation and personalisation can also be indirectly linked to a perceived privacy impact through the amount of personal information required and the awareness of the customer. Specifically, a non-hierarchical preference-based system cannot be used to derive customer priorities, but only their overall preferences. This systematically and categorically prevents invasive profiling in comparison with the most privacy invasive method of customisation, which requires the real-time tracking of the individual in both physical and digital spaces.

TABLE 9: FEATURES IMPLEMENTED IN MAAS SOLUTIONS ACCORDING TO MAAS ATTRIBUTES

| **MaaS Attribute** | **Functionality offered (user-perspective)** |
|---|---|
| Planning | Select departure and destination locations |
| | Choose favourite or frequently-used locations and/or routes |
| | Compare itineraries on distance travelled, travel duration, carbon dioxide emissions, calories burned, arrival time uncertainty, crowdedness, price |
| | Select modalities to be used |
| | Explore facilities along the route |
| | Change departure time and date |
| | Pricing-derived preferences<br>(e.g. limit modalities or lines used based on subscription allowance and other payment requirements) |
| | Include additional transfer time |
| | Limit to accessible journeys |
| | Limit walking distance |
| | Share real-time location with selected other people during transit |
| | Step-by-step guidance |
| | Text-to-speech (TTS) directions |
| | Offline navigation |
| | Filter or sort itineraries by minimum/ maximum distance, travel duration, carbon dioxide emissions, calories burned, arrival time uncertainty, crowdedness, price |
| | Real-time rerouting in case of (service) disruptions |
| | Real-time departure times of public transit |
| | Add itinerary to personal calendar (calendar export) |
| | View current weather situation for consideration in modality selection |

**TABLE 10: FEATURES IMPLEMENTED IN MAAS SOLUTIONS ACCORDING TO MAAS ATTRIBUTES (CONTINUED)**

| | |
|---|---|
| Ticketing | Select tickets/ time slots for each itinerary segment and/ or modality |
| | Choose single ticket, day return or other similar time- or use-restricted schemes |
| | Apply joint journey discount (i.e. fare reduction based on travel group size) |
| | Compare ticket offers by price between mobility providers/ booking offices |
| | Compare ticket offers by price based on applicable mobility subscriptions |
| | Choose different travel class for public transit tickets |
| | Choose from specific seating options (e.g. window seating or more legroom) |
| | Select tickets based on age group |
| | Select from (third-party) discount offers |
| Booking | Confirm ticket details before checkout |
| | Apply (first-party) discount coupons before checkout |
| | Export and print out tickets on paper (e.g. QR-/ barcodes) |
| | Digitally store tickets (offline) on mobile devices (e.g. QR-/ barcodes) |
| | Choose a tip (percentage) for ride hailing/ taxi drivers |
| | Change between anonymous tickets or person-bound tickets |
| Payment | Pay for single tickets through (third-party) payment providers |
| | Pay through prepaid or pay-as-you-go smart card schemes |
| | Pay through pre-defined mobility subscriptions |
| | Pay using payment terminals in or around individual modalities |
| | Pay using (first-party) direct debit/ credit schemes |

## 6.2 Privacy Assessment of MaaS Solutions

Following the discovery of the offered features by existing MaaS solutions, this section considers the personal data requirements associated with their respective mobile applications. For this, the APPA framework (Wettlaufer & Simo, 2020) was adapted to fit the requirements of this research. As such, the functionality-to-privacy trade-off was replaced by a user survey on functionality and PDR expectations and acceptance-rates. This privacy analysis of mobile applications associated with MaaS solutions therefore considers two metrics originally included in the APPA framework:

- the number of dangerous[17] and total permissions requested
- the readability and comprehensibility of the privacy policies associated expressed by means of the Flesch-Kincaid Grade Level

### 6.2.1 *Permissions requested*

First, the Android Package files (APKs) of the selected MaaS solutions were obtained from the Google Play Store for analysis. These packages were subsequently inspected by means of the APK Analyzer[18] offered as part of the Android Studio software bundle. This allowed for the easy inspection of the AndroidManifest.xml file, which includes references to all of the permissions the operating system is tasked to relay (e.g. request to the user) on behalf of the mobile application. A similar procedure was not feasible within the scope of this research study with regards to iOS applications due to closed platform restrictions.

Accounting for duplicates – supported permissions change as the operating system gets updated over time – and removing any vendor-specific permissions (i.e. those not included as part of the base Android operating system), the total amount of permissions for each application were noted down in addition to the number of permissions classified as “dangerous” (Table 11).

TABLE 11: PERMISSIONS REQUESTED BY MAAS SOLUTIONS

| MaaS Solution | Dangerous | Total |
|---|---|---|
| Google Maps | 10 | 30 |
| HERE WeGo | 3 | 13 |
| Moovit | 8 | 18 |
| NS Lab | 6 | 17 |
| Reach Now | 6 | 18 |
| TripGo | 4 | 10 |
| Turnn | 4 | 12 |
| Urbi | 6 | 15 |
| Whim | 6 | 14 |

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[17] The Android Developer documentation classifies various permissions as “dangerous” on the basis of the level of access that is granted: https://developer.android.com/reference/android/Manifest.permission

[18] More information on APK Analyzer: https://developer.android.com/studio/build/apk-analyzer

### 6.2.2 *Readability and comprehensibility*

To measure the readability and comprehensibility aspects of the privacy policies associated with the mobile applications, the Flesch-Kincaid Grade Level was determined for each of the privacy policies associated with the individual MaaS solutions (Table 12). For MaaS solutions with more than one privacy policy document, or in the case that those documents were distributed, only the lowest and highest determined Flesch-Kincaid Grade Level scores were included.

**TABLE 12: FLESCH-KINCAID GRADE LEVELS FOR PRIVACY POLICIES OF MAAS SOLUTIONS**

| MaaS Solution | Flesch-Kincaid Grade Level |
|---|---|
| Google Maps | 9.4 |
| HERE WeGo | 11 - 11.8 |
| Moovit | 13.2 |
| NS Lab | 7.8 - 8 |
| Reach Now | 8.2 |
| TripGo | 8.3 |
| Turnn | 10.9 |
| Urbi | 9.6 |
| Whim | 10.1 |

Due to the nature of determining the Flesch-Kincaid Grade Level, a lower word count can more easily result in a lower grade level. In this sample, this phenomenon occurs for NS Lab, for which the parent organisation provides a comprehensive well-distributed and high-quality privacy policy for all of its services. Although this does result in a skewed Flesch-Kincaid Grade Level score for NS Lab, the nature of its privacy policy structure makes finding specific data processing activities easier. As such, this approach to providing comprehensive insight is commended and therefore highly encouraged for use by other mobility applications.

In line with this example, other exceptions where the Flesch-Kincaid Grade Level method can fall short is in considering (HTML) layout and formatting of privacy policies and associated descriptive multimedia content. This can be seen in the results with Turnn and Google Maps, respectively. Whereas one could have a proper argument as to what degree the video content available on the webpage describing Google's privacy policy adds substantial value, the method Turnn leveraged to directly map processed personal data with their business processes undeniably yields considerable insight into otherwise obscure data processing practices.

### 6.2.3 *Comparative results analysis*

Overall, the results would seem to show a discrepancy with regards to the readability of privacy policies for mobility solutions and the MaaS concepts addressed. One could assume a possible relation between the number of addressed mobility concepts and their associated implementation requirements, however, there are some discrepancies with regards to this assumption.

First, whilst Google Maps only addresses one of the four MSP concepts incorporated in the MCF, it tops the chart with respect to both the total as well as dangerous amounts of permissions requested to mobile device users (Figure 5). This is above average in comparison with other mobility solutions and therefore indicates a presence of excessive data collection processes that are unnecessary from a comparative perspective with regards to the offered functionality.

Second, considering that all but one of the mobile solutions address all four MSP concepts from the MCF, there should not be a large differentiation between these applications. However, as seen in the results, the number of permissions requested varies between these mobile applications, therefore indicating that various privacy levels with different implementations for each feature associated with an MSP concept must exists.

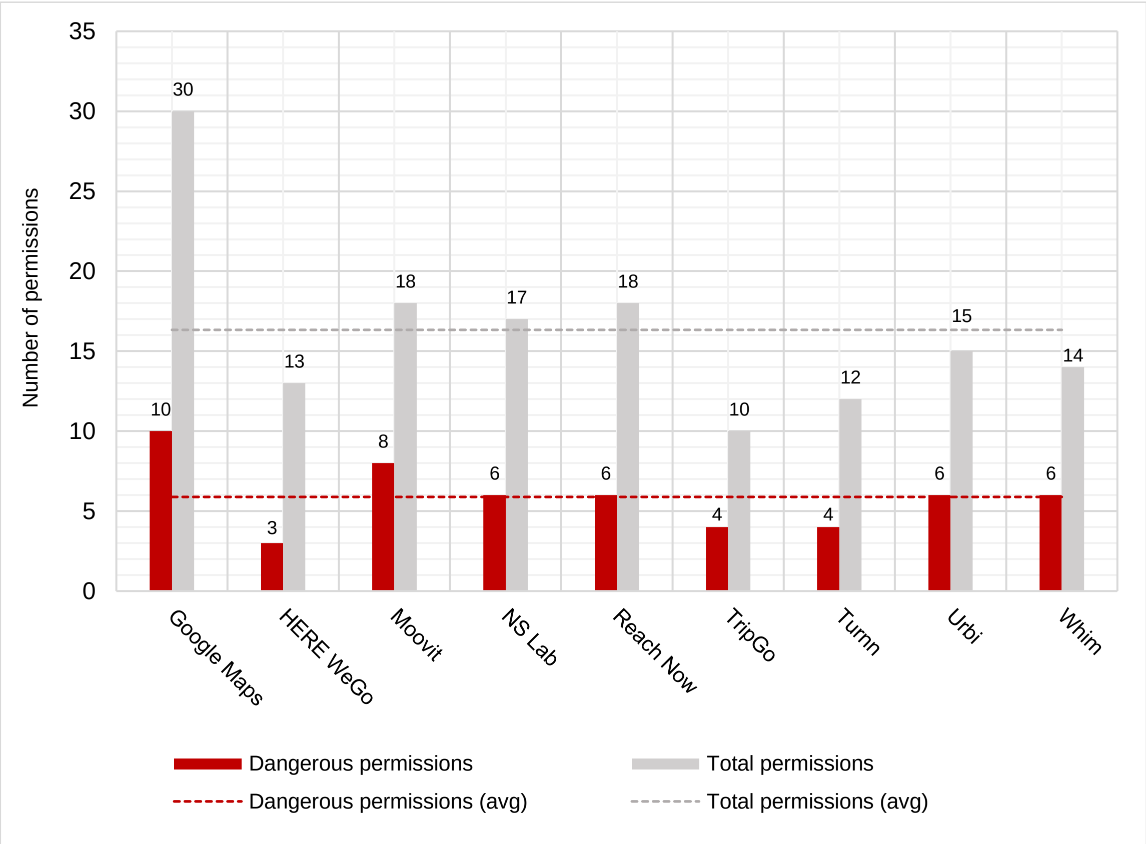


**FIGURE 5: OVERVIEW OF REQUESTED PERMISSIONS FOR EXISTING MAAS SOLUTIONS**

# 7 USER EXPECTATIONS ANALYSIS

*In this chapter, the methods presented in Section 4.6 are used to assess the user sentiment on MaaS capabilities and PDRs associated with existing MaaS solutions. First, descriptive sample results and notable socio-economic findings are discussed in relation to other scientific papers. Subsequently, user expectations with respect to the features offered by existing MaaS solutions are presented according to the MaaS attributes of the MCF, followed by a brief PDR-acceptance rating analysis, for which relevant insights are presented.*

## 7.1 Descriptive Sample Results

A user survey (Appendix C: ) comprised of 23 questions on the design of MaaS solutions was distributed online to an unknown research population. Respondents wishing to participate in the survey had 6 days (i.e. 4 working days and 2 weekend) to submit their contribution. Although a total of 63 respondents opted to partake in this part of the research study, only 62 respondents managed to complete the survey regardless of whether any question was skipped.

From all respondents, 2 respondents indicated that they had never used a mobile application to plan their itinerary for traveling purposes. Additionally, they indicated that they neither intend to use a mobile device for such purposes in the future, nor that it was due to privacy concerns. As their concerns therefore fall outside the scope of this study, they failed to qualify to participate in the later segments of the survey (i.e. expected features and privacy concerns). Consequently, their participation stopped after question 17. Their socio-economic responses remain evaluated. All other participants indicated that they had used a mobile application before to plan a journey.

## 7.2 Notable Socio-Economic and Demographic Results

Based on seven questions with regards to the socio-economic status of participants in this study, the results (Table 13; Table 14) shows that respondents were predominantly more male (66%), younger in age (71%), having obtained a higher degree (62.5%) than other representative samples, such as those presented in Alonso-González et al. (2020). Moreover, the sample of survey respondents presented in this research also works more often (67.7%) and are overwhelmingly more likely to be part of a household that is larger than one person (79%). Alternative answers provided by respondents when asked about their household composition predominantly referred to group accommodation, such as shared housing or college dormitories.

**TABLE 13: SURVEY RESULTS – SOCIO-ECONOMIC AND DEMOGRAPHIC COMPARISON**

| **Socio-economic variable** | **Category** | **Share sample** | **(Alonso-González et al., 2020)** |
|---|---|---|---|
| Net monthly income | No personal income | 19.4% | N.D.<br><br>(no details were provided on this level of detail outside of latent class clusters) |
| | Below €2000,- | 29% | |
| | Between €2000,- and €3000,- | 27.4% | |
| | Above €3000,- | 22.6% | |
| | Unknown | 1.6% | |

TABLE 14: SURVEY RESULTS – SOCIO-ECONOMIC AND DEMOGRAPHIC COMPARISON (CONTINUED)

| Socio-economic variable | Category | Share sample | (Alonso-González et al., 2020) |
|---|---|---|---|
| Gender | Male | 66.1% | 48.2% |
| | Female | 32.3% | 51.8% |
| | Non-binary | 0% | N/A |
| | Unknown | 1.6% | N/A |
| Age | 18 to 39 | 71% | 38.1% |
| | 40 to 64 | 25.8% | 35.6% |
| | 65 and above | 3.2% | 26.3% |
| Education[19] | Primary education | 3.2% | 25.2% |
| | Secondary education | 17.8% | |
| | Secondary vocational education | 14.5% | 32.5% |
| | Higher professional education | 40.3% | 42% |
| | Research-oriented education | 24.2% | |
| | Unknown | 0% | 0.2% |
| Work status | Working | 67.7% | 50.9% |
| | Not working | 32.3% | 49.1% |
| Household | 1-person household | 21.0% | 49% |
| | Living with partner(s) | 37.1% | 51% (no details were provided on this level of detail outside of latent class clusters) |
| | Living with partner(s) and children | 17.7% | |
| | Living with children | 1.6% | |
| | Other | 19.4% | |
| | Unknown | 3.2% | N/A |
| Living environment | City | 48.4% | 46.9% |
| | Suburbs | 17.7% | 53.1% |
| | Smaller village or rural | 32.3% | N/A |
| | Unknown | 1.6% | N/A |

[19] In Alonso-González et al. (2020), no definition for education level is provided. Based on the referenced figures from Netherlands Statistics, it is presumed that an education level of 'low' refers to those that have attended primary or secondary education, 'average' includes secondary vocational education, and 'high' referencing higher professional or research-oriented education such as universities of (applies) sciences.

### 7.3 Observations on Consumers' Mobility Lifestyle

To provide context to both the respondent and the results, respondents were asked about their mobility lifestyle, i.e. modes used, ownership of specific modalities, participating in specific mode sharing schemes and familiarity with existing mobility solutions.

#### 7.3.1 *Familiarity with Transport Modes and Mobility Solutions*

These results (Figure 6) seem to indicate that the majority of participants originated from the Netherlands – this was to be expected due to the research setting and online network effects – due to high volume of respondents indicating their familiarity with Netherlands-specific mobility solutions, such as NS Reisplanner in addition to other well-established global products such as Google Maps or HERE WeGo. Another data point that seems to support this reasoning is that the second-most frequently indicated mode of transport is a bicycle, only to be preceded by cars, whilst being followed by bus and train (Figure 7).

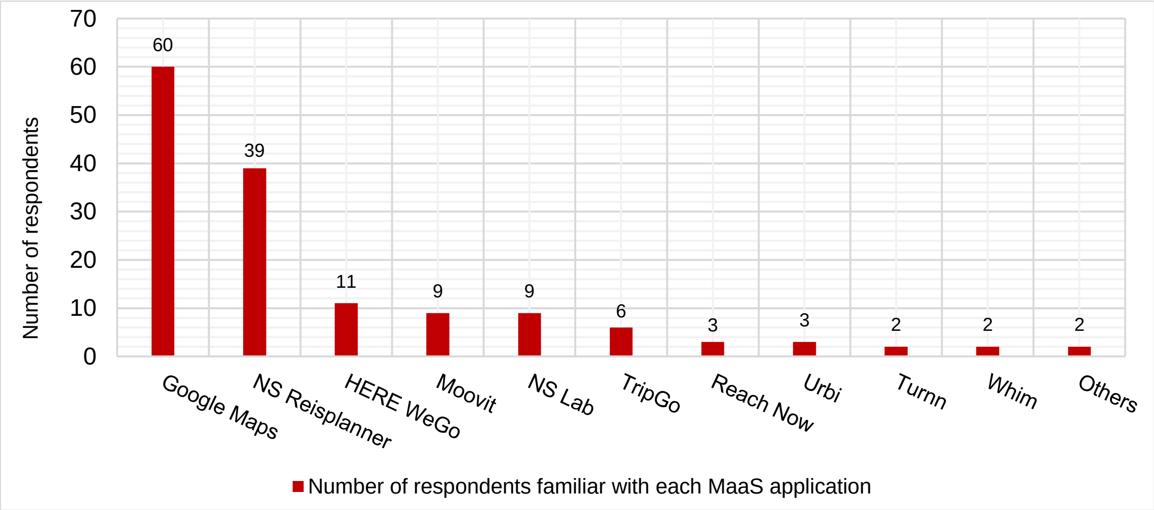


FIGURE 6: FAMILIARITY OF RESPONDENTS WITH MAAS APPLICATIONS

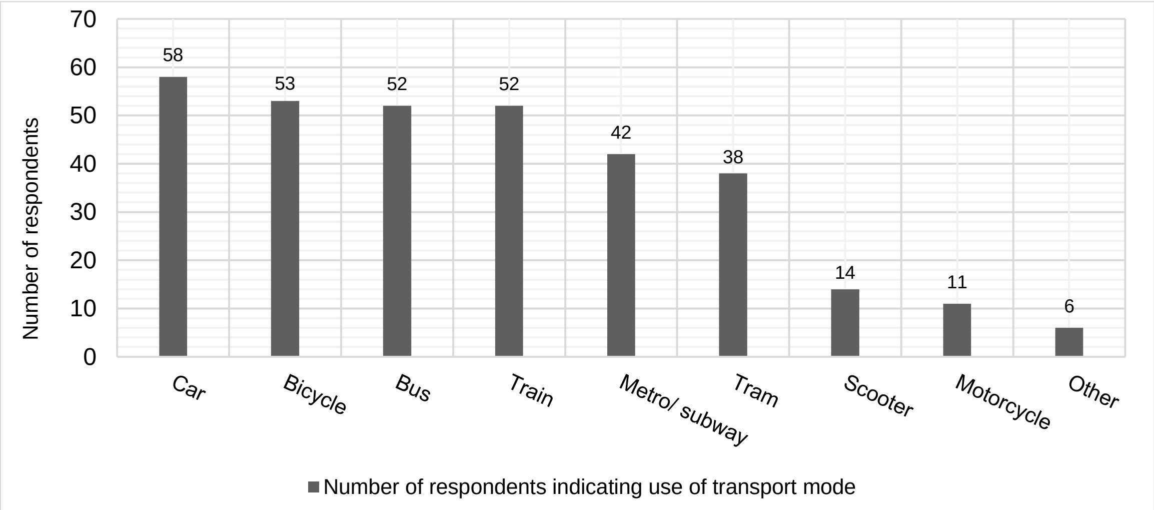


FIGURE 7: USE OF TRANSPORT MODES BY SURVEY PARTICIPANTS

### 7.3.2 *Modality Ownership and Usage*

Respondents were also asked about their ownership of transport modes and/ or access to public transportation and mobility sharing schemes (Table 15). With respect to providing mobility as a service, 13 respondents indicated to have used both a bicycle and car-based sharing schemes, with the latter including both car-sharing services such as Greenwheels as well as ride-hailing services such as Uber or Lyft. Individually, bicycle sharing schemes – this includes both private bike rental through schemes such as OV-Fiets as well as point-to-point bike sharing schemes like Mobike and Citi Bike – are not as successful as their car-based ride-hailing counterparts, with 18 respondents indicating to have used a bicycle sharing scheme compared to 21 with respect to car-based ride-hailing services.

Overall, there remains a 48% minority of respondents who have neither used a car-based, nor a bicycle-based mobility sharing scheme. Instead, these respondents were found to predominantly own a car (97%) or, to a lesser extent, own a public transport card (62%), the latter of which might also be influenced by the compatibility and supported functionality of a public transport card. Conversely, the well-established ownership of cars by households can also be reaffirmed with other results, with 76% of all respondents indicating household car ownership.

In addition, among the 76% of car-owning respondents, 96% of them indicated that they have, at some point, used a mobile application to plan their travel. Similarly, from the 76% of public transit card-owners, 96% of them also indicated to utilise a mobile application for planning their itinerary. As such, these results show that there does not appear to exist any direct relation between the types of modalities utilised and the usage of mobile mobility applications. Rather, it shows that mobile application aiming to providing combined mobility services should integrate both car and public transport services to provide a holistic and mobility offering. In addition, due to the increasing popularity of ride-hailing services – most of these depend on the presence of mobile applications during each phase of the journey – this growing trend of mobile application use within the mobility domain is expected to increase. This further underlines the importance of integrated travel information across different modalities.

**TABLE 15: SURVEY RESULTS – MODALITY OWNERSHIP AND USAGE**

| | **Response** | **Share sample** |
|---|---|---|
| Car in household | Yes | 75.8% |
| | No | 24.2% |
| Ownership of public transport card | Yes | 75.8% |
| | No | 24.2% |
| Bicycle sharing scheme used before | Yes | 29% |
| | No | 71% |
| Car sharing scheme or ride-hailing service used before | Car sharing only | 4.8% |
| | Ride hailing only | 33.9% |
| | Both | 3.2% |
| | Neither | 58.1% |

## 7.4 Expected Levels of Service

The expected levels of service offered to customers of MaaS solutions was measured by asking respondents to indicate the perceived level of importance (5-point Likert scale) for each of the MaaS capabilities identified in Section 6.1. In this section, the results are grouped and discussed based on their respective MaaS attribute, i.e. planning, ticketing, booking and payment.

### 7.4.1 *Planning*

From the capabilities surveyed amongst the respondents, the results with respect to the planning capabilities of MaaS solutions (Table 16) show that whilst 58% of surveyed MaaS features have a combined user expectancy score (i.e. 'very important' or 'important') of 50% or higher, only six features have a combined score of more than 75%, i.e.:

- Select departure and destination locations
- Real-time rerouting in case of disruptions
- Change departure time and date
- Real-time departure times of public transit
- Select modes of transport
- Compare travel advice based on distance travelled, travel duration, price, etc.

Whilst these features had already been found to be quite commonplace in existing mobility solutions during the literature review performed as part of the MaaS Solution Analysis, three of these features are more novel and have yet to reach their full potential in MaaS Solutions.

First, the real-time rerouting in case of disruptions requires real-time state information on both the modality used as well as the transportation network. Depending on the degree of vertical mobility integration within an organisation, and whether this organisation can provide alternate rounds either by themselves or using third-party services, any mobility provider should be able to build towards providing this feature as part of their mobility services. In practice, this feature has already been implemented as part of the NS Lab mobile application, yet limited to rail network disruptions, or as part of Google Maps and HERE WeGo, as part of their navigation services. As the cause of the need for dynamic rerouting (i.e. network disruptions) impacts the reliability and efficiency of the overall transportation network, the importance given to this capability by extension validates the inclusion of the reliability, efficiency, and speed concepts in the MCF.

Second, whilst selection of travel mode is present in most of the analysed MaaS solutions, it still ranks high amongst respondents, with 87% of them marking the feature of either 'important' or 'very important'. As this feature is currently present, one can only draw two conclusions with respect to these results: either the data indicates that respondents are very satisfied about the capability implementations of multimodal selection options; or they attach this importance to the abstract capability itself. Either way, the importance of multimodal selection in mobility solutions is evident and this should not be underestimated when developing these solutions.

Third, and finally, the highest scoring feature (98%) amongst respondents is the selection of departure and destination locations. Whilst it this arguably could be considered as self-evident, considering that mobility is about the transportation between two or more locations, there is more to this data. Most of the popular mobility applications in this study provide the capability to store favourite locations or routes, whereas only 62% of respondents finds this (very) important.

Conversely, the degree to which travel options can be compared is ranked much higher by respondents (83%), whilst current mobility solutions can often limit these route options based on either algorithmic or resource limitations, or design decisions. It could therefore be argued that mobility applications should prioritise research and development of innovative route planning and comparison solutions rather than the implementation of features that are deemed less important by comparison, i.e. storage of frequently-used or favourite locations.

With respect to the features least deemed important by respondents, there were no capabilities found that scored more than 75% combined between 'not at all important' and 'not important'. The least important capability according to respondents is to 'view the current weather situation for consideration in modality selection', with 57% of respondents indicating that it is either 'not important' or 'not at all important'. Based on analysed industry literature, this is quite surprising, considering that weather forecasting is frequently mentioned as a means for mobility providers to propose alternative modes of travel (Nederlandse Spoorwegen, 2019b), including providing the car as a 'weather proof' alternative to other transport modes (e.g. bikes) and walking in between transfers. The survey results also show that this relation does not change substantially on the basis of mode ownership, with 60% of car owners rating the 'view current weather situation' feature as either 'not important' or 'not at all important', compared with 62% of PT users and 78% of respondents indicating to have used a bicycle sharing scheme.

Whilst these results might seem to suggest that displaying weather information has no place in mobility applications, mobility providers might still correctly presume value in integrating weather information in the customers' travel planning process. However, the results clearly show that the current method (i.e. displaying weather information directly), is neither effective nor desired by respondents. Therefore, it stands to reason that such weather information might instead be better utilised as part of routing and planning algorithms, rather than being shown directly to the user.

Other software features that stand out from these results – in the sense that they score relatively low compared to other features – are the availability of Text-to-speech (TTS) directions (47%), sharing real-time location with selected other people during transit (40%), adding itineraries to personal online calendars (40%), exploring facilities along the route (38%), limiting walking distance (35%), and limiting to accessible journeys (28%). Whereas the latter feature, i.e. accessibly journeys, was expected to score lower compared with others listed due to the limited size of its associated applicable target group, the other low-scoring features were found to be in contrast to the existing designs, behaviours, and expectations of MaaS applications.

Moreover, TTS directions and exploring facilities along the route are known to be prominent features for both Google Maps and Here WeGo. As these applications are more car-focused than the other listed MaaS applications analysed in this research, more positive values would be expected when filtered for household car ownership. Consequently, it was found that whilst TTS remains unchanged in importance, respondents with car ownership rated 'exploring facilities along the route' slightly more important, with 36% of respondents indicating that this feature as 'not important' or 'not at all important'. This is likely due to the importance of finding gas and rest stations along the route, although this assumption cannot be verified with the results obtained.

With respect to the other low-scoring features, such as limiting walking distance and adding itineraries to personal calendars, no direct and substantial relation to modality ownership could be found within the results during the course of this research study.

**TABLE 16: SURVEY RESULTS – IMPORTANCE OF PLANNING CAPABILITIES IN MAAS APPLICATIONS**

| | Not at all important | Not important | Somewhat important | Important | Very important | N/A |
|---|---|---|---|---|---|---|
| Select departure and destination locations | 0.0% | 0.0% | 1.67% | 28.33% | 70.0% | 0.0% |
| Choose favourite or frequently-used locations and/or routes | 0.0% | 8.33% | 30.0% | 38.33% | 23.33% | 0.0% |
| Compare itineraries on distance travelled, travel duration, carbon dioxide emissions, calories burned, arrival time uncertainty, crowdedness, price | 0.0% | 1.67% | 15.0% | 56.67% | 26.67% | 0.0% |
| Select modalities to be used | 0.0% | 1.67% | 11.67% | 41.67% | 45.0% | 0.0% |
| Explore facilities along the route | 8.33% | 30.0% | 41.67% | 16.67% | 3.33% | 0.0% |
| Change departure time and date | 0.0% | 3.33% | 10.0% | 31.67% | 55.0% | 0.0% |
| Pricing-derived preferences (e.g. limit modalities or lines used based on subscription allowance and other payment requirements) | 0.0% | 6.67% | 21.67% | 40.0% | 31.67% | 0.0% |
| Include additional transfer time | 1.67% | 5.0% | 18.33% | 46.67% | 28.33% | 0.0% |
| Limit to accessible journeys | 6.67% | 21.67% | 21.67% | 28.33% | 20.0% | 1.67% |
| Limit walking distance | 11.67% | 23.33% | 31.67% | 25.0% | 6.67% | 1.67% |
| Share real-time location with selected other people during transit | 10.0% | 30.0% | 35.0% | 18.33% | 6.67% | 0.0% |
| Step-by-step guidance | 1.67% | 16.67% | 33.33% | 31.67% | 16.67% | 0.0% |
| Text-to-speech (TTS) directions | 23.33% | 23.33% | 28.33% | 20.0% | 5.0% | 0.0% |
| Offline navigation | 5.0% | 8.33% | 15.0% | 41.67% | 28.33% | 1.67% |
| Filter or sort itineraries by minimum/ maximum distance, travel duration, carbon dioxide emissions, calories burned, arrival time uncertainty, crowdedness, price | 1.67% | 6.67% | 20.0% | 45.0% | 26.67% | 0.0% |
| Real-time rerouting in case of (service) disruptions | 0.0% | 0.0% | 5.0% | 30.0% | 65.0% | 0.0% |
| Real-time departure times of public transit | 0.0% | 5.0% | 11.67% | 30.0% | 53.33% | 0.0% |
| Add itinerary to personal calendar (calendar export) | 10.0% | 30.0% | 28.33% | 26.67% | 5.0% | 0.0% |
| View current weather situation for consideration in modality selection | 21.67% | 35.0% | 23.33% | 15.0% | 5.0% | 0.0% |

7.4.2 *Ticketing*

Filtered to identified ticketing features, the results (Table 17) show that a substantial majority of respondents (68% to 93% depending on the feature) rated all listed ticketing features as either 'somewhat important', 'important' or 'very important'. By itself, this shows the significance of offering multiple ticketing options for various customers segments.

When only measuring importance by removing the indifference towards any capability by only assessing the 'important' and 'very important' metrics, only four ticketing features achieve an importance rating of 50% or higher, i.e.:

- Choose single ticket, day return or other similar time- or use-restricted schemes
- Select tickets/ time slots for each itinerary segment and/ or modality
- Compare ticket offers by price between mobility providers/ booking offices
- Select from (third-party) discount offers

**TABLE 17: SURVEY RESULTS – IMPORTANCE OF TICKETING CAPABILITIES IN MAAS APPLICATIONS**

| | Not at all important | Not important | Somewhat important | Important | Very important | N/A |
|---|---|---|---|---|---|---|
| Select tickets/ time slots for each itinerary segment and/ or modality | 1.67% | 10.0% | 25.0% | 41.67% | 21.67% | 0.0% |
| Choose single ticket, day return or other similar time- or use-restricted schemes | 0.0% | 6.67% | 23.33% | 31.67% | 38.33% | 0.0% |
| Apply joint journey discount (i.e. fare reduction based on travel group size) | 3.33% | 20.0% | 38.33% | 23.33% | 15.0% | 0.0% |
| Compare ticket offers by price between mobility providers/ booking offices | 3.33% | 8.33% | 28.33% | 40.0% | 20.0% | 0.0% |
| Compare ticket offers by price based on applicable mobility subscriptions | 1.67% | 10.0% | 38.33% | 36.67% | 13.33% | 0.0% |
| Choose different travel class for public transit tickets | 8.33% | 16.67% | 31.67% | 30.0% | 13.33% | 0.0% |
| Choose from specific seating options (e.g. window seating or more legroom) | 8.33% | 16.67% | 31.67% | 33.33% | 10.0% | 0.0% |
| Select tickets based on age group | 5.0% | 26.67% | 25.0% | 31.67% | 11.67% | 0.0% |
| Select from (third-party) discount offers | 3.33% | 5.0% | 30.0% | 45.0% | 16.67% | 0.0% |

Conversely, whilst no unimportant feature could be identified as each was overwhelmingly rated by respondents as anywhere from being somewhat to very important, the capabilities that scored the lowest amongst the ticketing features were mostly those related to the customisation options provided for PT tickets. Sorted (descending) according to the respective sum of their 'not at all important' and 'not important' metrics, these ticketing capabilities are:

- Select tickets based on age group → 32%
- Choose different travel class for public transit tickets → 25%
- Choose from specific seating options (e.g. window seating or more legroom) → 25%
- Apply joint journey discount (i.e. fare reduction based on travel group size) → 23%

When filtered for PT card ownership, selecting tickets based on age group is rated slightly more important by respondents, with only 27% rating it as not (at all) important. Amongst households with car ownership, this changes to 33% of respondents. In addition, selecting travel class for PT tickets is rated not (at all) important by 29% of respondents indicating household car ownership, compared with 25% of PT card owners.

### 7.4.3 *Booking*

With regards to booking features results (Table 18), there is a notable divide between the (very) important and not (at all) important features. Four out of six features were rated by respondents as (very) important, i.e. having a combined 'important' and 'very important' score of at least 50%. These capabilities, sorted (descending) in order of importance, are:

- Confirm ticket details before checkout
- Digitally store tickets (offline) on mobile devices (e.g. QR-/ barcodes)
- Apply (first-party) discount coupons before checkout
- Export and print out tickets on paper (e.g. QR-/ barcodes)

One might assume that the age of respondents influenced their response to the method by which the ticket is stored and/ or presented (i.e. print or digital), however for each of the two ticket storage methods, a Spearman's correlation coefficient – the nonparametric Spearman's rank-order correlation was applied as linearity could not be assumed in this ordinal data set – stronger than -0.03 and -0.15 for print and digital respectively could not be asserted. As these correlation coefficients are significantly weak, no correlation can be assumed with the sample used in this study. Instead, a stronger correlation coefficient was found to exist between the use and payment of single tickets and print, although this was still relatively moderate with a rho of only 0.433.

Two capabilities were found to be often marked as not (at all) important, i.e.: choosing a tip (percentage) for ride hailing/ taxi drivers (32%) and changing between anonymous or person-bound tickets (40%). Moreover, whilst the data shows that these features can be classified as least important of those surveyed, respondents were also significantly more neutral about these features (40% and 33% respectively) in comparison with others from the same category.

TABLE 18: SURVEY RESULTS – IMPORTANCE OF BOOKING CAPABILITIES IN MAAS APPLICATIONS

| | Not at all important | Not important | Somewhat important | Important | Very important | N/A |
|---|---|---|---|---|---|---|
| Confirm ticket details before checkout | 1.67% | 3.33% | 5.0% | 40.0% | 50.0% | 0.0% |
| Apply (first-party) discount coupons before checkout | 0.0% | 11.67% | 11.67% | 40.0% | 36.67% | 0.0% |
| Export and print out tickets on paper (e.g. QR-/ barcodes) | 6.67% | 18.33% | 23.33% | 33.33% | 18.33% | 0.0% |
| Digitally store tickets (offline) on mobile devices (e.g. QR-/ barcodes) | 0.0% | 1.67% | 11.67% | 38.33% | 48.33% | 0.0% |
| Choose a tip (percentage) for ride hailing/ taxi drivers | 6.67% | 25.0% | 40.0% | 20.0% | 8.33% | 0.0% |
| Change between anonymous tickets or person-bound tickets | 6.67% | 33.33% | 33.33% | 16.67% | 10.0% | 0.0% |

TABLE 19: SURVEY RESULTS – IMPORTANCE OF PAYMENT CAPABILITIES IN MAAS APPLICATIONS

| | Not at all important | Not important | Somewhat important | Important | Very important | N/A |
|---|---|---|---|---|---|---|
| Pay for single tickets through (third-party) payment providers | 0.0% | 5.0% | 18.33% | 38.33% | 38.33% | 0.0% |
| Pay through prepaid or pay-as-you-go smart card schemes | 5.0% | 11.67% | 25.0% | 33.33% | 25.0% | 0.0% |
| Pay through pre-defined mobility subscriptions | 1.67% | 10.0% | 30.0% | 33.33% | 23.33% | 1.67% |
| Pay using payment terminals in or around individual modalities | 3.33% | 11.67% | 25.0% | 43.33% | 15.0% | 1.67% |
| Pay using (first-party) direct debit/ credit schemes | 3.33% | 8.33% | 23.33% | 33.33% | 30.0% | 1.67% |

### 7.4.4 *Payment*

Based on the survey results regarding payment functionality (Table 19) in MaaS solutions, it can be stated that providing a variety of payment options their customers is the approach most likely to benefit user satisfaction. It was found that all of the surveyed payment options were rated between somewhat important and very important in 83-87% of the time, with the exception of the payment for single tickets through (third-party) payment providers, which was rated at 95%.

Although the importance of single tickets can therefore not be underestimated, alternative options, such as pay-as-you-go schemes and pre-defined mobility subscriptions approach the levels of importance only achieved by single ticket purchases through payment providers.

## 7.5 PDR-Acceptance Rates

In order to determine PDR-acceptance rates, respondents were asked to state their concern on 40 types of personal data requirements identified in the MaaS solution analysis (Section 4.5.5). From the 60 respondents of whom the levels of concern with respect to PDRs and application permissions were recorded (Table 20; Table 21), one respondent skipped all questions in this section of the survey, with a second respondent skipping a subset of the questions.

Based on preliminary data analysis, the results can be divided into four categories of PDRs: acceptable, unacceptable, polarised, and centralised. PDRs rated as ‘not concerned’ by most respondents are classified as acceptable for most use cases, whereas those rated as ‘very concerned’ are classified as unacceptable. A minimum threshold of 50% is used for both. PDRs are considered polarised when the number of respondents ‘not concerned’ about the PDR approaches or equals the percentage of those ‘very concerned’ about the requirement. Finally, PDRs are classified as centralised when there is a larger number of respondents that indicated to be ‘somewhat concerned’ with the requirement than there is of any of the two other options.

### 7.5.1 *Acceptable PDRs*

When filtering for PDRs with an acceptance score of at least 50% (i.e. selecting PDRs with a ‘not concerned’ value of more than 50%), only four personal data requirements remain:

- Connect to the internet
- Vibrate your device
- Keep the device awake (e.g. prevent the screen from dimming)
- Access your approximate location

Considering that any mobile application requires an internet connection to send or retrieve (real-time) data, it is unsurprising that users of such applications have come to accept this. A similar statement can be made with respect to vibrating the device, as this is often used for notifications and certain input events, and keeping the device awake, which can be encountered in mobile applications serving multimedia content. In other words, three out of the four ‘acceptable’ PDRs are related to behaviour already expected by mobile devices and it is therefore unsurprising that these PDRs have been found to be of no grave concern amongst the respondents of this survey.

With regards to accessing the approximate location of a mobile application user, this reasoning does not directly apply. As these results show that the use of approximate location to implement MaaS features is seen as acceptable only within the context of mobility applications – it is presumed that the context in which the PDR sentiment was surveyed (i.e. mobility applications) influenced the respondents’ concern rating –, this statement is therefore not directly transferable to other classifications of applications, such as direct messaging applications.

**TABLE 20: SURVEY RESULTS – PDR ACCEPTANCE RATES**

| | Not concerned | Somewhat concerned | Very concerned | N/A |
|---|---|---|---|---|
| Access your background location | 36.67% | 45.0% | 15.0% | 3.33% |
| Access your approximate location | 50.0% | 31.67% | 15.0% | 3.33% |
| Access your precise location | 30.0% | 36.67% | 31.67% | 1.67% |
| Access geographic locations of images | 23.33% | 31.67% | 41.67% | 3.33% |
| Access to information about nearby mobile networks, such as 4G | 48.33% | 33.33% | 16.67% | 1.67% |
| Access information about Wi-Fi networks | 45.0% | 30.0% | 23.33% | 1.67% |
| Recognise physical activity | 31.67% | 43.33% | 21.67% | 3.33% |
| Connect to paired Bluetooth devices | 28.33% | 40.0% | 30.0% | 1.67% |
| Discover and pair Bluetooth devices | 31.67% | 30.0% | 36.67% | 1.67% |
| Temporarily store data broadcasted to the device | 38.33% | 28.33% | 30.0% | 3.33% |
| Initiate a phone call without going through the dialling interface | 18.33% | 28.33% | 51.67% | 1.67% |
| Access all camera functionality | 10.0% | 25.0% | 63.33% | 1.67% |
| Enable or disable cellular network connectivity (e.g. 4G) | 15.0% | 31.67% | 50.0% | 3.33% |
| Enable or disable Wi-Fi network connectivity | 15.0% | 25.0% | 58.33% | 1.67% |
| Disable the lock screen PIN or other types of authentication | 5.0% | 15.0% | 78.33% | 1.67% |
| Download files and data in the background without notification | 6.67% | 21.67% | 70.0% | 1.67% |
| Enable or disable the flashlight | 28.33% | 21.67% | 48.33% | 1.67% |
| Appear in the foreground of the mobile device | 30.0% | 38.33% | 30.0% | 1.67% |
| Retrieve a list of accounts stored on your device | 8.33% | 21.67% | 68.33% | 1.67% |

**TABLE 21: SURVEY RESULTS – PDR ACCEPTANCE RATES (CONTINUED)**

| | Not concerned | Somewhat concerned | Very concerned | N/A |
|---|---|---|---|---|
| Check the size of any application installed on the device | 23.33% | 26.67% | 48.33% | 1.67% |
| Connect to the internet | 68.33% | 26.67% | 3.33% | 1.67% |
| Manage the accounts stored on your device | 16.67% | 30.0% | 51.67% | 1.67% |
| Change the audio settings of your device | 33.33% | 23.33% | 41.67% | 1.67% |
| Access NFC | 28.33% | 30.0% | 31.67% | 10.0% |
| Authenticate with other accounts on the device | 20.0% | 38.33% | 40.0% | 1.67% |
| Read your calendar | 13.33% | 36.67% | 46.67% | 3.33% |
| Read your contact list | 6.67% | 26.67% | 65.0% | 1.67% |
| Read the files on your SD card | 6.67% | 28.33% | 61.67% | 3.33% |
| Access the state of the phone, e.g. cellular network information, ongoing calls and SIM-cards installed | 11.67% | 33.33% | 51.67% | 3.33% |
| Read settings synchronised across devices | 15.0% | 56.67% | 26.67% | 1.67% |
| Get notified when the phone has finished starting up/ booting | 40.0% | 30.0% | 26.67% | 3.33% |
| Record audio | 5.0% | 25.0% | 66.67% | 3.33% |
| Appear on top of other applications | 25.0% | 46.67% | 25.0% | 3.33% |
| Access biometric authentication methods | 20.0% | 40.0% | 36.67% | 3.33% |
| Access your fingerprint | 18.33% | 33.33% | 45.0% | 3.33% |
| Vibrate your device | 68.33% | 20.0% | 10.0% | 1.67% |
| Keep the device awake (e.g. prevent the screen from dimming) | 56.67% | 25.0% | 16.67% | 1.67% |
| Write to your calendar | 43.33% | 30.0% | 25.0% | 1.67% |
| Write to your SD card | 35.0% | 31.67% | 30.0% | 3.33% |
| Write settings to be synchronised across devices | 25.0% | 50.0% | 23.33% | 1.67% |

### 7.5.2 *Unacceptable PDRs*

When filtering for PDRs rated as ‘very concerned’ by more than 50% of the respondents, twelve personal data requirements remain, which are listed below in descending order of concern:

- Disable the lock screen PIN or other types of authentication
- Download files and data in the background without notification
- Retrieve a list of accounts stored on your device
- Record audio
- Read your contact list
- Access all camera functionality
- Read the files on your SD card
- Enable or disable Wi-Fi network connectivity
- Initiate a phone call without going through the dialling interface
- Manage the accounts stored on your device
- Access the state of the phone, e.g. cellular network information, ongoing calls and SIM-card installed
- Enable or disable cellular network connectivity (e.g. 4G)

Based on the underlying personal information, these PDRs fall into four distinct categories:

- the PDR concerns either a device sensor that can capture and record real-world information (i.e. audio and camera functionality);
- a method by which explicit security settings and user interactions are circumvented (i.e. reads/ writes of SD card files, background data downloads and lock screen authentication settings);
- a mechanism to manage the connectivity of the device with external communication networks (i.e. Wi-Fi and cellular network settings);
- or the implicit request to retrieve or manage personal information stored on the device (i.e. contact lists and account settings).

These four categories can be used to determine which of these unacceptable PDRs should be avoided all-together, and which need to be implemented differently, e.g. using voluntary consent to improve the accuracy and user experience of implemented MaaS features, without necessarily impeding on users’ access to these capabilities.

### 7.5.3 *Polarised PDRs*

Whilst the results show strong positive or negative levels of concern towards specific permissions and personal data requirements, other phenomena can also be observed, such as respondent polarisation for certain PDRs. To determine the degree polarisation, the difference between the shares of respondents not concerned and very concerned with PDRs was used. It was found that for six of the surveyed PDRs, a roughly equal number of respondents expressed their concerns (i.e. very concerned) compared to those indicating their acceptance (i.e. 'not concerned') within a tolerance of 5%. The PDRs which were found to be most polarised amongst respondents are:

- Access your precise location
- Access NFC
- Connect to paired Bluetooth devices
- Appear in the foreground of the mobile device
- Appear on top of other applications
- Write settings to be synchronised across devices

### 7.5.4 *Centralised PDRs*

Another phenomenon that can be observed in the results data set is that an average of 31.7% respondents indicated their indifference (i.e. 'somewhat concerned') towards the surveyed PDRs, consequently resulting in centralisation of their associated concern-values.

Whilst this is not concerning by itself, it indicates that either: (1) the question was not sufficiently understood; (2) the technical terms and implications were not sufficiently understood; (3) that respondents expect a privacy-functionality trade-off to be serving to their use-case; or (4) that respondents simply do not care about the specific PDR being satisfied for use of the MaaS application. Considering that no questions were received on the definitions of technical concepts surveyed, nor that any respondents indicated that language used throughout the survey was ambiguous and given that respondents were encouraged to skip any questions they did not understand, it must be presumed that the respondents fall within either of the last two categories (i.e. they do not care about these PDRs or are expecting a privacy-functionality trade-off).

In total, nine PDRs were found to both have a numerically larger group of respondents indicating their indifference compared to those indicating to be either 'very concerned' or 'not concerned', as well as have a higher indifference score than average:

- Access biometric authentication methods
- Access your precise location
- Connect to paired Bluetooth devices
- Appear in the foreground of the mobile device
- Read settings synchronised across devices
- Appear on top of other applications
- Write settings to be synchronised across devices
- Recognise physical activity
- Access your background location

# 8 DESIGN RECOMMENDATIONS

*In this chapter, design recommendations are made with regards to privacy-functionality trade-offs for use in the design processes of MaaS solutions. This is performed according to the methods listed in Section 4.7. First, privacy-functionality trade-offs are presented based on the user study. Then, design recommendations are considered in the context of project management and design methods. Finally, recommendations are made with respect to the design of MaaS solutions.*

## 8.1 Privacy-Functionality Trade-Offs

Following the results from the user survey, this segment of the research aims to provide privacy recommendations for use in the design processes of MaaS solutions based on identified privacy-functionality trade-offs. As such, various relations between surveyed MaaS features and personal data requirements were examined.

Although the assessment of MaaS feature expectations can be used to determine which features ought to be supported by any given MaaS mobile application, there remains the question of how these features should be implemented. Not only is the method of implementation based on factors such as programming language, used frameworks, software libraries or the requirements associated with the business processes the application should address, but it is also highly dependent on which PDRs are both suitable and acceptable.

Most of the PDRs deemed unacceptable by respondents (see Section 7.5.2) are not necessary for the implementation of any MaaS feature (see Section 6.1), however certain capabilities can still be required depending on solution design decisions. Moreover, if these PDRs are polarised, this can result in a mismatch of priorities between the customer and the mobility provider.

Whilst overcoming polarisation in a society might be classed as a difficult feat, it is certainly feasibly for software applications. As a consequence of mandating solution designers by means of privacy legislation to implement user-choice (i.e. opt-in) mechanisms that do not unnecessarily restrict provided functionality (*Regulation (EU) 2018/1725*, 2018), a pathway was created to allow for the implementation of functionality dependent on both polarised and centralised PDRs whilst meeting the expectations of all respondent groups.

These design decisions vary based on the to-be implemented features, and as such, it should be noted that any design decision can significantly influence the privacy impact of MaaS solutions through their implementation choices. It is therefore not only recommended that implementation choices are discussed, and their privacy impact weighed, but also to put in place user-choice mechanisms to prevent any unlawful processing of personal data, whilst still allowing for novel uses of personal data to enrich the user experience.

For instance, providing users with the optional ability to willingly share their real-time location with the mobility service can enrich the contextual travel information provided to the user (e.g. nearby facilities/ friends or real-time service disruptions in a given area) without enforcing the feature on those that do not desire it. Similarly, for those not willing to share their real-time location, but still wanting to be aware of real-time service disruptions, the impact on any user’s itinerary can be inferred from track-bound ticket reservations.

## 8.2 Assorted Levels of Privacy

The user survey results show that an average of 31.7% of the respondents are indifferent towards the surveyed personal data requirements (see Section 7.5.4). Therefore, rather than overwhelming these users with a higher degree of granular control over their privacy settings – this should always be an "advanced" option to comply with legally mandated opt-in mechanisms for data collection and processing –, it is instead suggested to use assorted levels of privacy.

Assorted levels of privacy are determined at the feature-level and provide a more coarse-grained overview of the privacy impact of each implementation option available. Considering that multiple levels of personal data protection can exist for any given feature due to the differences between feature implementations, and given that each PDR has a different acceptance rate classification, these assorted levels of privacy can be perceived as a data set with the following dimensions:

1) Acceptance classification of personal data requirements identified in Section 7.5
2) Different implementation options for each software feature

Each cell represents the number of personal data requirements from each classification needed for a given implementation. The totals derived can be used to compare the total number of data points required for each implementation option, and as such determines its level of privacy within the larger framework for a given software feature. An example table (with dummy values) for a single software feature can be found in Table 22.

The method of assorted levels of privacy is primarily to be used as a decision-support tool for making privacy-functionality trade-offs during the requirements specification process in the software design cycle, however, a version could be adapted to be shown directly to the user. This user-facing version of the method would have to include more specific information on the requested PDRs but could ultimately serve as a form of coarse-grained privacy controls, where the feature implementations available in the application are ordered by level of privacy impact.

**TABLE 22: ASSORTED LEVELS OF PRIVACY TEMPLATE FOR A GIVEN SOFTWARE FEATURE**

| | **Implementation 1** | **Implementation 2** | **Implementation 3** |
|---|---|---|---|
| **Polarised** | 2 | 1 | 3 |
| **Centralised** | 3 | 5 | 1 |
| **Acceptable** | 1 | 2 | 1 |
| **Unacceptable** | 0 | 1 | 3 |
| Total PDRs | 6 | 9 | 8 |

## 8.3 Incorporating Privacy Recommendations

The practice of incorporating design process recommendations based on the identified privacy-functionality trade-offs can either be perceived as either a business/ strategy decision, or as part of the software requirements specification process. In fact, within the context of the GDPR, and other privacy directives incorporating 'privacy-by-design' philosophies, these types of requirements are arguably similar, if not the same, as business and strategy decisions ought to align with personal data protection requirements outlined in the applicable privacy directives. Business or strategy decisions aimed at reducing the privacy impact of MaaS solutions should therefore directly translate to software or enterprise architecture requirements. Conversely, as privacy legislation dictates how software (platforms) ought to be designed, the requirements for software and enterprise architecture projects also limit the impact of these business and strategy decisions on the overall design process.

Considering that privacy recommendations can therefore be perceived as design requirements, it was reasoned that design methods providing reoccurring mechanisms by which to control project requirements throughout its lifecycle would likely be most suitable. Based on these selection criteria and the degree to which the method is both useful in the focused MaaS domain as well as representative of methods (widely) used in practice, two solution design and management methods were selected, namely:

- Disciplined Agile Delivery (DAD);
- The Open Group Architecture Framework (TOGAF).

Both methods were adapted to incorporate privacy constructs and recommendations, for which the implementation, function and effect of these constructs varies between the two methods due to the differences with regards to project applicability. As such, the incorporation of these privacy constructs and recommendations was performed in accordance with their internal context, i.e. privacy recommendations made in the context of TOGAF were considered from an (enterprise) architecture perspective, whereas those made in the context of DAD had to consider the more versatile nature of the project management method, as it supports a wider range of project types.

### 8.3.1 *Disciplined Agile Delivery (DAD)*

Disciplined Agile Delivery (DAD) is a hybrid approach to project management and IT solution delivery that incorporates aspects from methods such as Extreme Programming (XP), Unified Process (UP), Lean Software Development and SAFe® amongst other methods (Project Management Institute Inc., n.d.). It is classified as a process decision framework that is inherently goal and context-driven and does not prescribe a working method or technical practice (Ambler, 2013). Because of this, DAD addresses all aspects of solution delivery, including modelling and governance practices excluded from other methods (Project Management Institute Inc., n.d.).

This degree of versatility and comprehensiveness makes DAD both unique and representative of other IT solution delivery methods, given the various supported lifecycles by the decision framework. Similarly, because of the common basis for each of these lifecycles, it is possible to incorporate privacy recommendations as design requirements in all lifecycles simultaneously.

As privacy requirements can be perceived as legally mandated software design requirements, not adhering to them introduces risk to the software project. Within the DAD framework, these privacy risks are identified early during the Inception Phase (Ambler, 2013) and addressed throughout the entire project's lifecycle.

Whilst privacy design requirements in Agile DAD lifecycles are best operationalised as part of the initial modelling and architecture vision, legal environments can change. Whether this is because of business expansion to countries with a different legal framework, the enactment of new legislation in existing business markets, or any number of unforeseen internal or external factors, it is important that the project's lifecycle allows for changes with respect to privacy-related design requirements. As such, DAD relies on a non-prescriptive approach to requirements management that promotes the use of several techniques and methods that might be used to resolve any number of issues because of changing stakeholder needs.

In the context of privacy design requirements, this adaptive technique can also be applied using the various implementation options available for each desired MaaS capability, for instance according to the assorted levels of privacy. Changes to the context of the software project that necessitate a change involving PDRs can be iteratively added to the work items based on (internal) feedback and (external) enhancement requests. As such, privacy impact can be controlled, regardless of lifecycle choice, in both the initial modelling, architecture vision and (iterative) construction phases.

### 8.3.2 *The Open Group Architecture Framework (TOGAF)*

The TOGAF standard (The Open Group, 2018b) is an Enterprise Architecture methodology that places requirements management at the heart of the Architecture Development Method (ADM). Whilst the majority of the business requirements elicitation and risk identification is performed during Phase A: Architecture Vision, the architecture principles are established in the Preliminary Phase (The Open Group, 2018a).

As TOGAF ADM is also designed to be tailored to its use context during the Preliminary Phase, 'privacy-by-design' can be applied to the method as one of the selected architecture principles, i.e. establishing the importance of privacy design requirements throughout the ADM process.

Subsequently, privacy recommendations can be incorporated in Phase A of the ADM process as business requirements resulting from the external legislative context. Similarly, the stakeholder identification process as part of Phase A can be applied to identify third-party data processors, of which disclosing their identity can be a legal requirement in EU privacy law (Article 13, Paragraph 1(c), *Regulation (EU) 2018/1725*, 2018), even though the exact details of data sharing between information systems is not fully worked out until Phase C: Information Systems Architectures.

Such a dynamic and continuous approach to requirements management throughout every step of the TOGAF ADM process allows for entire organisations, not just individual software projects, to consider privacy-functionality trade-offs at every stage of the migration process.

### 8.3.3 *Considerations on the Operationalisation of Privacy Requirements*

Whereas TOGAF promotes the documentation of work performed throughout its processes, the minimisation of documentation is a common trait amongst Agile methods (Chemuturi, 2013, p. 230). This is incompatible with the notion that personal data processes should be documented and available to the application user in accordance with privacy directives. Whilst the provided assorted levels of privacy will likely provide an overview of data collected, a separate log of data processing partners across all tiers of service should be kept and published where required.

# 9 CONCLUSIONS

*In this chapter, the results and other insights obtained in the previous sections are discussed in individual segments. First, remarks are made on the process of identifying academic and industry characteristics of MaaS. Thereafter, some generalised insights with respect to conceptualising Mobility-as-a-Service are discussed. The identified research gaps are then presented, with research areas being highlighted based on their relevance. Subsequently, the results from the feature and PDR identification process are discussed in more depth, after which the survey results are taken into perspective. Finally, the process by which privacy recommendations are incorporated in the design of MaaS solutions is reflected upon and final remarks are given.*

## 9.1 On Identifying MaaS Characteristics

Initially, this research set out to identify the characteristics of MaaS in both academic and grey literature. Based on a comprehensive literature research, the core characteristics of MaaS have been identified for both academic (Table 23) and grey literature (Table 24). It is important to note that whilst the original research questions did not make a distinction between industry and government publications on the concept of MaaS for the purposes of identifying its characteristics, some generalised findings can be inferred. This can specifically be found in two focus areas: mobility data and customisation/ personalisation.

First, whereas a data-centric approach to MaaS can be found in both academic, industry and government publications, its role is substantially different between each. For example, whereas academic and industry publications often consider real-time mobility information exchange as a supportive aspect of MaaS for the purposes of supporting the relevant business goals and processes, government publications often consider mobility data as their main focus, especially in terms of its accessibility, portability, safeguard the privacy of its citizens and its ability to create a level playing field, while simultaneously addressing a variety of policy goals.

TABLE 23: MAAS CONCEPT CHARACTERISTICS IN ACADEMIC PUBLICATIONS

| | |
|---|---|
| MaaS Characteristics | MaaS is the consolidated offering of various mobility options and modes (i.e. modality choice). |
| | Route planning is dynamic and customisable through internal (e.g. network) and external (e.g. contextual/ environmental) parameters. |
| | Ticketing, booking, and payment services are exposed to the end-user through a centralised application. |
| | Tariff options provide dynamic access to diverse and potentially incentivised modes of transport. |
| | The effectiveness of MaaS solutions is measured through their ability to increase the transportation network's (spatial) efficiency by improving the methods by which supply and demand are matched. |
| | Collaboration between multiple actors, among which PT operators, government entities and third-party organisations is required for operation. |
| | MaaS solutions depend heavily on the use of telecommunications (e.g. real-time tracking) and information technology. |

**TABLE 24: MAAS CONCEPT CHARACTERISTICS IN INDUSTRY AND GOVERNMENT**

| | |
|---|---|
| **MaaS Characteristics** | MaaS, in essence, is envisioned as the integrated offering of multi-modal transportation (e.g. modality choice and combined modality). |
| | Public-private partnerships (e.g. between public transit and private transportation companies) are central to any kind of MaaS solution. |
| | MaaS is inherently demand-orientated and focused on network and/ or spatial efficiency, regardless whether it is interpreted as a vision or a platform. |
| | Customer segmentation and personalisation through various parameters (e.g. comfort, convenience/ ease-of-use, dynamic pricing, and flexibility) are deemed as important focus areas for industry MaaS solutions. |
| | Reduction of the environmental impact resulting from personal mobility and other policy goals (e.g. speed, accessibility, affordability, reliability, and inclusivity) are often indicated as success metrics for MaaS. |
| | Integration in MaaS often exceeds the concept of integrated mobility, as it also requires addresses planning, ticketing, booking and payment services. |
| | Government policy on MaaS is primarily data-centric and includes references to, or requirements for, data sharing schemes between participating organisations. |

Second, whereas the option to customise the intended journey based on various internal and external parameters is a key characteristic of MaaS, it is inherently different from the notion of personalisation. However, while each type of examined literature includes at least a single publication that addresses the notion of personalisation, it is observed that personalisation is more often encountered in publications of industry origin. No explanation can be given for this phenomenon based on the analysis performed in this paper, yet it is presumed that the monetary value of personal information creates an incentive for commercial organisations to capitalise on this aspect of MaaS.

## 9.2 On Conceptualising MaaS

Based on these characteristics, a definition and conceptualisation of MaaS could be derived. In this research, it was found that MaaS ought to be defined as:

> *MaaS is an evolution of the traditional transport system, either conceptualised as a physical artefact or a vision, which should ultimately benefit society by improving the efficiency of the transport network, and optionally meet certain policy goals with respect to social welfare and the environment.*

The MaaS Conceptual Framework (Figure 8) was developed to go alongside this definition and integrate the concepts and characteristics identified in the prior literature search.

### 9.2.1 *On the MaaS Conceptual Framework*

Since the inception of the concepts, policy makers and industry leaders have eagerly been looking into Mobility-as-a-Service (MaaS), most often incorporated in ‘smart city’ projects (Transport Systems Catapult, 2016). As such, it is unsurprising to encounter concepts such as ‘public-private partnerships’ and concepts (e.g. real-time data; open data) describing a data-driven approach to attaining societal goals in the MaaS Conceptual Framework.

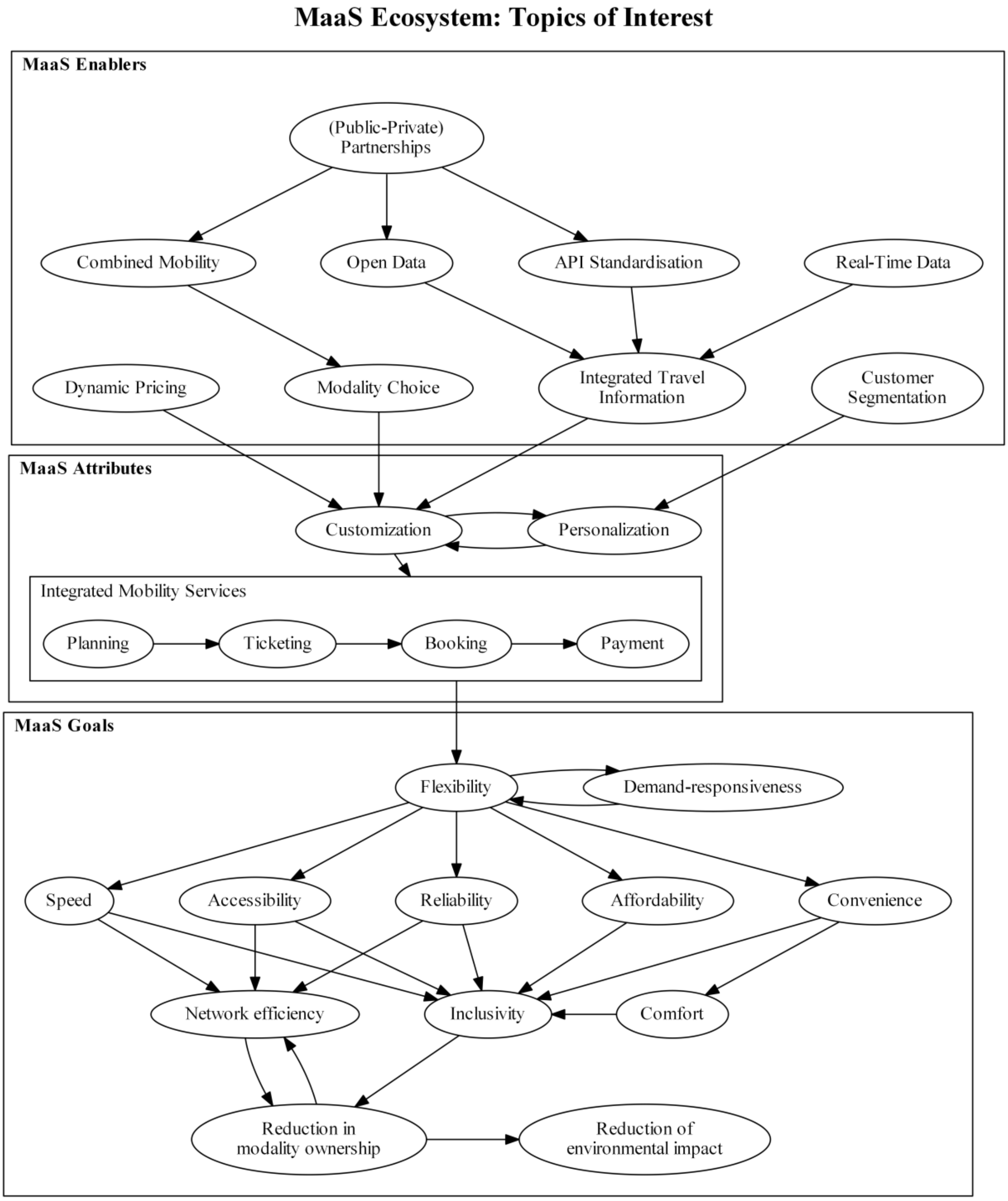


**FIGURE 8: MAAS CONCEPTUAL FRAMEWORK: RELATIONS BETWEEN IDENTIFIED MAAS CONCEPTS DIVIDED INTO ENABLERS, ATTRIBUTES AND GOALS**

With respect to the ‘core technical aspects’ of MaaS (i.e. those included in the MaaS artefact), the MaaS Conceptual Framework portrays those in a similar manner as features listed for MSPs. The MaaS artefact and its main attributes can be therefore be considered as an evolution of MSPs: expanding on customisation options through enabling concepts such as personalisation. Conceptualising MaaS was therefore achieved by combining the three components of the MaaS ecosystem (i.e. enablers, attributes, and goals).

Considering it was found that studies not addressing any of the listed attributes for the MaaS artefact were less likely to refer to the overall MaaS ecosystem, creating a clear and distinct separation of internal and external goals allows for more focused MaaS studies to emerge. Specifically, studies addressing the attributes of the MaaS artefact are be more likely to attain a higher degree of relevance within the MaaS domain. Conversely, solely discussing enablers and goals associated with MaaS could produce studies less relevant to the overall domain.

Determining which concepts could be included in each of the three components of the MaaS ecosystem is a process entirely dependent on the context of the study. For instance, whilst certain concepts were omitted due to being infrequently referred to in either type of assessed literature – this action was taken to create a comprehensive, yet focused conceptualisation of the MaaS ecosystem –, it can still be of relevance within the specific research context. Examples of these concepts include ‘spatial efficiency’ and ‘time horizons’ as both discussed extensively by Cuttone et al. (2018). The dynamic nature of the MaaS ecosystem as suggested by this example allows not only for incorporating future developments in the research field, but it also reflects the dynamic nature and ever-expanding demand expectations of personal mobility networks. Conversely, the conceptualisation of the MaaS artefact as an evolution of MSPs creates a clear and concise definition of the MaaS artefact.

### 9.3 On Identifying Research Gaps

First, whilst the identification of research gaps/ opportunities or challenges associated with MaaS was mostly performed from the basis of the MaaS Conceptual Framework, other key papers were also consulted for their insights into the field. With respect to the process of identifying research gaps on the basis of the MaaS Conceptual Framework, it is important to note that while great care was taken with respect to the inclusion/exclusion criteria in the process of marking the discussed concepts, it was difficult to ascertain at which point a concept is discussed sufficiently in order to be marked as such. The other key papers were selected based on their relevance to the MaaS ecosystem, and therefore whether they addressed the derived MaaS artefact, its attributes, and any potential challenges.

The research gaps identified in the SLR, SMS and SSLR were often found to exist as (potential future) edges between MaaS ecosystem concepts, most of which represented in the MaaS Conceptual Framework. In addition, a smaller number of research gaps were found to be concept-specific, even though the concept itself can be considered part of the interconnected MaaS ecosystem. An example of such a concept is Time Horizons, as discussed by Cuttone et al. (2018), of which the improvement of the accuracy algorithm can be considered concept-specific, even though the concept could be argued to have intrinsic relations to other MaaS ecosystem concepts such as ‘real-time data’ and ‘integrated travel information’.

#### 9.3.1 *On Personal Data Protection*

With respect to the personal data protection challenges found in the research gaps, the recently announced and implemented directives on personal data protection (e.g. GDPR, CCPA and LGPD) have created an environment in which the development of MaaS could be hindered if the (potential) impact of the directives on individual MaaS concepts is not sufficiently explored. The need for such studies is underlined by comments made in a debate of the Dutch committee on public transport and mobility, in which one member of parliament expressed concerns on the for-profit data processing of traveller information (e.g. patterns, occupation, personal information) as well as the accessibility of these data sources by third-parties (Vaste commissie voor Infrastructuur en Waterstaat, 2018, p. 15). As data ownership and its associated storage location are fundamental to any MaaS solution – without clarity on data ownership, functional and non-functional requirements for MaaS solutions could be too ambiguous or even result in a substantial redesign later in the project's expected lifecycle –, examining the effects of data protection directives on individual MaaS ecosystem concepts is deemed to be one of the most contemporary relevant challenges in this research field. Whilst some researchers have made strides on this topic (Cottrill, 2019), there remain unanswered questions, specifically with regards to the means (i.e. data sets) by which personalisation of itineraries is achieved. Whereas this research has progressed the body of knowledge on this topic, there remains a significant challenge in validating these results overall as well as in various societal contexts.

#### 9.3.2 *On (Public-Private) Partnerships*

Another concept fundamental to the implementation of MaaS is '(Public-Private) Partnerships', as several publications have demonstrated that the extent of government involvement can have a direct impact on potential barriers to market entry and whether a level playing field is established (Wong et al., 2019, pp. 9–11). However, whilst the importance of this concept cannot be understated, it is believed that the knowledge gap for this concept solely exists in terms of longitudinal studies, i.e. assessing the impact of government involvement in MaaS pilots directly in terms of attaining a set of both internal and policy-defined societal MaaS goals.

The final fundamental and contemporary relevant research field discussed in this paper is the type of integration between actor-owned mobility services, and consequently the degree of integration with regards to MSPs. Not only does the type of integration[20] have a direct impact on the level of personalisation that can be offered to the customer, but also on the overall network efficiency. As such, it is believed that because of the fundamental nature of software architecture and the potential impact of privacy regulations, there exists an immediate need for clarity with respect to best practices for the development of MaaS solutions.

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[20] Broker-type systems act much like interfaces to systems exposed by mobility providers. As such, the information known about the travel modalities would be limited to what is made public by these providers. These restrictions could not only result in reduced efficiency for the overall solution, as matching demand with supply becomes more challenging if managed improperly, but also limit the factors by which customisation is possible. An aggregator-type solution for MaaS faces similar challenges, however, would benefit from its customer-oriented nature and therefore have access to more customer data required for offering personalised services, which other types of MaaS solutions can often lack.

## 9.4 On the Identified Features and PDRs

With respect to the MaaS solution analysis performed in chapter 6, several features were identified and categorised on the basis of the MaaS Attributes listed in the MCF (Table 9; Table 10). The hierarchical interdependency between MaaS Attributes (Figure 4) was also found to be present in applications that contained functionality attributed to two or more of the MaaS Attributes. The latter is unsurprising due to the nature of the underlying data processes. This can be traced back to the subservient relations between MSP-type MaaS concepts.

Conversely, the comparison of MaaS solutions based on their PDRs yielded considerably more valuable insights. In a study performed by Cottrill (2019, p. 7), the privacy policy and underlying data resource requirements for Whim was analysed and argued to be representative of the field. In this study, it was instead found that Whim, whilst scoring below average and on-average on the 'total amount of requested permissions' and 'requested dangerous permissions' respectively, their privacy policy is of a relatively high complexity level in terms of readability and comprehensibility. To state that the privacy practices of Whim is therefore representative of other solutions in the MaaS domain – notwithstanding that their track record in balancing functionality-privacy trade-offs has been excellent so far – would be, in simple terms, a one-sided statement. From this analysis, it can be determined that MaaS solutions are, at the moment, simply too diverse in the functionality they offer, the goals they desire to achieve or the means by which the offered functionality is supported in order to argue that one is representative of the others.

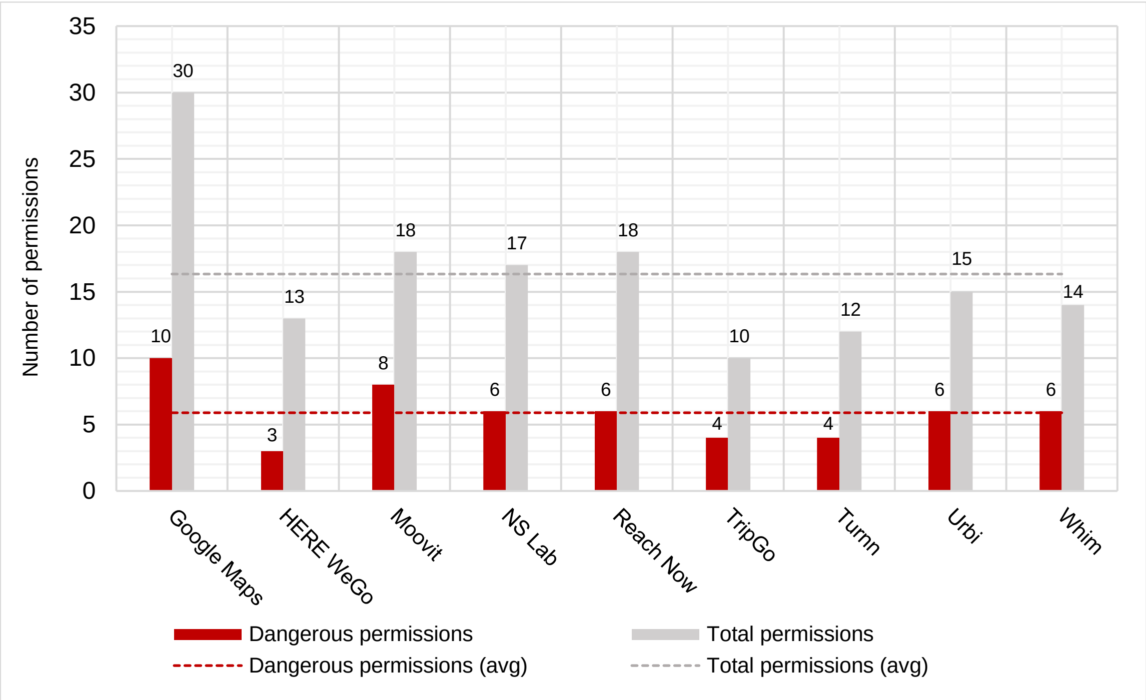


**FIGURE 9: OVERVIEW OF REQUESTED PERMISSIONS FOR EXISTING MAAS SOLUTIONS**

### 9.4.1 *Further Considerations on Feature/ PDR Identification Methods*

The features and personal data requirements identified as part of the research performed in this study are comprehensive within the limitations determined by its scope. This statement holds especially true when considering the momentum by which the mobility sector leaps forward with respect to the innovations in the field of information technology and telecommunications. This became clear during the course of the research, as new applications were launched or existing ones got updated almost every two weeks, or less. Therefore, it is realistic to assume that the information gathered as part of the privacy assessment or feature identification processes will be outdated not long after the research study's termination. One example of this phenomenon occurring can be seen in the NS Lab application, which was updated during the course of this research to include multimodal transport (i.e. shared electric scooters) otherwise not included in the basic services of NS to their customers[21].

In addition, the identified features do not include any publicly known upcoming features as this was not considered during the drafting of the used methodology. Whereas there is little information available on upcoming features – mostly due to the confidential nature of such documents –, some government and academic programmes can be used to infer upcoming features. One example is the TOMP-API specification, which is used in the development of a proposed standardised API model for Transport Operators to become MaaS Providers in the Netherlands (Reyes Garcia et al., 2020).

## 9.5 On the Feature Expectations and PDR-Acceptance of Users

Although the identification of MaaS capabilities and personal data requirements in Chapter 6 provided considerable insight into the (technical) design of MaaS applications, the information obtained was disconnected from practice until the associated user expectations and concerns related to the design of mobility applications were identified in Chapter 7 by means of a user study and a quantitative analysis performed on surveyed user preferences. During this user study, the feature expectations of users of mobility applications were mapped to socio-economic data provided by respondents, and relevant insights on privacy concerns were highlighted.

The results of the survey indicate that although mobility applications mostly cover the expected capabilities of MaaS applications in terms of ticketing and payment, several of the planning concepts proposed as part of novel mobility solutions (e.g. exploring facilities along the route, sharing real-time location with friends, or providing itineraries based on weather conditions) scored very low in terms of the functionality expected by respondents. As this can be dependent on local factors, detailed customer segmentation is recommended to mobility providers to verify the results of this research study for their local context.

Additionally, acceptance of PDRs by respondents was measured and PDRs were consequently classified as either 'acceptable', 'unacceptable', 'centralised' or 'polarised'. Most notably, an average of 31.7% of the respondents indicated their indifference towards the PDRs, indicating either that the respondents expected a privacy-functionality trade-off or that respondents simply did not care about the specific PDR being satisfied for use of a MaaS application.

[21] NS Lab was updated in the summer of 2020 to include Go Sharing scooters: https://community.ns.nl/denk-mee-met-de-ns-lab-app-68/go-sharing-in-ns-lab-65941

### 9.5.1 *Survey Limitations*

However, whilst the user study provided an increased general perspective, it was limited by its setup and research context. As there was no controlled research population set for the survey, the representativeness of the sample could not be verified, not successfully matched with other relevant publications in the field. Conversely, the survey was able to gather information from various countries and regions – this can be inferred from the limited familiarity of respondents with several of the surveyed MaaS applications that have a varying geographic coverage –, consequently resulting in a sample that is substantially more diverse in social values than otherwise would have been achieved.

## 9.6 On Design Recommendations

Addressing the final research question of this study, Chapter 8 aimed at providing a reference guide to designing and managing the development of MaaS solutions following design principles such as 'privacy-by-design' and 'privacy-by-default'. This was achieved by recommending the incorporation of privacy-functionality trade-offs into the design processes of software applications and enterprise architectures for DAD and TOGAF ADM, respectively.

Concerning DAD, privacy design requirements were incorporated in the initial modelling phase, architecture vision and feedback processes during the construction phase, whereas three phases of the TOGAF ADM (i.e. the Preliminary Phase, Phase A and Phase C) were marked as key moments in the architecture delivery process where privacy requirements can be embedded. Provided that mobility stakeholders are able to use one of these adapted design processes, it should provide their organisations with the means to deliver MaaS solutions that both adhere to 'privacy-by-design' and 'privacy-by-default' principles, whilst also achieving user-expected levels of service and limiting the overall impact on personal data processing.

Assorted Levels of Privacy was also proposed as a method to aid in the decision-making process for both the development team and the end-user, with the latter depending on the organisation's stance towards implementing maxims such as 'adaptability-by-design' in their software solutions (i.e. whether multiple feature implementations are provided to the user to choose from). This method should also provide product teams with the means to select from and operationalise privacy-specific design requirements, regardless of the selected design process.

## 9.7 Concluding Remarks

This research considers most cited definitions and conceptualisations of Mobility-as-a-Service in its own effort to conceptualise a novel mobility concept. Whilst some sources might have been left out due to the used literature selection methods, it is believed to be comprehensive and representative of the entire domain. As such, whilst it might not be complete, it both serves as a foundation for future research in this domain as well as a reference for those seeking to design, develop or otherwise interact with MaaS solutions.

Moreover, this study has provided insight into the data collection and processing practices of Mobility-as-a-Service applications. Although the results of the analysis are limited in scope as it attempts to cover all of the attributes identified in the previously-mentioned conceptualisation of MaaS, its implications are by no means limited. The results of the privacy analysis can be used to better tailor the design of current and future Mobility-as-a-Service applications to the needs and expectations of MaaS customers. Despite not being able to deliver a single template for the design of MaaS applications due to the higher conceptual levels of analysis, a method to utilise assorted levels of privacy was proposed as a privacy-focused process enhancement to enable privacy-aware design and development of Mobility-as-a-Service solutions.

To conclude, the findings and methods developed in this research have satisfied the research objectives set out at the start of this master’s thesis, provide a foundation for future research and aid in the privacy-aware design and development of Mobility-as-a-Service applications.

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# APPENDIX A: MATERIALS INCLUDED IN THE SLR

| Author(s) & Year | Title | DOI |
|---|---|---|
| (Sakai, 2019) | MaaS trends and policy-level initiatives in the EU | 10.1016/J.IATSSR.2019.11.00 |
| (Wong et al., 2019) | Mobility as a service (MaaS): Charting a future context | 10.1016/j.tra.2019.09.030 |
| (Esztergár-Kiss & Kerényi, 2019b) | Creation of mobility packages based on the MaaS concept | 10.1016/j.tbs.2019.05.007 |
| (Beutel et al., 2018) | Mobility service platforms: Cross-company cooperation for transportation service interoperability | 10.5220/0006705501510161 |
| (Willing et al., 2017) | Electronic mobility market platforms – a review of the current state and applications of business analytics | 10.1007/s12525-017-0257-2 |
| (Lamberth-Cocca & Meiren, 2017) | Service empathy board: A method for the agile development of mobility as a service | |
| (Tura et al., 2018) | Platform design framework: conceptualisation and application | 10.1080/09537325.2017.1390220 |
| (Mukhtar-Landgren & Smith, 2019) | Perceived action spaces for public actors in the development of Mobility as a Service | 10.1186/s12544-019-0363-7 |
| (Cottrill, 2019) | MaaS surveillance: Privacy considerations in mobility as a service | 10.1016/j.tra.2019.09.026 |
| (Jittrapirom et al., 2017) | Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges | 10.17645/up.v2i2.931 |
| (Melis et al., 2016) | Public transportation, IoT, trust and urban habits | 10.1007/978-3-319-45982-0_27 |
| (Pangbourne et al., 2019) | Questioning mobility as a service: Unanticipated implications for society and governance | 10.1016/j.tra.2019.09.033 |
| (Giesecke et al., 2016) | Conceptualising Mobility as a Service | 10.1109/EVER.2016.7476443 |

# APPENDIX B: MATERIALS INCLUDED IN THE SSLR

| Author(s) & Year | Title |
|---|---|
| (UITP, 2011) | Becoming a Real Mobility Provider |
| (Transport Systems Catapult, 2016) | Exploring the Opportunity for Mobility as a Service in the UK |
| (MaaS Alliance, 2017) | Guidelines & Recommendations to create the foundations for a thriving MaaS Ecosystem |
| (Polis, 2017) | Mobility as a Service: Implications for urban and regional transport |
| (Connekt, 2017) | Nederlands actieplan Mobility-as-a-Service |
| (European Parliamentary Technology Assessment, 2017) | Shaping the Future of Mobility – Mobility Pricing in Europe and beyond |
| (Goodall et al., 2017) | The rise of Mobility as a Service |
| (Van Audenhove et al., 2018) | Future of mobility 3.0 |
| (Kamargianni et al., 2018) | Londoners’ attitude towards car-ownership and Mobility-as-a-Service: Impact assessment and opportunities that lie ahead |
| (Foresight & Government Office for Science, 2018) | Mobility as a Service (MaaS) in the UK: change and its implications |
| (CUBIC Transportation Systems, 2018) | Mobility as a Service: Putting Transit Front and Center of the Conversation |
| (Falconer et al., 2018) | Mobility-as-a-Service – The value proposition for the public and our urban systems |
| (Dooley, 2018) | Special report: The future of mobility in Helsinki |
| (Ministerie van Infrastructuur en Waterstaat, 2019b) | Contouren Toekomstbeeld OV 2040 |
| (Nederlandse Spoorwegen, 2019b) | Journey to the future |
| (Urban Transport Group, 2019) | MaaS Movement? Issues and options on mobility as a service for city region transport authorities |
| (van Nieuwenhuizen Wijbenga & van Veldhoven - Van der Meer, 2019) | Optimaliseren van het mobiliteitssyteem via MaaS |

# Appendix C: User Survey

You are being invited to participate in a research study titled "Inner Join Privacy: Incorporating Functionality-Privacy Trade-Offs in Mobility-as-a-Service Solution Design Methods". This study is being performed by P.B. den Boer as part of his master's thesis for Business Information Technology at the University of Twente.

The purpose of this research study is to improve personal data protection practices in Mobility-as-a-Service (MaaS) solutions by developing a comprehensive privacy assessment of mobility applications. As part of the analysis, the importance given by you to specific functionality of these applications is included.

The survey will take you approximately 20 minutes to complete. The data collected in this survey will be used to assess the importance of application functionality and personal data requirements within the design of these mobile applications. The personal data collected in this survey is collected anonymously and used only to compare groups of respondents between studies.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any question. You must be at least 16 years old to participate in this survey.

We believe there are no known risks associated with this research study; however, as with any online related activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by limiting the number of personal questions to a minimum, restricting access to the raw data set to the researchers involved with the study and deleting the raw data set after the research study has concluded. No personally identifiable information will be reported in any research product.

If you have any questions, please reach out using the following contact details: P.B. den Boer, p.b.denboer@student.utwente.nl

* Required

1. I have read the research description, and agree to the above-mentioned data collection practices for the purposes this research study *

   ☐ Yes, I agree

## Your Living Situation

In this section, you will be asked several questions regarding your living situation. Please answer these questions as accurately as possible. If you do not know the answer to a question, do not believe any of the options apply to you, or you simple don't want to answer, you can leave that question blank.

2. What is your gender?

- ◯ Woman
- ◯ Man
- ◯ Non-binary

3. What is your age?

[ ]

Please enter a number greater than 16

4. What is your highest level of education that you have completed?

- ◯ Primary Education
- ◯ Secondary Education
- ◯ Secondary Vocational Education and Training
- ◯ Higher professional education (e.g. University of Applied Sciences)
- ◯ Research-oriented education (e.g. Research Universities)

5. What is your work status?

- ◯ Working
- ◯ Not working

6. What is the composition of your household?

- ◯ Just me
- ◯ Living with my partner(s)
- ◯ Living with my partner(s) and children
- ◯ Living with my children
- ◯ Other

7. What is your living environment?

- ◯ I live in the city
- ◯ I live in the suburbs
- ◯ I live in a smaller village or rural area
- ◯ Other

8. What is your personal net monthly income?

- ◯ No personal income
- ◯ Below € 2000
- ◯ Between € 2000 and € 3000
- ◯ Above € 3000

## Your Mobility Lifestyle

In this section, you will be asked several questions regarding your living situation. Please answer these questions as accurately as possible. If you do not know the answer to a question, do not believe any of the options apply to you, or you simple don't want to answer, you can leave that question blank.

9. Which modes of transport have you used? (select all that apply)

- ☐ Bicycle
- ☐ Scooter
- ☐ Motorcycle
- ☐ Bus
- ☐ Tram
- ☐ Metro/ subway
- ☐ Train
- ☐ Car
- ☐ __________ Other

10. Do you own a car in your household?

- ◯ Yes
- ◯ No

11. Do you own a public transport card?

- ◯ Yes
- ◯ No

12. Have you ever used a bicycle sharing scheme?

*Popular examples include OV-Fiets, Mobike, Citi Bike, Bicing and Santander Cycles.*

- ◯ Yes
- ◯ No

13. Have you ever used a car sharing scheme or ride-hailing service?

- ◯ Yes, a car sharing scheme (e.g. Greenwheels, ShareNow)
- ◯ Yes, a ride-hailing service (e.g. Uber, Lyft)
- ◯ Yes, I've used both
- ◯ No, I've used neither

14. Are you familiar with any of the following mobile applications? (select any that apply)

- ☐ Google Maps
- ☐ HERE WeGo
- ☐ Moovit
- ☐ NS Reisplanner
- ☐ NS Lab
- ☐ Reach Now
- ☐ TripGo
- ☐ Turnn
- ☐ Urbi
- ☐ Whim

## Planning your journey

In this section, you will be asked questions regarding your journey planning behaviour. Please answer these questions as accurately as possible. If you do not know the answer to a question, do not believe any of the options apply to you, or you simple don't want to answer, you can leave that question blank.

15. Have you ever used a mobile application to plan your journey?

- ◯ Yes
- ◯ No

## Planning your journey

In this section, you will be asked questions regarding your journey planning behaviour. Please answer these questions as accurately as possible. If you do not know the answer to a question, do not believe any of the options apply to you, or you simple don't want to answer, you can leave that question blank.

16. Do you intend to use a mobile application in the future to plan your journey?

- ◯ Yes
- ◯ No
- ◯ Maybe

## Planning your journey

In this section, you will be asked questions regarding your journey planning behaviour. Please answer these questions as accurately as possible. If you do not know the answer to a question, do not believe any of the options apply to you, or you simple don't want to answer, you can leave that question blank.

17. What is your reason for not using a mobile application to plan your journey?

- ◯ I prefer paper maps
- ◯ I don't own a mobile device
- ◯ I don't need a mobile application
- ◯ I have privacy concerns
- ◯ [ ] Other

## Your expectations of functionality offered by mobility applications

In this section, you will be asked questions regarding your expectations of mobility applications. Please answer these questions as accurately as possible. If you do not know the answer to a question, do not believe any of the options apply to you, or you simple don't want to answer, you can leave that question blank.

18. Please indicate for each of the functionalities whether you consider it "important" for mobility applications to offer this functionality whilst planning your journey.

| | Not at all important | Not important | Somewhat important | Important | Very important |
|---|---|---|---|---|---|
| Select departure and destination locations | ◯ | ◯ | ◯ | ◯ | ◯ |
| Choose favourite or frequently-used locations and/or routes | ◯ | ◯ | ◯ | ◯ | ◯ |
| Compare travel advice based on distance travelled, travel duration, price, etc. | ◯ | ◯ | ◯ | ◯ | ◯ |
| Select modes of transport | ◯ | ◯ | ◯ | ◯ | ◯ |
| Explore facilities along the route | ◯ | ◯ | ◯ | ◯ | ◯ |
| Change departure time and date | ◯ | ◯ | ◯ | ◯ | ◯ |
| Limit search results to only include modes of transport that I have access to | ◯ | ◯ | ◯ | ◯ | ◯ |
| Include additional transfer time | ◯ | ◯ | ◯ | ◯ | ◯ |
| Limit to accessible journeys | ◯ | ◯ | ◯ | ◯ | ◯ |
| Limit walking distance | ◯ | ◯ | ◯ | ◯ | ◯ |
| Share real-time location with selected other people during transit | ◯ | ◯ | ◯ | ◯ | ◯ |
| Step-by-step guidance | ◯ | ◯ | ◯ | ◯ | ◯ |
| Text-to-speech (TTS) directions | ◯ | ◯ | ◯ | ◯ | ◯ |
| Offline navigation | ◯ | ◯ | ◯ | ◯ | ◯ |

| | Not at all important | Not important | Somewhat important | Important | Very important |
|---|---|---|---|---|---|
| Filter or sort travel advice based on distance travelled, travel duration, price, etc. | ○ | ○ | ○ | ○ | ○ |
| Real-time rerouting in case of disruptions | ○ | ○ | ○ | ○ | ○ |
| Real-time departure times of public transit | ○ | ○ | ○ | ○ | ○ |
| Add itinerary to personal calendar (calendar export) | ○ | ○ | ○ | ○ | ○ |
| View current weather situation | ○ | ○ | ○ | ○ | ○ |

19. Please indicate for each of the functionalities whether you consider it "important" for mobility applications to offer this functionality whilst selecting your ticket.

| | Not at all important | Not important | Somewhat important | Important | Very important |
|---|---|---|---|---|---|
| Select tickets or time slots for each part of the journey | ○ | ○ | ○ | ○ | ○ |
| Choose single ticket, day return or other ticket types | ○ | ○ | ○ | ○ | ○ |
| Apply fare reduction based on travel group size | ○ | ○ | ○ | ○ | ○ |
| Compare ticket offers by price between different providers and booking offices | ○ | ○ | ○ | ○ | ○ |
| Compare ticket offers by price based on applicable mobility subscriptions | ○ | ○ | ○ | ○ | ○ |
| Choose different travel class for public transit tickets | ○ | ○ | ○ | ○ | ○ |
| Choose from specific seating options (e.g. window seating or more legroom) | ○ | ○ | ○ | ○ | ○ |
| Select tickets based on age group (e.g. tickets for elderly citizens or minors) | ○ | ○ | ○ | ○ | ○ |
| Select from discount offers | ○ | ○ | ○ | ○ | ○ |

20. Please indicate for each of the functionalities whether you consider it "important" for mobility applications to offer this functionality whilst booking your ticket.

| | Not at all important | Not important | Somewhat important | Important | Very important |
|---|---|---|---|---|---|
| Confirm ticket details before checkout | ◯ | ◯ | ◯ | ◯ | ◯ |
| Apply discount coupons before checkout | ◯ | ◯ | ◯ | ◯ | ◯ |
| Export and print out tickets on paper (e.g. QR-/ barcodes) | ◯ | ◯ | ◯ | ◯ | ◯ |
| Digitally store tickets on mobile devices (e.g. QR-/ barcodes) | ◯ | ◯ | ◯ | ◯ | ◯ |
| Choose a tip for ride hailing/ taxi drivers | ◯ | ◯ | ◯ | ◯ | ◯ |
| Change between anonymous tickets or person-bound tickets | ◯ | ◯ | ◯ | ◯ | ◯ |

21. Please indicate for each of the functionalities whether you consider it "important" for mobility applications to offer this functionality whilst paying for your ticket.

| | Not at all important | Not important | Somewhat important | Important | Very important |
|---|---|---|---|---|---|
| Pay for single tickets | ◯ | ◯ | ◯ | ◯ | ◯ |
| Pay through prepaid or pay-as-you-go smart card schemes | ◯ | ◯ | ◯ | ◯ | ◯ |
| Pay through pre-defined mobility subscriptions | ◯ | ◯ | ◯ | ◯ | ◯ |
| Pay using payment terminals in or around individual modalities | ◯ | ◯ | ◯ | ◯ | ◯ |
| Pay using direct debit or credit schemes | ◯ | ◯ | ◯ | ◯ | ◯ |

## Personal Data Requirements

In this section, you will be asked questions regarding your perspective on the personal data requirements of MaaS applications. Please answer these questions as accurately as possible. If you do not know the answer to a question, do not believe any of the options apply to you, or you simple don't want to answer, you can leave that question blank.

22. Please indicate your level of concern for each of the following permissions requested by a mobile application.

| | Not concerned | Somewhat concerned | Very concerned |
|---|---|---|---|
| Access your background location | ○ | ○ | ○ |
| Access your approximate location | ○ | ○ | ○ |
| Access your precise location | ○ | ○ | ○ |
| Access geographic locations of images | ○ | ○ | ○ |
| Access to information about nearby mobile networks, such as 4G | ○ | ○ | ○ |
| Access information about Wi-Fi networks | ○ | ○ | ○ |
| Recognize physical activity | ○ | ○ | ○ |
| Connect to paired bluetooth devices | ○ | ○ | ○ |
| Discover and pair bluetooth devices | ○ | ○ | ○ |
| Temporarily store data broadcasted to the device | ○ | ○ | ○ |
| Initiate a phone call without going through the dialing interface | ○ | ○ | ○ |
| Access all camera functionality | ○ | ○ | ○ |
| Enable or disable cellular network connectivity (e.g. 4G) | ○ | ○ | ○ |
| Enable or disable Wi-Fi network connectivity | ○ | ○ | ○ |

| | Not concerned | Somewhat concerned | Very concerned |
|---|---|---|---|
| Disable the lock screen PIN or other types of authentication | ○ | ○ | ○ |
| Download files and data in the background without notification | ○ | ○ | ○ |
| Enable or disable the flashlight | ○ | ○ | ○ |
| Appear in the foreground of the mobile device | ○ | ○ | ○ |
| Retrieve a list of accounts stored on your device | ○ | ○ | ○ |
| Check the size of any application installed on the device | ○ | ○ | ○ |

23. Continued from the previous question: please indicate your level of concern for each of the following permissions requested by a mobile application.

| | Not concerned | Somewhat concerned | Very concerned |
|---|---|---|---|
| Connect to the internet | ◯ | ◯ | ◯ |
| Manage the accounts stored on your device | ◯ | ◯ | ◯ |
| Change the audio settings of your device | ◯ | ◯ | ◯ |
| Access NFC | ◯ | ◯ | ◯ |
| Authenticate with other accounts on the device | ◯ | ◯ | ◯ |
| Read your calendar | ◯ | ◯ | ◯ |
| Read your contact list | ◯ | ◯ | ◯ |
| Read the files on your SD card | ◯ | ◯ | ◯ |
| Access the state of the phone, e.g. cellular network information, ongoing calls and SIM-cards installed | ◯ | ◯ | ◯ |
| Read settings synchronized across devices | ◯ | ◯ | ◯ |
| Get notified when the phone has finished starting up/ booting | ◯ | ◯ | ◯ |
| Record audio | ◯ | ◯ | ◯ |
| Appear on top of other applications | ◯ | ◯ | ◯ |
| Access biometric authentication methods | ◯ | ◯ | ◯ |
| Access your fingerprint | ◯ | ◯ | ◯ |
| Vibrate your device | ◯ | ◯ | ◯ |

| | Not concerned | Somewhat concerned | Very concerned |
|---|---|---|---|
| Keep the device awake (e.g. prevent the screen from dimming) | ◯ | ◯ | ◯ |
| Write to your calendar | ◯ | ◯ | ◯ |
| Write to your SD card | ◯ | ◯ | ◯ |
| Write settings to be synchronized across devices | ◯ | ◯ | ◯ |