SUPPORTING DOOR-TO-DOOR AIR TRAVEL: TOWARDS A PRIVACY PRESERVING VIRTUAL ASSISTANT FOR PASSENGERS

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ABSTRACT

Seamless and personalised door-to-door air transport, supported by virtual assistants, has the potential to make air travel more convenient and profitable. However, processing passengers’ data comes with major privacy concerns. Commercial interests and functionalities need to be reconciled with data protection. Current concepts do not meet these requirements. Filling this gap, this paper conceptualises an architecture for a travel assistant that mediates between mobility and air transport providers as well as passengers while assuring privacy through local computation. The concept targets a time horizon of 10+ years and addresses steady growth of air passenger volume (post-Covid) with a technical solution that includes an open, modular platform. The proposed architecture can support business advantages like network effects, the improvement of passengers’ overall travel experience, and a new approach that ensures traveller’s privacy online. Further research and the development of a prototype are necessary for first simulations and implications.

KEYWORDS

privacy, intermodal travel, mobility integrator, travel companion, virtual travel assistant, local computation

1 INTRODUCTION

1.1 Personalised Door-To-Door Air Travel

The current aviation system requires a rethinking of intermodal travel chains, especially those including air transport. Air travellers need to consider not just the flight segment, but also organise corresponding feeders to and from the airport (DATASET2050, 2018; Rothfeld et al., 2019; Schmitt & Gollnick, 2016). Such intermodal, door-to-door (D2D) travel chains are associated with high organisational efforts on the demand side: coordinating timetables, purchasing several tickets, and comparing fares, including buffer time in case of disruptions and delays. Increasing complexity further, tickets and schedules are often not compatible with other systems and several information sources are available, e.g. the airport website, airline website or app, and third parties such as Expedia (2019) or Skyscanner (2021). A large amount of personal data are created along those D2D air journeys, for instance passengers' name, date of birth, financial data, and itineraries. Further, passengers have different travel profiles and respective needs (Grahn & Jacquillat, 2020; Kluge et al., 2018; Siren & Haustein, 2013, 2015; Zorro et al., 2018). Personal requirements will continue to rise in the future, as passengers are likely to demand a high degree of personalisation and value-adding usage of travel time throughout their D2D journey (Kluge, Ringbeck et al., 2020). Digital transformation in the mobility sector offers new opportunities to air transport providers for advancing their services but also to air travellers for getting personalised support on their journeys. Tailored, intermodal mobility with the use of technology are main pillars within the endeavour of *Mobility as a Service (MaaS)* (Jittrapirom et al., 2017; Kamargianni et al., 2016). Looking ahead, travellers might be supported by a virtual assistant to create a seamless and individualised travel experience.

The data that users provide for and create during the journey will be of utmost importance for an effective virtual assistant but on the other hand, the protection of personal data is one main user requirement for such digital companion applications (Dolinayova et al., 2018). At present, users of such systems must disclose their personal data to various service providers for support and personalisation, which poses a threat to their privacy and raises legal concerns in international travel. Thus, a trustworthy personal D2D travel assistant is needed and will only be successful if the users' sovereignty in terms of privacy can be guaranteed, while also including many mobility providers' offers. Current solutions seem to be insufficient and ignore the important need for genuine privacy protection, as there are hardly any incentives for providers to protect the privacy of users. The only way to participate in the more comfortable digital services is to give up on at least some privacy concerns and sign off on agreements that cover only a legal minimum. In fact, privacy protection seems to conflict with business objectives, as personal data might also be used for secondary exploitation or passed on to subsidiary companies, which can hardly be in the interest of passengers. In addition, multiple mobility providers process this information to make matching offers.

1.2 A Concept for the Virtual Air Travel Assistant

To tackle these issues, this work proposes the concept of a virtual travel assistant (VTA) which aims to support seamless D2D air travel while maintaining user privacy. The concept is an outline of how this goal can be achieved. The focus on privacy protection is motivated by the functional and personal interests of the traveller, by the successful integration of air transport and mobility providers, as well as by the societal effects of increased digital travel. All essential requirements, such as (1) commercial business interests, (2) user privacy, and (3) personalisation and seamless travel, should be aligned. As these requirements are partly in conflict with each other, the goals are defined here as the "Triangle of Tension" (ToT).

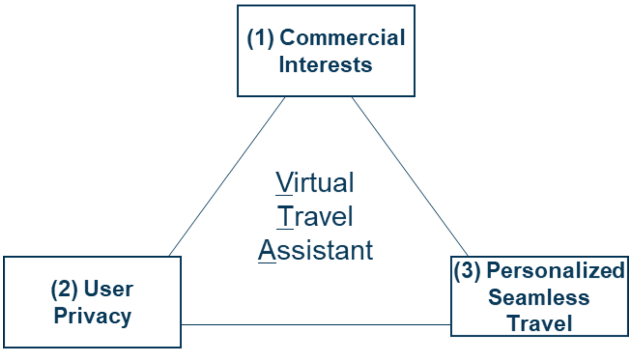


Figure 1 - VTA requirements summarised within the "Triangle of Tension" (authors' depiction)

The problem examined here is driven by preliminary considerations: Firstly, focusing on the airport environment as a main connecting node within intermodal travel, a time horizon of 10+ years is considered. Secondly, technological developments soon will enable new network and hardware services that influence the provision of digital travel services.

The proposed concept addresses privacy concerns for supranational travel assistants, such as: data sovereignty, reliable personal data flow control, metadata leakage and trustworthiness. To this end, the concept combines advances in computing, networking and the software stack into an architecture that tackles the challenges of the ToT. The major technical component towards this goal is the exclusive use of local computing, combined with suitable isolation and networking strategies. A comprehensive overview of the results is summarised in Table 2.

1.3 Contribution to Academia and Practice

To the best of our knowledge, simultaneously addressing potential conflicting requirements as presented in the ToT does not take place in existing concept or related work explored by scholars (Classen et al., 2017; Csiszár & Nagy, 2017; Faye et al., 2017; Schulz et al., 2018). Although there is agreement on the benefit of travel companions in research (DORA, 2018; Fei et al., 2016; Keseru et al., 2020; Lubbe & Louw, 2010; Mobility4EU, 2018; My-TRAC, 2017; PASSME, 2018; Urban et al., 2017), most approaches focus on business or functional requirements and leave out a socio-technical perspective that recognises "Why Privacy is Important" (Rachels, 1975, S. 1) – which may be one reason for the users' avoidance attitude towards virtual assistants (Chowdhury, 2018). This is supported by prior research which suggests that more discussion and design approaches need to be conducted on information systems with privacy as a key construct (Bélanger & Crossler, 2011). Hence, this paper fills this gap within academia by proposing a solution addressing and aligning the challenge of combining commercial and user needs. The review in section 3.2 further discusses how privacy is taken into practice within current mobility integrators on the market. This proposal harmonises all requirements illustrated in the ToT, while at the same time providing feasible business incentives, making the VTA concept also of high interest for mobility providers in the industry. Especially practitioners in the air transport sector (airlines and airports) can benefit from the solution proposal as the architecture offers a feasible way to provide real D2D transport, beyond the mere air transport segment. This can increase the satisfaction and experience of passengers and meet their demands for personalisation. Further, data protection is becoming a widely discussed topic. We consider guaranteed privacy as a key feature to stand out, create trust and attract passengers. Finally, the Covid-19-related crisis is affecting the aviation system since 2020 (Albers & Rundshagen, 2020; Maneenop & Kotcharin, 2020; Pearce, 2020) and the VTA could help to regain travellers' trust into air travel post-Covid (Kluge, Paul et al., 2020). Next to operational measures and health screening controls (Alonso Tabares, 2021; IATA, 2020) the VTA concept could support practitioners to create a touchless environment with high data safety within industry mitigation initiatives, such as in the (digital) health pass proposed by the IATA (2021).

The paper is structured as follows. After the introduction, section 2 presents a stakeholder analysis and the system requirements. Section 3 delineates prior work and existing products on the market. Section 4 presents the technical solution proposal of the VTA concept. Section 5 presents results and managerial implications. Further research and limitations are discussed in section 6.

2 DEFINITIONS AND PROBLEM DESCRIPTION

The goal of this research is to review the requirements that a future travel assistant will have to fulfil and to provide a high-level architecture for a VTA. Stated simply, the VTA problem is the following: *How can a virtual travel assistant support a future passenger on his/her D2D air journey while, at the same time, maintaining strict information privacy?* To address this problem, let us first provide a stakeholder analysis, followed by definitions and requirements.

2.1 Stakeholder Analysis

As mentioned, VTAs are motivated by the goal of a seamless, intermodal travel experience and by the digital transformation in the travel process. This involves various stakeholders; however, their interests might differ. The VTA's key stakeholders, adapted from the systematic description of air transport by (Schmitt & Gollnick, 2016), are discussed below.

The *traveller* (demand side) has two main interests: First, being supported in the D2D journey according to his/her needs (personalisation) and second, maintaining his/her privacy and sovereignty. The *mobility providers'* core business is the transport of people and surrounding business opportunities (supply side). Next to airlines, these can be taxi providers, public transport providers (Budd et al., 2016; Rothfeld et al., 2019; Schmitt & Gollnick, 2016), private vehicles for access and egress (Alkaabi, 2019) or novel mobility concepts like ridesharing (Young & Farber, 2019). Future modes of transport, such as autonomous driving vehicles (Lutin, 2018) and urban air mobility (Straubinger et al., 2020; Sun et al., 2018) could also become airport feeders in the period of 10+ years. Providers have a commercial interest in increasing the load factor, operating cost-efficiently, maintaining the brand and selling tickets. Often, the mobility provider overlaps or is affiliated with service providers. The traveller as well as the mobility provider are most important in the service provision and any travel assistant must clearly lay out how their commercial offer will be integrated. The *service provider* builds on the existing travel service ecosystem and sells accompanying service offers (supply side). The ecosystem may include digital travel agencies (Javornik et al., 2018) but also hotel chains, local stores, travel insurers or agencies for special personalised services. Such service providers might be interested in sales, visibility, and customer loyalty. The *infrastructure provider* maintains the infrastructure used by the mobility provider and the traveller (supply side). This might be a municipality, an airport operator (air traffic infrastructure (Schmitt & Gollnick, 2016)) or a private investment group. The infrastructure provider has an interest in its stationary facilities being used or in more visitors coming to an area. *Legislature* (or politics) provide the regulatory and legal framework

(Schmitt & Gollnick, 2016); here in particular with regard to freedom of travel, international travellers' and data protection. The interest of the legislature is to protect its citizens, maintain security and enable business operations, which is all handled differently in various countries and becomes important especially regarding sovereignty during national and international travel. Further, agendas such as the Flightpath2050 set the tone for many research and industry activities. For instance, seamless travel is named as one of the main key objectives for the European aviation system (European Commission, 2011). A strong focus is also set on environmental protection in transport through decarbonisation and operational efficiency improvements, as elaborated in the European Green Deal (European Commission, 2019). Currently, travel applications are mostly offered directly by mobility providers or service providers. Travellers' interests can easily fade into the background: for example, an airline providing flights is interested in functions that increase turnover or customer loyalty, while a travel manager tries to sell accompanying services.

All stakeholder described share a common interest in an effective travel assistant, but individual interests vary and must be considered in the architecture. To provide real D2D air travel services, both supply and demand side are required to participate in a VTA. Consequently, there must be a commercial incentive for mobility and service providers to participate - otherwise the VTA will not be able to deliver the desired functionality. This assumption is incorporate in this VTA concept proposal.

2.2 Time Frame

This research examines the concept for a VTA with a period of 10+ years in the future. The reason for this relatively far forward view is based on the following two considerations. First, one motivation is the expected increase in global air travel during this period. Currently, we face the Covid-19 induced crisis and a stagnation in air travel activities. We assume a recovery within the next years and air travel levels to recover by 2024 as outlined by (Pearce, 2020). We are aware of many uncertainties regarding air travel recovery and hence, assume 2024 as a hypothetical year for a full recovery (but are not stating any forecasts at this point). Further, some domestic markets, such as China, USA and Russia, are already on the road to pre-Covid-19 levels (as of mid-2021). Air travel will continue to have a considerable impact on greenhouse gas emissions and other types of emitted pollution (Lee et al., 2021). This subsequently demands to further increase efficiency in air travel, as outlined as a major (air) mobility long-term goal in the CAMERA Performance Framework (Paul et al., 2018). Overall, the next years provide ample room for improving the system and prepare it towards a better air travel experience. Second, the VTA poses challenges in terms of privacy protection as well as the integration of various mobility providers, since many service providers from the infrastructure sector must be persuaded to cooperate. However, changes affecting established mobility providers, in particular in aviation, can take a long time before the implementation, which makes a sustainable, prospective concept necessary. A ten-year perspective also allows for the possibility of envisioning radically new concepts that include capabilities only available in future technological platforms. Current solutions are centralised, and most upcoming concepts still disregard the protection of travellers' privacy, a situation that demands for new concepts under different preconditions. These future concepts, however, must have a broad time horizon to offer long-term alternatives.

2.3 Functionality

As explained in section 2.1, the main function of the assistant is to provide comprehensive support to the traveller in his/her D2D air journey while maintaining privacy. The focus on international, multimodal travel requires a concept that supports the inclusion of multiple providers. To achieve a sustainable platform, the functionality must also include strong incentives for commercial operators to participate in the platform and uphold their own interests.

2.4 Detailed Explanation of Door-To-Door Travel

D2D air travel needs to be understood from the traveller's point of view. In this paper, the term door-to-door is defined as the entire travel chain for air transport passengers, covering each segment from the physical door of the starting point to the physical door of the final destination. The door-to-kerb (D2K) and kerb-to-door (K2D) segments are equivalent to the access and egress of passengers to respectively from the airport, known as feeder traffic or surface transport. Such feeders can be covered by public transport, private vehicle, taxi-services, ride-and car sharing (Budd et al., 2016; Rothfeld et al., 2019; Schmitt & Gollnick, 2016; Young & Farber, 2019) but also future modes of transport (Lutin, 2018; Sun et al., 2018). The airport environment is one of the main touch points in the travel chain, covering the kerb-to-gate (K2G) and gate-to-kerb (G2K) segments. The gate-to-gate (G2G) part of the journey is covered by the actual flight provided by airlines (DATASET2050, 2018; Schmitt & Gollnick, 2016).

In a Delphi study (Kluge, Ringbeck et al., 2020) examined future passenger needs within D2D air travel in 2035. Among other confirmed projections, they identify one future requirement on the demand side: the option for personalisation of one's D2D journey. Travelers differ in many ways, for instance, elderly passengers already travel differently than younger digital natives (Ketter, 2020; Siren & Haustein, 2013, 2015). This becomes apparent in their travel planning (Grahn & Jacquillat, 2020) and shall be incorporated as a main requirement in the VTA solution proposal. Within each travel segment, passengers can also experience different levels of stress and the airport contains stressful touch points. Negative emotions have their peaks at the passport check, the security check, and the bag collection in the K2G and G2K segments (Kefalidou, 2015). One solution for reducing these stress levels is the use of virtual assistants. However, airports do not seem to be an innovative business environment to promote improvements in the travel experience with little investments being made into start-ups and products (Lufthansa Innovation Hub, 2019b). Developing a customers' journey map for leisure air travellers', (Inversini, 2017) discovers that passengers' activities before, during and after the journey vary greatly. Whereas pre-journey activities are often related to organising, checking, and booking, passengers seem to look for relaxation in the airport environment, such as shopping, enjoying coffee, reading and eating. Hence, travel assistants such as the VTA concept shall provide required information and services at the right time of the journey and according to respective individual needs. Besides these direct effects during travel, the airport is also the interface to countries with different privacy protection laws and regulation. An approach to a VTA must consider this and provide a high level of privacy protections for users throughout different regions.

2.5 Privacy In Digital Traveling

A future traveller will travel within a reliable and capable digital infrastructure; mobile devices will become more powerful, reliable, and widely distributed. First exploratory studies have shown how personal devices could increase the overall customers' D2D air journey (Inversini, 2017). This will lead to more mobility providers worldwide offering their services via digital distribution channels and ultimately reducing their range of analogue services, making traveling with digital tickets and travel assistants the norm. This has two consequences. Firstly, international journeys will increasingly be handled digitally. Secondly, travel without a digital device will become cumbersome, time-consuming and expensive. By going through a complete digital travel chain, the traveller discloses sensitive personal information that is not needed for the actual transport and whose processing the passenger can no longer control. This creates an imbalance in favour of transport companies, as mobility providers can then track and otherwise use the movement of individuals. While in many countries lawful obligations exist to carry passengers for all public transport providers (for example the "Beförderungspflicht" in Germany (PBefG, 1961)), the privacy policies of transportation providers vary greatly. Although some providers advertise to sell tickets online without registration, the provisioning of personal information – in addition to payment information –

is still required to complete the checkout process, for example at the major transportation provider "Deutsche Bahn". In general, traveling without the disclosure of personal information is only possible as far as digital services can be avoided. New mobility platforms often even build upon their users' personal data instead of the actual transportation service fees. While not all transportation providers make further use of the customers' data, the collected information is nevertheless at risk to be exposed by unauthorised access. This puts all digital passengers at the risk of unwillingly exposing sensitive information, and largely restricts the privacy-aware traveller in their choice of mobility. Finally, once installed, personalised digital travel can be abused to selectively restrict access to public transportation, as recent developments in China's social credit system, the selective travel ban, have shown (Chan, 2017; Jee, 2019; Kuo, 2019). On the other hand, it can be argued that the preservation of unrestricted access to digital traveling supports the application of Article 12 (about privacy) and Article 13 (with regard to freedom of movement) of the Universal Declaration of Human Rights. Dependence on digital travel in its current and emergent form thus becomes a threat to individual sovereignty and fundamental rights – even more during journeys abroad, where one's data is less protected by national privacy laws. Guaranteed privacy is therefore a key feature to stand out, create trust and attract users.

2.6 Triangle Of Tension

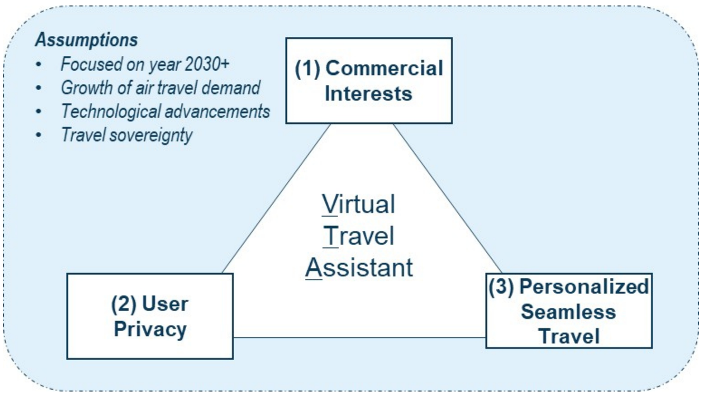


Figure 2. Triangle of Tension with assumptions in this research

In the previous analysis, the user's data protection was identified as a central building block for confidence building and acceptance. The user's privacy is therefore on a par with the commercial interests of the mobility and service providers. This result in the following "Triangle of Tension" (see Figure 2).

A VTA concept will have to provide a personalised yet private and seamless travel experience while attracting commercial providers, on the assumption of technological advancements and a growth in traffic volume. As elaborated, these goals have partially conflicting interests. In the following, requirements on such concept are discussed in more detail.

2.7 Requirements

The VTA shall offer services partly adapted from (Dolinayova et al., 2018), who reveal traveller's requirements on a travel companion application with a focus on public transport. The requirements have been adapted for the purposes of this research, as D2D air travel chains also include public transport as part of the D2K and K2D segments. The list of requirements is further underpinned by the review in section 2.3.1, by work from (Bélanger & Crossler, 2011; Jittrapirom et al., 2017; Kluge et al., 2018; Kluge, Ringbeck et al., 2020; Urban et al., 2017) and by strategic goals outlined in the Flightpath2050 (European Commission, 2011). The different functions are shown below.

Functional requirements

- **Seamless travel support:** assistance on a multimodal air journey, with pre-arrangements before and during the journey, to the greatest possible extent.
- **Disruption** management**:** real-time updates on any possible disruptions, automatic re-routing and re-booking if necessary.
- **Personalisation:** ability to integrate personalised information to fulfil the needs of diverse users as travellers will increasingly demand personalisation throughout their travel chain.
- **Purchase of tickets and services:** enabling a payment process for purchasing mobility and other journey related services.

Non-functional requirements

- **Information privacy:** the VTA must not reveal personal information of the traveller to any provider or operator. It shall also be traceable in what way personal data will be stored and processed.
- **Sovereignty in travel:** the VTA must allow to book tickets for any mode of transport anonymously (in accordance to the law) without registration.
- **Transparency:** the actions of the VTA must be comprehensible as far as they concern information that is transferred to another party.
- **Openness:** the VTA concept must be open for participation by all interested providers and operators without restrictions or fees.

3 LITERATURE REVIEW

3.1 Prior Work on Travel Assistants

Intermodal air travel is in scope of recent publications, showing its high relevance. (Li et al., 2018) explore factors influencing air-rail partnerships. (Chiambaretto et al., 2013) measure passengers' willingness to pay for air-rail products. (Merkert & Beck, 2020) show how the integration of services between providers (on example of air-bus services) can create a competitive advantage. Several scholars also work on theoretical concepts of D2D travel assistants. (Dolinayova et al., 2018) explore passengers' preferences regarding travel assistants. (Classen et al., 2017) present a modular research prototype improving passengers' D2D travel experience and managing airport operations in an efficient and proactive manner. However, Classen et al. rely on passengers' input from the concept of the *Passenger-Trajectory*. Hence, passenger have to disclose their personal travel plans in order to gain real-time updates (which is a part of the overall system). Sample data from the *Passenger-Trajectory* (e.g. via passengers' device) can also be integrated into the forecasting for the prototype, hence, potentially passing data to third parties as the system is built to various stakeholders operating at the airport. Moreover, passengers' data (individual and anonymous) are gathered and used within several modules within the prototype system. The lack of integrating several providers, data sources and journey information within one application is explored by (Csiszár & Nagy, 2017), who develop a framework for an integrated information system solution for air passengers. Personal mobile applications are identified as the feasible channel to provide such integrated services (front end). Their concept builds on existing databases and does not consider future technological advancements. Moreover, the concept lacks strong managerial implications and only provides the theoretical framework. Another travel companion pilot is developed in the My-TRAC (2017) project providing multimodal services to passengers, such as route planning, disruption management, journey customisation, and ticketing. The architecture allows an easy integration of various provider on one platform. Although functionalities and goals are similar to the VTA concept, the My-TRAC ecosystem does not build on strict privacy requirements and focuses on D2D rail journeys. Other work focus on travel assistants' concepts within the sphere of regional and urban mobility. Focusing on personalisation and making use of different modules, a multimodal travel route planner is developed by (Faye et al., 2017) as part of the MAMBA project. The prototype has its focus on regional and daily mobility of commuters within the Luxembourg region, excluding the air transport segment.

3.2 Travel Assistants on The Market

A review is conducted analysing sixteen [1] travel assistant applications that support passengers within their door-to-door air journey. Table 1 provides an overview of all considered applications and its main characteristics. As a main review requirement, reviewed applications should include an air travel segment within their offers or provide tailored services. City route planners (e.g. Moovit (2019) or Citymapper (2019)), and platforms providing only search and booking options for flights and hotels (e.g. KAYAK (2019), Skyscanner (2021), and Expedia (2019)) are not considered. A review of service integrator for urban mobility is available in other studies (Esztergár-Kiss, 2019; Kamargianni et al., 2016). Applications shall be on the market or in the BETA-phase. Some services recently closed down, such as Flio (Lufthansa Innovation Hub, 2019a), or are not available such as the DORA (2018) application. These are not included either.

All reviewed applications can be categorised into three main groups: 1) Trip planner (TP); 2) Airport transfer (AT); 3) Air travel assistant (ATA). They often have a multi-language interface, with the availability of up to 32 languages and various functionalities. For instance: "D2D travel planning" refers to the functionality of offering intermodal travel options, such as combining flights and feeder traffic (including the management of disruptions during the journey). "Single ticketing" refers to the offer of combining several tickets into one ticket. "Automatic flight check-in" can be provided by an interface with the airlines check-in options or simply as reminder for the user to check-in himself. "Accommodation" refers to the search for – and maybe booking of – hotels, holiday homes, or others as part of the travel chain. "Booking option" is the functionality for purchasing directly on the travel assistant platform. "Price comparison" and "price notification" provide additional functions for the user to get the lowest price possible. The "travel notification" is referring to real-time updates on delays, boarding time, gate changes, flight status, baggage claim, and other information. The "airport assistant" function is concerned with providing any kind of supporting service within the airport environment (help with boarding, integrated routing etc.). "Offline options" provide the opportunity to use the travel assistant also without an internet connection. "CO2-emissions comparison" provides transparency regarding the carbon footprint of a journey and the opportunity to choose the most environmentally friendly itinerary. The "management flight refunds" provides post-journey support. Other secondary services might be available, such as an aircraft seat assistant, options to share travel information on social media or via messenger (social sharing), or even the tracking of the users' heart rate and emotional state

[1] App in the Air (2019); AtYourGate (2019); Checkmytrip (2019); Flewber (2019); From A to B (2019); GO Airport Shuttle (2019); Hopper (2019); LoungeBuddy (2019); Lufthansa - My taxi match (2019); MiFligh (2019); Omio (2019); PASSME Airport Application (2019); Rome2rio (2019); Time2Gate (2019); TripCase (2019); TripIt (2019)

to calculate stress levels. The degree of personalisation of services ranges from low to high.

Trip planners offer the best options for D2D travel planning, combining different modes and adopting travel plans in case of disruptions. The applications are mostly free of charge to use. Air travel assistants aim to manage the travel at the airport and along the travel chain rather than providing booking itineraries and booking options. Some also offer pre-travel services, such as price alerts, or post-travel (after sale) features, such as the management of flight complaints. Users might have to pay a yearly or monthly subscription fee. Airport transfers focus on covering the first and last mile and airport feeders. Some of these services are offered in cooperation with airlines for additional transfer features.

Table 1 - Review of travel assistant planners' functions (own depiction, findings from November 2019); ATA = air travel assistant, AT = airport transfer; TP = trip planner

Application	Category	D2D Travel Planning	Single Ticketing	Automatic Flight Check-In	Accommodation	Booking Option	Price Comparison	Price Notification	Travel Notification	Airport Assistant	Offline Option	CO2-Emissions Comparison	Management Flight Refunds	Availability	Degree Personalisation
TripCase	ATA	x							x	x				global	low
App in the Air	ATA	x		x					x	x	x			global	middle
TripIt	ATA			x					x	x			x	global	middle
AtYourGate	ATA									x				selected a/p	low
Hopper	ATA				x	x	x	x						global	middle
LoungeBuddy	ATA									x				global	low
PASSME Airport Application (currently tested)	ATA								x	x				local	low
MiFligh	ATA								x	x				selected a/p	low
GO Airport Shuttle	AT	x				x								regional	low
Lufthansa-Mytaxi match	AT	x				x								local	low
Time2Gate	AT	x					x			x				locally	low
Checkmytrip	TP	x		x		x			x					global	middle
From A to B	TP	x	x		x	x	x		x		x	x		global	high
Omio	TP	x	x		x	x	x		x					Regional	middle
Flewber	TP	x				x								Regional	low
Rome2rio	TP	x	x		x	x		x						global	middle

3.3 Privacy Policies and Data Exchange of Travel Assistants

All travel assistants provided detailed information on data protection policies for users. However, different laws and regulations are applying, depending on the physical location of the user. As D2D air travel is considered here, the users' country can change quickly. For some services, it seems unclear which laws and regulations are applicable. Besides, travel assistant providers describe in what way personal data can be further exchanged. Figure 3 provides an overview of possible data exchange between such applications and other parties (summarised from several reviewed data privacy policies explored in Section 3.2). Although undesirable, personal data (or in some cases anonymous data) can be distributed between internal project teams and affiliated business unites. Personal and anonymised data can also be passed on outside of the company, such as to external and analytics service providers and even social media platforms. It seems unlikely that users pay detailed attention towards such data policy regulations to detect these data exchanges of their personal data, neither does it seem desirable for the traveller.

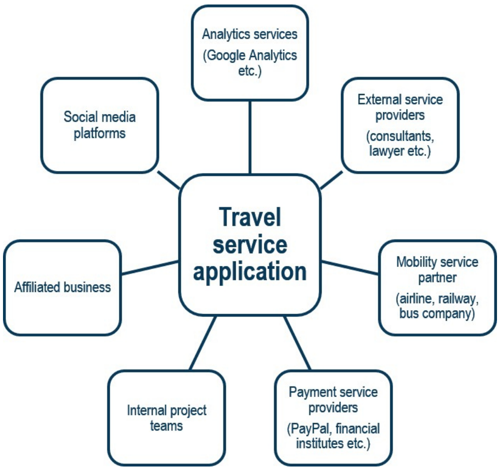


Figure 3 - Exchange of personal and anonymised data between applications and others (authors' depiction based on review in 2019)

3.4 Gap Filled by The Virtual Travel Assistant

Current travel services on the market have a focus on only a limited number of features, such as the air travel assistants or the airport transfer. Notably, personal data of users might be exchanged with additional partners and service providers, including those not directly involved in the actual travel service process such as external consultancies. The proposed VTA concept aims to connect many different features with a high degree of personalisation options for travellers in line with strengthening privacy protection and sovereignty for users while incorporating the required functions and user requirements developed in Section 2. Simply said, the solution proposal fills two gaps: 1) limited intermodal services and 2) protection of personal data.

3.5 Platform Ecosystems

The last decade has seen a shift in the industry from traditional software models towards platform ecosystems. This shift is based on the intention to offer consolidated services and is often accompanied by a new business strategy with platforms or ecosystems that are operated by commercial tech companies. However, powerful open-source software frameworks and modern software delivery models also allowed for successful community-driven platforms and repositories, like F-Droid as one example, which allow for more privacy-oriented principles. A VTA platform needs to consider claims from both communities to get passenger attention.

In the literature, (Amrit Tiwana, 2014) looks at platform ecosystems by following four key ideas: 1) Core Concepts and Principles; 2) Platform Architecture and Governance; 3) Orchestrating Evolution; 4) Evolutionary Dynamics and Metrics. The approach in this paper takes up the first two of these ideas. At first, core principles are introduced that distinguish the intended platform from the existing travel platforms discussed above. Then, the platform architecture and core elements to support the desired principles are presented. As mentioned in section 2.2, the envisioned time horizon allows to incorporate technological developments into the platform concept. In particular, assumptions can be made where developments have already begun today or are foreseeable on the basis of trends in the past years. This includes developments in the area of mobile computing: on the one hand, a further significant expansion of the digital infrastructure can be expected in the current decade, leading to more reliable and available data bandwidth (Winzer et al., 2018). On the other hand, driven through massive parallelism and special-purpose-chips, the computing capacity of mobile devices will increase significantly (Winzer & Neilson, 2017). On the software side, a strong trend towards containerisation - i.e. the provision of isolated execution environments - is already established in the DevOps area.

4 SOLUTION PROPOSAL VIRTUAL TRAVEL ASSISTANT

The solution proposed in this paper is an open, software-based platform that runs locally on the traveller's end device. The platform provides a modular assistant system, which allows service providers to build a collaborative and privacy-preserving virtual travel assistant. The main characteristic of this architecture is that no personal data leaves the device – the assistant is highly personalised but runs on the user's end device only. Figure 4 shows the fundamental functionalities of the VTA and the basic principles by which these are achieved.

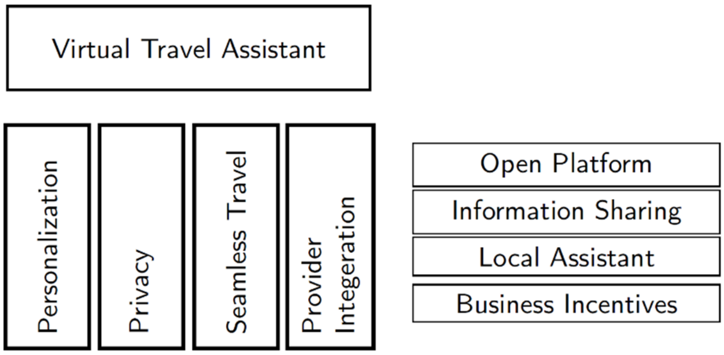
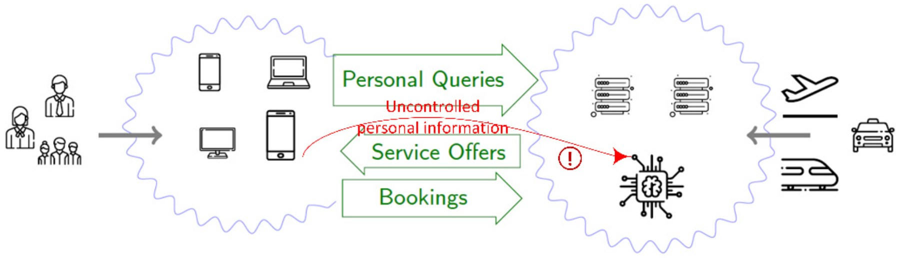


Figure 4 - VTA pillars (left) and according solution building blocks (right)

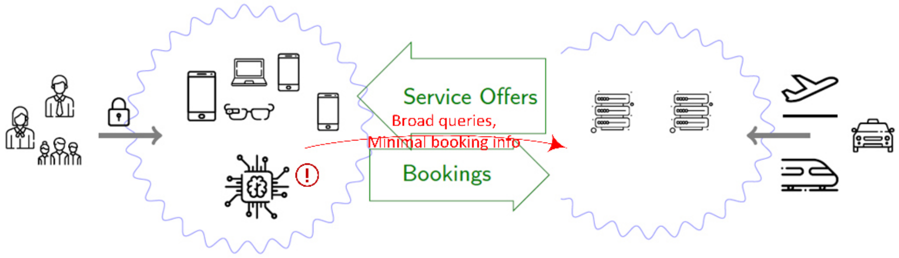
4.1 Basic Idea

The basic idea of the VTA is to reverse the ratio of information in the communication flow with the providers. A current trend in online services is that information about the traveller is collected by service providers, which then process this information on their servers and offer matching services. The VTA protocol, on the other hand, functions more like a consultation with an omniscient companion: the traveller has a literal "personal" assistant that calculates the best matching service on his/her device, and no external records about the inquiry are kept.

Figure 5 illustrates this information flow. The left side depicts the digitally enabled traveller and their devices, while the right side shows the transportation service providers and their digital offers. The upper figure (a) shows the status quo: the traveller queries the service providers and reveals information and metadata about himself and his journey; the users' personal information are entangled with the request, information flows towards the provider, and all intelligence lies within the realm of the service provider. In contradiction, the lower figure (b) shows a future VTA setup: the traveller's assistant processes queries about large amounts of information from the provider, while revealing only minimal personal information. All recommendation algorithms are performed on the device.



(a) Travel booking as of today: Travelers (left) reveal their personal information to the transportation providers (right). Service offers are compiled at the providers' server side.



(b) Travel booking in the VTA future: All personal information are processed locally. Personal local assistants provide offers that lead to direct bookings.

Figure 5 - The information and computation flow today (top) and for a future VTA (bottom)

4.2 Core Principles and Techniques

The VTA needs to follow four core principles to fulfil the requirements discussed. (1) Privacy: the platform is committed to the protection of the user's privacy. All interfaces and rules are subordinated to this principle. (2) Modularity: the platform encourages the collaboration of so-called assistant modules by providing a modular design. (3) Transparency: the platform and the accompanying ecosystem is open in participation to all interested parties. (4) Security: the platform allows ensuring compliance with aviation and travel security measurements. (5) Trustworthiness: the platform provides technical mechanisms to ensure all participants are following the principles. Principles 1 and 5 empower the traveller, while principle 2 and 3 offer business incentives and allow for the actual functionality.

These core principles are implemented by applying a number of techniques, mainly:

- **Local computation:** all computations are performed through resources on the device. No personal data leaves the device.
- **Modularisation:** the VTA provides a framework that facilitates modules to interact with each other. The functionality is thus composed of multiple modules from different vendors.
- **Personalisation:** the user allows the platform to access his/her private information, in addition to custom preferences. The platform, in turn, provides a framework that lets modules access the user's information.
- **Isolation:** the modules run in their own environment, which is disconnected from the

internet. Thus, the modules can be closed source and still trusted to handle the user's private data. The modules interact with the base system and other modules through the platform framework.

- **Network monitoring:** the modules can access the internet by requesting certain network resources. These networks requests are carried out and monitored by the platform and must not contain personal data.
- **Insight:** provide clear information when, which and for what reason personal information is shared with external parties, e.g. for security compliance or bookings.
- **Open Source:** the architecture and regulations are free to implement and reproduce.
- **Regulation:** the governance of the regulation development is led by a transparent committee formed by different interest groups.

4.3 VTA Platform Architecture

The proposed platform architecture centres on the local computation design approach and covers three parts: the users end device, the data transmission network and the provider endpoints. The core principles are applied to each of these three parts. In this approach, all information about a journey is processed locally, on the end device of the user, without exception – no personal information leaves the device, unless it is required to finish a booking process.

Figure 6 includes the participating parties, their information, and the main architectural parts of the VTA. The central system outlines the structure inside the VTA on the user's end device: The local VTA is a platform that runs several modules with varying journey-related functionalities, provided by or for different vendors, which can communicate with each other and have restricted access to user information and the network. All recommendations are calculated locally, based on the available assistant modules. The necessary information is retrieved via read-only information endpoints from the mobility providers. Personal information of all forms and sources can be made available to the modules. However, a module can access the internet only to make very specific requests, like an online booking. While this design decision challenges the overall data provisioning, it also offers opportunities that would not be available in current server-centric application models. The local computation approach allows the platform to give the local virtual assistant modules more access to personal information without the fear of losing control over one's own information.

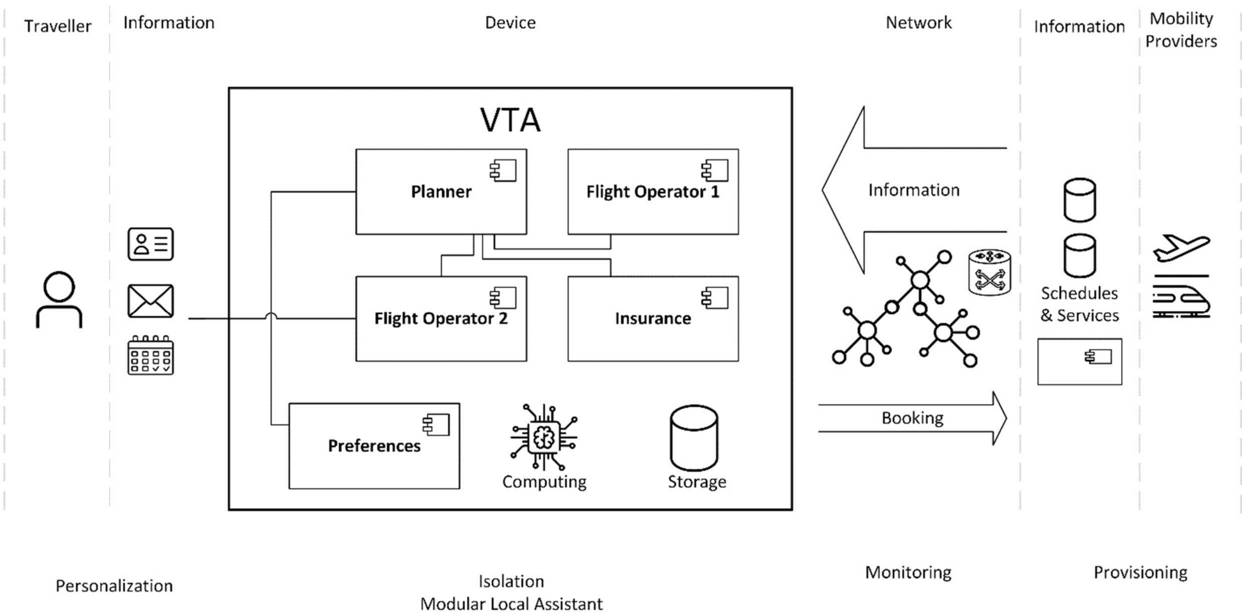


Figure 6 - VTA platform architecture overview

4.4 Modularisation

The functionality of the VTA is provided by so-called assistant modules, which come bundled with the platform or can be downloaded and activated once the VTA is installed. The modularisation serves the purpose of extending the functionality of the assistant dynamically while having a common ground for different providers and operators. Each of the assistant modules can offer varying services, which range from mobility offers, travel insurance, Artificial Intelligence (AI) planning to communication capabilities. For instance, a VTA could be composed of various modules that offer different services including information on transportation providers, a digital travel agency, a planning AI, and the User Interface (UI) module (Figure 7). The transportation provider modules propagate their schedule information to the other modules in the background, and the AI module combines these offers to compile a route for the traveller, which is then presented through the UI module. There are multiple ways to implement such a modular system in a platform. One way would be to specify an extension application programming interface (API) or to build a plugin system.

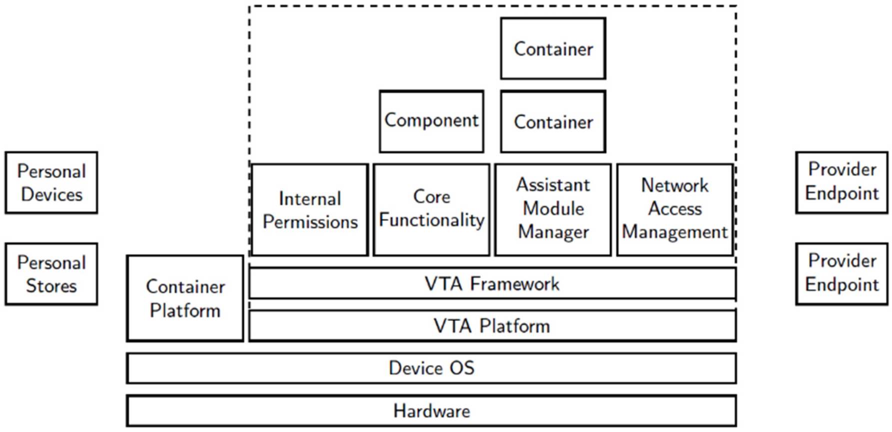


Figure 7 - VTA platform architecture detail

However, the assistant modules of a future VTA have certain computing and security requirements. The modules need strict supervision when it comes to the access of personal information and network access to prevent data leakage. That means that the access to system or API calls made by a module will have to be restricted by a whitelist. On the other hand, the modules are expected to do resource-intensive computations, which require access to many system resources or even hardware-level access to special purpose chips, as well as the usage of advanced frameworks and libraries. This in turn would not be compatible with the trust model that the VTA has to provide to the traveller. One solution to this problem is the use of virtual machines or containers for the isolation, in combination with a VTA-internal API. This architecture proposes to use container technologies, which is already available for many devices and suitable to provide hardware-level access as well as controlled data communication. The ongoing development and research of this popular technology promises to become a common technology not only in the server world but also for various end devices. Figure 7 outlines the layers of this architecture. The VTA platform resides inside the dotted line and runs on top of existing hardware (the device) and the operating system – similar to a mobile app today. The core element of VTA platform is the Assistant Module Manager, which runs and isolates all assistant modules and allows access to other VTA components. A module will have to comply with certain specification standards in order to qualify as an assistant module. This includes the implementation of a special VTA contract to communicate with other modules, and the absence of unsupervised network communication. The VTA contract is a form of API where consumers and providers of journey information can propagate their state and share service requests and offers. Assistant modules can then communicate and combine different services to reach a certain journey goal.

4.5 Personalisation And Privacy Protection

A digital seamless travel assistant poses multiple risks to the traveller's privacy: The risk to expose the traveller's personal information to mobility or platform providers (active exposure), and the risk to become dependent on their digital services to be able to travel (passive dependency). Both risks are addressed by an encompassing privacy and data security concept. Aviation security versus privacy in context of air mobility, however, requires a more detailed discussion on its own. Certain security measurements, like revealing names to board a flight, must be fulfilled by exceptional insight events where personal information is shared with trusted parties, as mentioned in section 4.2. Personalisation, on the other hand, can be realised without personal information leaving the device. The VTA protects the user's personal information through its strict application of local computation. In return, the users share personal information with the assistant modules, thereby achieving a higher degree of personalisation for their journey and receiving tailored offers from commercial providers. Travelers can share travel preferences as well as access to personal information stores with assistant modules (see Figure 6 and 7). Personal preferences are specific information about travel preferences. The user could indicate whether he or she prefers to travel timesaving or rather stress-free, particularly cheaply or with high comfort, eco-friendly paying for CO2-compensation. These settings are stored by the VTA and can be included by the assistant modules in their travel planning algorithms upon request.

The second layer of personalisation is the access to personal information of the user like the calendar, contact book or mails. Including this private information can further enhance the personal assistant experience, as the VTA can now react to changes in the travel plan according to the individual needs (e.g. by making sure that a business traveller arrives to an important meeting in time no matter the costs, or, in case of a private trip to a family meeting, by keeping the family members up to date about the travel schedule). In a traditional setting, e.g. on a smartphone, each individual journey planner app would request access rights to these private information from the user. However, it is not clear what happens with this information once the app has access to it and communicates with the internet – for example, whether the address book or calendar is synchronised with a company server for a more "personalised experience". The local computation approach of the VTA platform allows for a different approach to this problem: the assistant modules are not allowed to access the network or have a very restricted access only. The open platform model of the VTA addresses the second risk, the growing dependency on digital services of different mobility providers. The VTA makes it transparent which mobility providers participate in the trust model of the platform and offer a privacy-preserving way to travel with digital appliances.

4.5.1 Network and Hardware Access

Network, information, and hardware access is crucial to every future travel assistant, but without appropriate precautions, it conflicts with the promise of trust and privacy. Figure 8 expands on the isolation model from section 4.4 with a permission model to access these important device resources. A module may request personal information of the traveller via the information access manager, which controls access to authorised personal resources like the calendar. The local computation approach also makes it necessary to access specialised hardware like AI accelerator chips, which is provided through the chosen container platform.

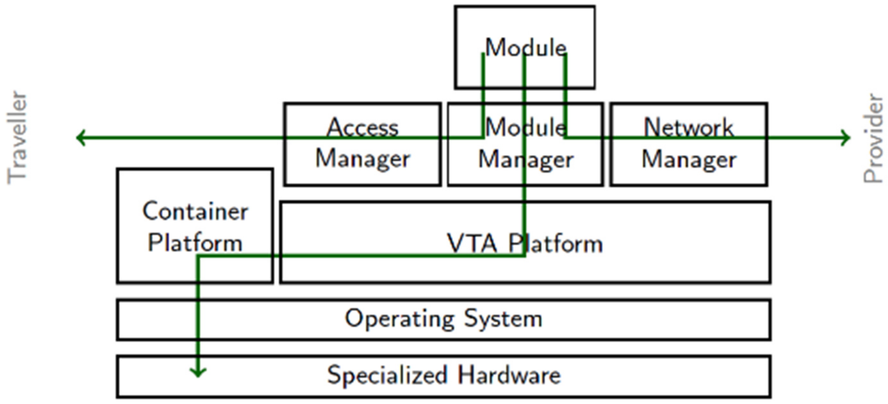


Figure 8 - Information and hardware access

The network is the crucial barrier to protect personal information at one hand, and to receive necessary service provider input at the other hand. It must be allowed for some assistant modules to retrieve data updates to populate their service offers to the local VTA. However, the VTA also exposes sensitive personal information to these modules and must therefore ensure that this information does not leave the device – otherwise, travellers loose trust in the VTA and the overall concept of a personalised secure travel experience does not hold any longer. To achieve these two goals, the VTA establishes a series of rules for network traffic and monitors compliance to those rules: 1) Transparency: all network access must have a reasonable justification, be registered in advance by the module, and be observable. 2) One-way communication: a network request must not include any upload data, but instead is allowed to include a few documented parameters only. Exceptions (like ticket booking) must be well documented. 3) Generality: requests must not disclose sensitive information; queries like timetable schedules or ticket enquiries must be inexact through techniques like bulk requests or differential privacy, such that the actual purpose of a query (e.g. exact travel time and destination) is concealed from the information provider. 4) Metadata protection: all requests are to be routed through an overlay network that disguises the origin and other metadata of the call. 5) Anonymity: tickets and services must be offered by providers and operators without asking for personal information, if this conforms to the national law. In the technical architecture setup, these rules are applied through a managed network provider. Assistant modules will have to register their network endpoints with the network manager upon installation in a static manner. Other modules or interested experts can then validate the trustworthiness of the announced resource and investigate possible parameters in the URL. During runtime, the network manager will assemble the parameters, request the resource, and deliver the response to the assistant module. The metadata of requests, like IP addresses, will still be accessible by the service provider and need protection in a different way. The VTA architecture provides this protection by routing all network traffic through an anonymising overlay network. Assuming that the digital infrastructure will be further developed in the future and that significantly higher bandwidths will be available, the capability of overlay networks will be sufficient for large transmission patterns, given that enough servers are provided. Since complete non-traceability is not the driving factor in this scenario, an existing overlay network structure can be used, or operated by several different interest groups.

4.5.2 Freedom of Movement in Digital Traveling

At one point, the traveller (or an autonomous assistant) must decide on a certain ticket and initiate the purchase process. In today's mobility apps, the purchase process is often accompanied by a login process, which removes the anonymity of the buyer and thus makes independent prices and travel restrictions no longer controllable. However, this loss of control can be prevented if the mobility provider offers anonymous tickets, like paper tickets from a vending machine. While some tickets, like international flights, must be personalised due to legal requirements, most tickets for feeder traffic can also be issued impersonalised and become valid upon receipt of some form of digital payment. The VTA combines the above methods of local computation, anonymous service requests, collaborative journey planning, and impersonalised ticket purchase to provide a completely personalised and assisted D2D journey experience.

4.6 Provider Integration

Mobility providers and operators that want to participate in the VTA have three options to offer their services, which build on top of each other and range from passive data provisioning over public module contributions to distributing a custom branded VTA. Option 1 is a public digital provisioning of the company's offered mobility services, i.e. a server backend that delivers a timetable upon the request of the VTA. Such a provisioning can take any form as long as the request adheres to the VTAs overall rule, that is: it must not be possible to draw conclusions on personal information or intentions. Option 2 is to offer an assistant module, which requests travel schedules and propagates them to the VTA locally. Such a module can then be installed in any open VTA platform to participate in the travel bidding. Option 3 is to build and publish a custom branded and sealed VTA, which contains only selected modules. In this last scenario, the VTA platform and protocol is still used to ensure privacy, but it is not possible to install further VTA modules. To give an example, let us consider a flight operator who wants to integrate a flight schedule into the VTA. The flight operator then has to write a local VTA module that complies with the VTA standards and, once installed, registers itself as a mobility provider. The module also registers a set of URLs with the VTA's network manager where the complete flight schedule for the next week can be downloaded. Once the VTA is running, the URL is queried; the flight schedule is downloaded to the device and indexed by the local assistant module. When the traveller wants to book a flight, a planning module queries all installed flight providers and asks for flights to specific destinations in a specific time range. The flight operator's module answers to this request and handles the booking request once the planning module confirms the journey. In this scenario, the flight provider has to offer a network resource that distributes its flight schedule plus a module that populates this information locally in the VTA.

Privacy and the traveller's sovereignty is identified in the ToT as one of the main requirements to be fulfilled for a travel assistant. Privacy protection returns the control over their data back to travellers but restricts mobility providers in their current data processing practices and may, in their view, have a potentially negative impact on business practices. In addition, mobility providers today usually have no interest in making data about their services available to the public in a machine-readable form. One reason for this is the fear of losing control over pricing or of giving competitors insight into planning.

4.7 Platform Standardisation

A platform such as the VTA that wants to create both trust and business incentives needs to follow an open and transparent standardisation process to maintain these values. As outlined in Figure 9, the participating parties need to come together at a "round table" to make sure that their interests are upheld as the platform evolves. Both the industry and digital rights associations (NGOs) have strong advantage in this setup: NGOs make trusted recommendations that grow the user base of the VTA; the industry and start-ups make investments and provide the actual service; and the government protects the laws that are fundamental to travel sovereignty. An open VTA standardisation would not require all mobility to work together – it is merely a standard that guarantees personalised, private travel.

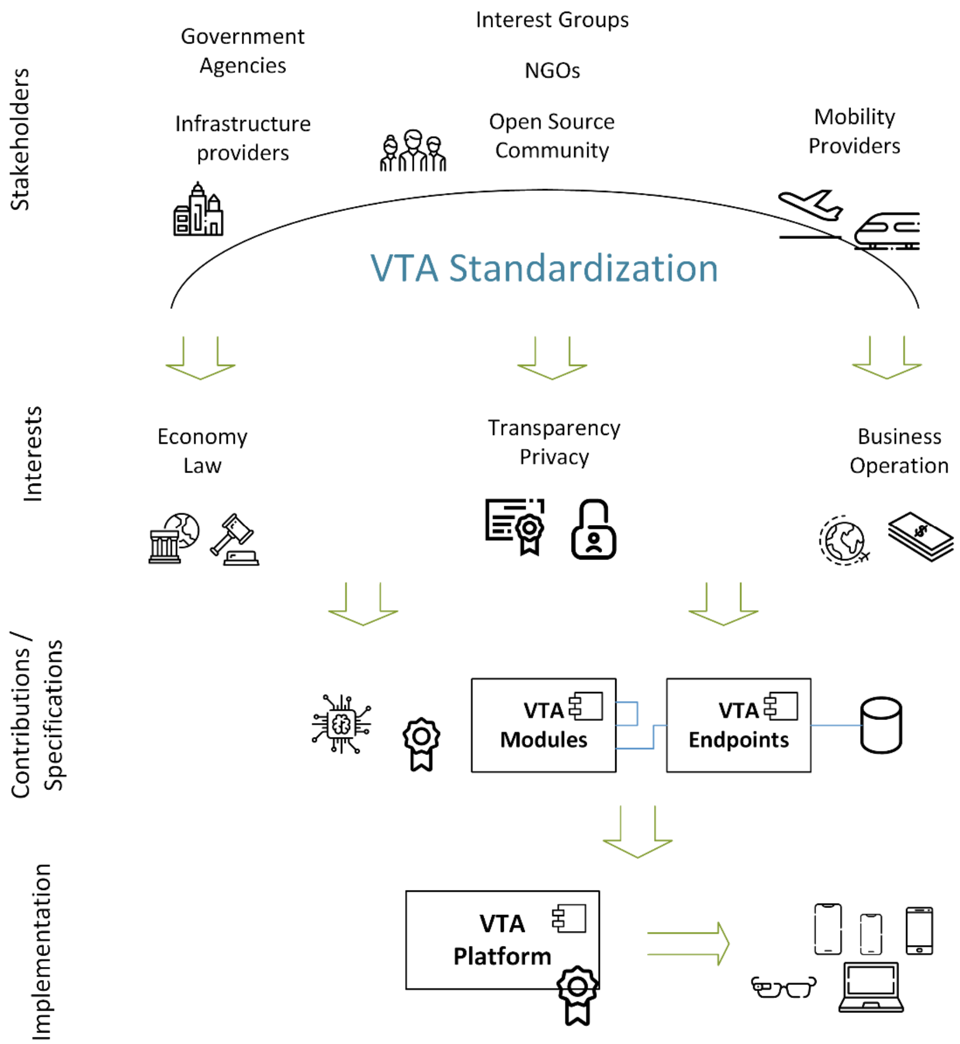


Figure 9 - Standardisation committee and outcomes

From a technical viewpoint, the platform specification describes interfaces and methods but is independent from the actual implementation. It is therefore possible to develop the platform for different kinds of (future) end devices, build tailored VTA applications with exclusive mobility providers, or to build assistant modules that remain transferable for various targets. This would furthermore encourage competing implementations in different languages or from different organisations.

4.8 Privacy Preserving VTA Techniques – Summary

The following table contains a concise list of the technical components integrated into the platform and the most challenging privacy issues per component, as discussed in section 4.

Technical component	Addressed privacy issue
Local computation	Assurance of compliance and confidentiality
Differential privacy	Prevent leakage of metadata
Isolation	Prevent rule bypassing, malicious hardware access
Modularisation	Allow controlled data sharing Allow central data control
Network monitoring	Control data flow, prevent data leakage
Open Source	Provide transparency (framework only)
Committee regulation	Integrate data sovereignty (privacy laws) Enhance trustworthiness

Table 2 - Technically addressed privacy issues

5 PRACTICAL IMPLICATIONS

5.1 Journey Scenarios and Benefits for Passengers

As explored, passengers have differentiated travel needs along the door-to-door air travel chain. The travel scenarios in Figure 10 depict how the VTA concept could support different travel types along the journey, exemplified by elderly travellers and a business traveller.

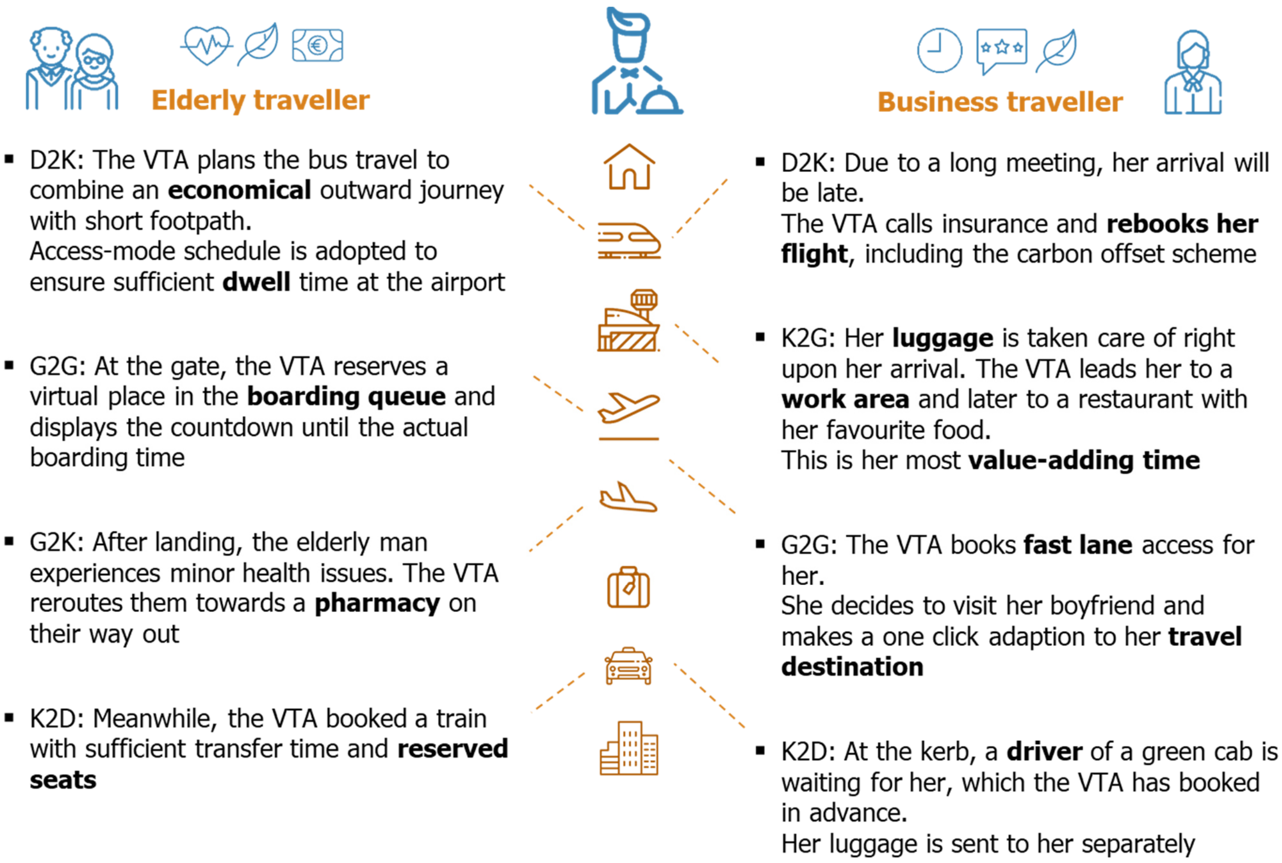


Figure 10 - Archetype passenger journeys supported by the VTA concept (example)

As seen in the archetype journeys, the VTA concepts aims to combine many features – nowadays fragmented in several apps – into one application. Travellers would not need to install several heavy apps on their end device, save time, and memory capacity. Using this proposed VTA, payment data and personal preference settings would only need to be entered once and could be adapted for all travel segments with just one click. The users would also have the possibility to plan, purchase, and customise their entire D2D journey in one application, resulting in an enhanced travel experience for journeys. Organisation efforts for air travel journeys will be reduced significantly. Finally, the proposed concept protects personal data. Another benefit and at the same time distinguishing feature is the focus on guaranteed privacy, which is crucial for the acceptance and wider distribution of the VTA. A recent study on the German "Corona-Warn-App" performed in the context of the Covid-19 pandemic indicates that the assurance of not sharing any personal data does increase the acceptance of an app that handles sensitive personal information.

5.2 Participation Incentives for Mobility Providers

As D2D journeys and hence many different itineraries are in scope, one essential factor for the success of a privacy preserving VTA is the participation of as many mobility providers as possible, to ensure a true D2D offer within the VTA architecture. Missing parts of the travel chain, such as feeder traffic, would disrupt the intermodal travel chain and hinder the provision of a true seamless, personalised travel experience. Mobility providers and operators have incentives to participate in the VTA system and to provide their services in the VTA ecosystem due to several major business benefits:

1. **Large customer base:** the VTA's verifiable promise on privacy earns the recommendation of public organisations and thus attracts a large user base, potential customers that become immediately accessible to companies that offer their services via the VTA.
2. **Personalisation of products and services:** by the privacy concept of the VTA, the user is ready to make data that are substantially more personal available for a tailored service. Personal circumstances, such as appointments, preferences for additional services, or travel budget can further be used within the VTA architecture for personalisation. The VTA offers providers the possibility of a very high personalisation of the own services, even without remote access to the traveller's data.
3. **Network effect:** as the VTA is open and transparent towards mobility providers and operators; there is no dependence on aggregations and a low technical and strategic entry hurdle. After a boot phase, the VTA becomes increasingly attractive for companies and gains value with more companies and users involved, known as the network effect.
4. **Cost benefits and market access:** the costs for investing into an own sales platform (development, operations, marketing, and maintenance) and its application are eliminated while at the same time market access to a range of new potential customers is gained. Additionally, own apps can still be offered resulting in multi-income revenue streams.
5. **Digital business model:** transport service providers are being supported in transforming their business model into a service model. Transport providers can publish their service offers without having to maintain the complete digital distribution chain, while the open standard of the platform still prevents a vendor lock-in.
6. **Ancillary revenue:** revenues gained by selling accompanying non-ticket services (such as flight insurance, in-flight meals, or commission-based products) are still possible by integrating the service partnerships within one's own assistant module.
7. **Competitive advantage:** a good integration into the major travel platform can be a competitive advantage for airports, public transport, local facilities, and finally municipalities. For example, a city can advertise to international tourists that their city can be fully explored using the VTA.

8. **On-demand services:** assistant modules can be published that provide additional services along the journey, which complete the travel experience. Such services might be a good reason to use the VTA and thus the mobility provider can address a larger target group.

5.3 Limitations

The key component in this concept is the restriction to local computation, which entails limitations. One limitation is the partial publication of business logic in the code since assistant modules have to be installed on the user's device. Although the platform, due to the isolation and network management concept, allows for closed source, the possibility of reverse engineering currently confidential algorithms remains. However, it should be noted that only algorithms that process personal information must be executed on the device, all other reasoning and business logic might remain in the back-end infrastructure. Another possible solution to this problem might be the application of homomorphic encryption on the server side. Increasing work in this area is currently done towards integrated solutions and *MaaS*, which usually run in cloud-based environments. Future devices and specialised chips will make it possible to run advanced AI-powered algorithms locally, but it cannot compete with cloud-supported solutions that allow for even smaller devices and low energy requirements. This competition leads to technical and social questions on how to approach privacy.

The consistent enforcement of privacy may encounter legislative resistance in some countries. Countries that do not support anonymity and sovereignty in travel might not allow for anonymised itinerary requests or unrestricted access to transport services. The same argument could be applied to foreigners in less restrictive countries. Finally, the proposed VTA concept is based on assumptions: first of all, on the expected availability of high data rates, high computing capacity as well as on the increase in travel and passenger volume. In the light of to the current environmental debate and the "flight-shaming"-movement, the future growth rates of air travel are currently not predictable. However, the VTA does support environmental travel as environment-conscious travellers would be able to set personal preferences accordingly, and for instance select the most environment-friendly modes to travel as climate-neutral as possible.

5.4 Further Research & Validation

This paper conceptualises an architecture for a travel assistant that mediates between mobility and air transport providers as well as passengers while assuring privacy through local computation. Following this first solution proposal, further research in terms of the concept evaluation, transferability, and practical relevance is needed. The proposed VTA should be evaluated from different perspectives. Questions include: does the concept meet a true need of the demand side? Can the concept incorporate all required functions? Can the concept be translated into a feasible business case? Who would operate the VTA? How could the secure payment work in practice? A compliance check with the EU GDPR is evident. The outlook on strong privacy could spark a separate discussion on the issue of privacy versus security.

For developing a real-world prototype VTA additional analyses are necessary. Testing the market potential, a feasibility study, a market assessment, and customer segmentation studies would need to be conducted. Details for the business models and operating model should be explored. We have not discussed possible revenue streams and whether travellers have to pay for the VTA services. There is also the open question for which end devices the VTA could be available, however, one has limited knowledge about the end devices that might exist in 10 years' time.

Another next research step is the development of an agent-based model depicting passengers' door-to-door air travel chain and testing the VTA-architecture within this simulation. In that way, one could also derive the personalization and timesaving benefits of the travel assistant. Further, the VTA concept is focused on D2D air travel as a possible use case. However, the concept can also be applied to intermodal urban mobility, urban air mobility (once feasible as mass transport), railway and other means of transport. Next to the mobility sector, it would be possible to apply this architecture to other industries. Examples could be the education sector (with its high demand for personalisation of content and digitisation) or the financial and health care sector (with a strong focus on privacy and data protection).

6 CONCLUSION

This research provides a concept of the Virtual Travel Assistant (VTA) supporting future travellers on the international door-to-door journey while maintaining strict information privacy. For that purpose, assumptions about foreseeable market and technology growth are made: an increase in overall travel and passenger volume (post-Covid-19), further investments in digital infrastructure and a significant increase in data transfer capacity as well as significant technical advancements in and availability of data processing capabilities. The period of 10+ years (2030+) are here in focus. After defining the functional and non-functional requirements for the VTA, a review of existing applications is provided. It is shown that current applications may pass data to many third parties, which are not all involved in the booking process. The solution proposed in this paper is an open, software-based platform that runs locally on the travellers end devices. The platform provides a modular assistant system, allowing service providers and operators to build a collaborative and privacy-preserving virtual travel assistant. The main characteristic of this architecture is that no personal data leaves the device. The assistant is highly personalised but runs on the user's device only. Benefits for the passenger (such as an enhanced D2D air travel experience) and business incentives for mobility providers (such as tailored offers and cost savings) are discussed. Depicted in the ToT, three main requirements for such travel assistant application – commercial interest, privacy, and personalisation and seamless travel – are solved within this proposed concept of the VTA.

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