Designing for Urban Mobility - Modeling the traveler experience

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université
PARIS-SACLAY

CentraleSupélec

NNT : 2019SACLC006

Designing for urban mobility: Modeling the traveler experience

Thèse de doctorat de l'Université Paris-Saclay
préparée à CentraleSupélec

École doctorale n°573 : interfaces : approches interdisciplinaires, fondements, applications et innovation (Interfaces)
Spécialité : sciences et technologies industrielles

Thèse présentée et soutenue à Gif-sur-Yvette, le 29 Janvier 2019, par

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Thèse de doctorat

To my dear parents

To my beloved wife

To my dear brother and my big family

To all my dear friends and comrades

To all those whom I love and who believe in me

In memory of my grandfather

To my dear teachers

To anyone working for the good of humanity

Acknowledgements - Remerciements

I first would like to warmly thank the jury members of this PhD thesis: Stéphanie Buisine from CESI Group and Crisitna Pronello from University of Technology of Compiègne, for accepting to review this work. The reports were rich in useful advice and information for the continuation of my work. I thank professor Fabien Leurent from Paris-Est University, Alexandra Millonig from the Austrian Institute of Technology and Isabelle Nicolaï from Paris-Saclay University for accepting to evaluate this work as examiners. It is a great honor to have my work assessed by you. The exchanges in the defense allowed me to accentuate my perspective on this work, and I hope that we will still have the opportunity to exchange in the future.

Mon voyage pendant ces trois années de thèse n'aurait pas été agréable sans la présence et le soutien de plusieurs personnes.

Tout d'abord, mes trois encadrants Flore Vallet, Jakob Puchinger, et Bernard Yannou, qui m'ont accompagné dans mon cheminement de chercheur en herbe, du premier jour jusqu'à ma soutenance. Flore, pour m'avoir assisté dans les plus petits détails de mes activités de recherche et pour son engagement sans égal. Jakob, pour ses commentaires constructifs et sa bienveillance. Bernard, pour ses recommandations clairvoyantes et pour les différentes opportunités qu'il m'a offertes.

Je remercie les différents interlocuteurs des partenaires industriels de la Chaire Anthropolis qui m'ont éclairé sur leurs enjeux et leurs attentes, puis pour leurs retours très constructifs qui m'ont permis d'améliorer les résultats de ma recherche.

Je suis également reconnaissant aux personnes qui ont accepté de participer à mes interviews et focus groups : la grande famille des doctorants et plus particulièrement Tasneem Adeeb Bani Mustafa, Hichame Benbitour, Selmen Boubaker, Haythem Selmi, Fabio Antonialli et Shaohua Yu. Puis mes amis e l'IRT SystemX : Danya Bachir, Omar Dib, Joseph Kamel, Nada Essaouini, Hanane Fadiaw, Niezi Mharsi, Mohamed Zayani, Rim Kaddah, Farah Haidar, Nabil El Fadli et Alam Mahabub.

Une mention spéciale pour mes deux compagnons et frères Abood Mourad et Reza Vosooghi sans qui ces années de thèse auraient été ennuyeuses et mon manuscrit sans cinquième chapitre.

Je suis également reconnaissant aux piliers du Laboratoire de Génie Industriel pour les merveilleux moments passés à leurs côtés, pour leur soutien et leur amitié : Delphine Martin, Sylvie Guillemain, Corinne Ollivier, et Carole Stoll. Je tiens à remercier Jean-Claude Bocquet qui a été le premier à m'accompagner dans mon cheminement au sein de la chaire.

Je tiens à remercier chaleureusement mes amis du LGI et de l'IRT SystemX Alexandre Bekhradi, Sonia Ben Hamida, Islam Abdin, Guillaume Lamé, Youssef Dammak, Lara Qasim, Naouress Fatfouta, Tim Sissoko, Diya Moubdi, Sarra Fakhfakh, Rodrigo Gandia, Bruna Habib Cavazza, Hoang-Phuong Nguyen, Amira Ben Hamida, Fereshteh Asgari.

Un grand merci à mes professeurs et collègues François Cluzel, Vicent Mousseau, Yann Leroy, Marija Jankovic, Ludovic-Alexandre Vidal, Franck Marle, Asma Ghaffari et Julie Le Cardinal pour tout ce qu'ils m'ont appris durant ces années.

Finalement, pour le meilleur et pour le pire, l'amour de mes proches était toujours là pour moi. Ma famille : Mes parents Naziha et Belkacem, qui n'ont jamais cessé de me soutenir et de me pousser vers l'avant, qui ont fait le voyage du Maroc pour assister à ma soutenance, je leur dédie ce travail. Ma tante Souad et son mari Majid qui sont venu de Dijon pour m'encourager, puis mon très cher ami Omar Fadlaoui pour s'être libéré un jour de la semaine et avoir été présent. Mes amis depuis des années en France ou au Maroc. Une pensée particulière à mes deux meilleurs amis Anass Mekouar et Abderrahim Boujida. Enfin, merci à ma femme Amina pour ses encouragements et son support pendant mes derniers mois de thèse qui ne sont que le début d'un chemin plein d'Amour et de projets pour l'humanité.

Abstract

A user of urban mobility systems interacts with many products and services while heading to some destination. However, the design of urban mobility systems does not usually rely on a door-to-door representation of the traveler experience. Human-centered design represents a relevant way to bring together the views of urban mobility stakeholders in designing integrated mobility systems that meet travelers wants and needs. However, generic human-centered models and methods are not adapted to urban mobility specificities and do not integrate the door-to-door product and service experience of a traveler including his/her activities within a city. This has repercussions on design practice such as sampling, scaling, setting performance indicators, gathering and analyzing qualitative data, involving stakeholders, and setting the boundaries of the system to be designed. For designers and transport operators, these are not obvious to set when it comes to design complex systems, at the scale of a city, which are anchored in the urban life. This thesis aims at developing a model of traveler experience to assist the diagnosis of travel problems in urban mobility systems. Combining the views of user-experience (UX) design and transportation, it addresses the following research questions:

Q1: How can traveler experience be modeled to feed travel problems diagnosis?
Q2: What are the problems travelers experience using urban mobility systems?
Q3: What is the effect of a traveler-centered stimulus on travel problem generation effectiveness?
Q4: How can specific traveler attributes improve transport modeling and simulation?

A conceptual model is first proposed based on human-centered and transportation literature, observations of four urban areas, six interviews, and three workshops. It describes and analyzes different facets of traveler experience and proposes a conceptual setting for problems that travelers face when they interact with an urban mobility system. The model illustrates how the traveler interacts, at different scales with mobility technical systems, and how situations from the urban context can provoke a shift from an expected to a real travel scenario. A case study is conducted to illustrate the use of the conceptual model in identifying travel problems for a demand-responsive transport service. It shows a need for pre-defined categories of problems when identifying causation of problems declared by users. A taxonomy of travel problems is then proposed to complete the missing categories in the conceptual model. It is based on a grounded theory approach using interview scripts from three metropolises and codes them into twenty-two categories of travel problems. Moreover, it proposes a definition of travel problems that synthesizes the views of interviewees and a causality scheme that connects the travel problems categories. The categories cover both objective and subjective dimensions of how problems are perceived by travelers. A case study shows the value of having pre-defined problem categories in bringing deeper insight into mobility systems diagnosis. However, the conceptual model needed validation in a design activity. It was therefore simplified to fit the focus group format of travel problem generation. A textual stimulus is designed to help travelers generate varied and novel travel problems. An experiment is conducted with two control groups as a baseline for non-stimulated problem generation and two experimental groups that are provided with a traveler-centered stimulus. Results show that the stimulated groups generate novel problems with a greater variety than the non-stimulated ones, covering most of the traveler experience dimensions. These dimensions are translated into traveler specific attributes to enhance the accuracy of the determinants of modal shift. Finally, an online survey (457 responses) is conducted for the greater Paris region to estimate the population that is more likely to shift towards using shared autonomous transport services. Results show that, in addition to cost and value of time, the subjective satisfaction criteria play an important role in estimating a potential transport mode shift. Moreover, these criteria brought more accuracy to agent-based simulation of the population that could use autonomous vehicles (AVs) and better profiling to AVs-riders optimization models. The conceptual model has allowed to deepen traveler experience and travel problems understanding. Its different uses have allowed insightful diagnostics of several urban mobility systems. This was recognized by the industrial partners involved in this thesis' research project.

Keywords: urban mobility, traveler experience, travel problems, problem generation, human-centered design, grounded theory.

Résumé

En voyageant vers une destination donnée, l'utilisateur des systèmes de mobilité urbaine interagit avec de nombreux produits et services. Cependant, la conception des systèmes de mobilité urbaine ne repose généralement pas sur une représentation porte-à-porte de l'expérience-voyageur. La conception centrée sur l'humain représente un moyen pertinent de rassembler les points de vue des acteurs de la mobilité urbaine pour concevoir des systèmes de mobilité intégrés qui répondent aux souhaits et aux besoins des voyageurs. Toutefois, les modèles et méthodes génériques centrés sur l'humain ne sont pas adaptés aux spécificités de la mobilité urbaine et n'intègrent pas l'expérience porte-à-porte d'un voyageur en matière de produits et de services, y compris ses activités dans une ville. Cela a des répercussions sur les pratiques de conception, telles que l'échantillonnage, la mise à l'échelle, la définition d'indicateurs de performance, la collecte et l'analyse de données qualitatives, la participation des parties prenantes et la définition des limites du système à concevoir. Pour un industriel ou un opérateur de transport, il n'est pas aisé de mettre en œuvre ces pratiques lorsqu'il s'agit de concevoir des systèmes complexes, à l'échelle d'une ville, qui sont ancrés dans la vie urbaine. Cette thèse vise à développer un modèle de l'expérience-voyageur pour faciliter le diagnostic des problèmes de voyage dans les systèmes de mobilité urbaine. Combinant les points de vue de la conception de l'expérience utilisateur (UX) et du transport, elle aborde les questions de recherche suivantes :

Q1 : Comment peut-on modéliser l'expérience-voyageur pour alimenter le diagnostic des problèmes de voyage ?
Q2 : Quels sont les problèmes rencontrés par les voyageurs lors de l'utilisation de systèmes de mobilité urbaine ?
Q3 : Quel est l'effet d'un stimulus centré sur le voyageur sur l'efficacité de la génération de problèmes de voyage ?
Q4 : Comment des attributs propres au voyageur peuvent-ils améliorer la modélisation et la simulation du transport ?

Un modèle conceptuel est d'abord proposé sur la base d'une littérature du transport centré sur l'humain, d'observations de quatre zones urbaines, de six entretiens et de trois ateliers. Il décrit et analyse différentes facettes de l'expérience-voyageur et propose un cadre conceptuel pour les problèmes auxquels les voyageurs sont confrontés lorsqu'ils interagissent avec un système de mobilité urbaine. Le modèle illustre les interactions du voyageur, à différentes échelles, avec les systèmes techniques de mobilité, et indique comment des situations provenant du contexte urbain peuvent provoquer le passage d'un scénario de voyage attendu à un scénario réel. Une étude de cas est menée pour illustrer l'utilisation du modèle conceptuel dans l'identification des problèmes de voyage pour un service de transport à la demande. Cela montre la nécessité de définir des catégories de problèmes prédéfinies lors de l'identification des causes des problèmes déclarés par les utilisateurs. Une taxonomie des problèmes de voyage vient compléter les catégories manquantes du modèle conceptuel. La taxonomie repose sur une approche théorique ancrée dans les scripts d'interview dans trois métropoles et les code en vingt-deux catégories de problèmes. De plus, un schéma de causalité reliant les différentes catégories de problèmes de voyage est proposé. Les catégories couvrent à la fois les dimensions objectives et subjectives de la perception des problèmes par les voyageurs. Une étude de cas montre l'intérêt de disposer de catégories de problèmes prédéfinies pour mieux approfondir le diagnostic des systèmes de mobilité. Cependant, le modèle conceptuel devait être validé dans le cadre d'une activité de conception. Il a donc été simplifié pour s'adapter à la configuration en focus-group pour la génération de problèmes de voyage. Un stimulus au format textuel a été conçu pour aider les voyageurs à générer des problèmes variés et nouveaux. Une expérience a été menée avec deux groupes de contrôle servant de base à la génération de problèmes non stimulés et à deux groupes expérimentaux dotés du stimulus. Les résultats montrent que les groupes stimulés génèrent de nouveaux problèmes d'une plus grande variété que sans stimulus, couvrant la plupart des dimensions de l'expérience-voyageur. Ces dimensions sont traduites en attributs propres au voyageur afin d'améliorer la précision des déterminants du transfert modal. Enfin, une enquête en ligne (457 réponses) a été réalisée pour la région parisienne afin d'estimer la population la plus susceptible de s'orienter vers l'utilisation de services de transport autonomes partagés. Les résultats montrent que, outre le coût et la valeur du temps, les critères de satisfaction subjectifs jouent un rôle important dans l'estimation du transfert modal. De plus, ces critères ont apporté plus de précision à la simulation à base d'agents de la population pouvant utiliser des véhicules autonomes (AV) et un meilleur profilage des voyageurs pour les modèles d'optimisation. Le modèle conceptuel a permis d'approfondir la compréhension de l'expérience-voyageur et des problèmes de voyage. Ses différentes utilisations ont permis un diagnostic pertinent de plusieurs systèmes de mobilité urbaine. Ceci a été reconnu par les partenaires industriels impliqués dans le projet de recherche de cette thèse.

Mots-clés : mobilité urbaine, expérience-voyageur, problèmes de voyage, génération de problèmes, conception centrée sur l'humain, théorie ancrée.

List of Figures

List of Tables

Contents

General introduction

In one of the workshops of the International Transport Forum entitled “designing cities for people” (OECD, 2014), it was pointed out that the world's population is increasingly concentrated in cities causing problems of inequality and accessibility. This poses a risk for the quality of life. To avoid such a future, urban planning will need to adopt approaches that focus on the diversity of citizens and their needs, thus encouraging the development of new approaches to observe travelers and ensure their quality of life.

The citizen, user of transportation systems, has always been one of the centers of interest of urban mobility actors, since, directly - for the car manufacturers, for example - or indirectly - for train manufacturers – he/she is the customer, as for the public authorities he/she is the finality. However, through the evolution of the paradigm of urban mobility (Jones, 2014), the conceptualization of the user has changed. Indeed, during a first step, the user was reduced to a simple constraint, the mass in kilograms for example for civil engineering. The second stage, on the other hand, represented travelers as a physical flow whose circulation must be optimized. Finally, faced with the failure of these models (Boy & Narkevicius, 2014) to be able to solve evolving problems of mobility (Priester et al., 2014), the user has become a much richer concept. We are now talking about a corporate employee, a father, a businessman, a student, taking into account the dimensions that make of a user a particular citizen performing urban activities within a city (Nielsen, 2014).

Furthermore, a user of urban mobility systems interacts with many products and services while heading to some destination, while these systems are not designed and not operating together to offer him/her a seamless experience (Preston, 2012).

In this perspective, human-centered design appears as a relevant answer to initiate the shift from passive “end” user towards an active contributor to all system’s design phases (Talbert, 1997). The comprehension of users’ needs and wants is a matter that concerns every stakeholder of urban mobility and a powerful way to bring together their views in designing integrated mobility systems.

However, the human-centered approaches remain often too generic to urban mobility issues and do not integrate the door-to-door multi-products and services experience of a traveler including his/her activities within a city. This is why this PhD thesis focuses on the development of a model that integrates urban mobility complexity factors, having the traveler in the center.

Chapter I

Context and research questions

Challenges cities are facing nowadays are impacting the practice of urban mobility of both travelers and transport industry. The traveler is challenged by daily travel problems. Urban mobility actors, therefore, are given opportunities to innovate and create new products and services responding to the evolving wants and needs of travelers. Human-centered design research, as a scientific driver for this change, contains a rich literature on models that consider the human in the center. They lack however consideration of some important aspects of urban mobility complexity factors. This chapter discusses these matters and proposes research questions for this thesis and a general methodology through which they will be answered.

I.1 General context

The urban challenges cities are facing in our era have an impact on urban mobility. A city is invented every day. It is imagined and formed by many people at the same time (Kempf 2009, p.2). On the one hand, decision makers, such as local authorities or transport operators and manufacturers, have to make decisions about the future of urban mobility. On the other hand, citizens are consulted for questions regarding democracy, acceptance, and quality of urban mobility systems. Therefore, along with the city, urban mobility has to evolve to meet the challenges of the future smart and sustainable city.

I.1.1 Urban challenges

Nowadays more than 54% of the world population live in urban areas (United Nations, 2016). This is expected to increase up to 60% in 2030, and 67% in 2050 (Figure 1). As a consequence, the city has to face challenges such as social disparities, insecurity, unemployment, housing need, governance complexity, etc. (Van Den Berg et al., 2007).

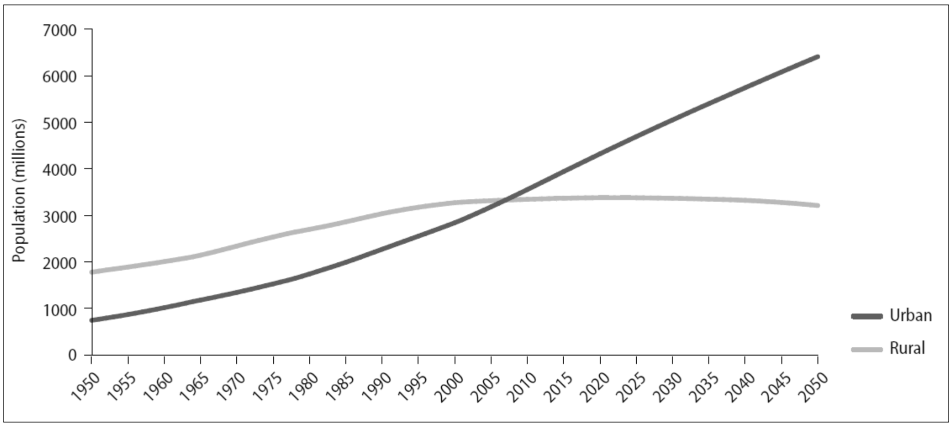


Figure 1. Urban and rural population of the world, 1950-2050 (UNDESA, 2014)

Population growth comes with the augmentation of road and rail transport of persons raising between 120 and 150% at the 2050 horizon (ITF, 2017). Urban mobility accounts for 40% of CO_2 emissions of road transport, and up to 70% of other pollutants emitted by transportation. Consequently, air pollution contributes in shortening life expectancy of populations and causing several pollution-related diseases (WHO, 2005). From Elkington's (1998) triple bottom line (People/Profit/Planet) perspective, urban challenges take several forms (Van Audenhove et al., 2014). Table 1 illustrates these challenges projected on profit, planet, and people.

In this context of global challenges, "smart" and "sustainable" are the two key attributes a city needs to acquire. There is a need of transforming existing settlements into smart and sustainable cities. This means to couple their ICT potential with human-centered innovation, engaging people in participatory processes, environmental resources preservation, and the use of new business models (Bisello *et al.*, 2017, p. vii).

Table 1. Challenges confronting cities (Van Audenhove et al., 2014)

Dimensions	Challenges
Planet	- Air & noise pollutions - CO_2 emissions - Increasing ecological footprint
People	- Traffic jam, chaos, and security - Decreasing quality of life and convenience
Profit	- Overloaded infrastructures - Insufficient public transport capacities - Increasing motorization - Limited parking places

I.1.2 Sustainable and smart city

If urbanization remains the way it is practiced now, it will aggravate the unsustainability of cities (Bibri, 2018). Indeed, urbanization as a clustering of people and buildings forces the limited urban resources, exposes the city to climate driven-natural disasters and climate change, increases the vulnerability of the poor, and deepens inequality of access to urban services (K.-G. Kim, 2018). Hence the need of a sustainable city is exposed.

The buzz concept of "smart cities", as an answer to the cities' sustainability challenges, gives most of the time the sense of technology-laden projects using Internet-of-things, green energy, artificial intelligence, or autonomous vehicles (Lehr, 2018). However, a smart city is a twofold concept indeed (Kitchin, 2013). On the one hand, it uses technology in the form of digital devices and infrastructures that enable real time analysis of the city life through modeling and prediction of processes. On the other hand, a smart city must enhance human capital, education, economic development and governance. In other words, a smart city is also sustainable insofar as it offers a pleasant healthy way of life, accessible to every citizen by conducting a responsible management of its transport networks, urbanism, energy, and resources consumption. Indeed, beyond the improvement of abiotic and biotic aspects of urban life, urban sustainability is about people's satisfaction, experiences and quality of the daily environments (Chiesura, 2004).

Giffinger (2007) has set six dimensions to define a smart city. Indeed, the "smart" attribute covers at the same time; economy, people, governance, mobility, environment, and living. Table 2 illustrates for each characteristic, the factors that should be present in a city to be "smart". These dimensions are usually aggregated to rank cities regarding their "smartness" (Arroyo-Cañada & Gil-Lafuente, 2017).

The City of Paris, for instance, succeeded in realizing this dual vision and got high scores in these rankings. It was awarded the European Commission's most innovative city in 2017 (European Commission, 2017). Indeed, Paris now hosts the world's largest start-up campus where citizens, innovators from the private, non-profit and academic sectors work together reinventing and rebuilding many of the city's significant sites (Mairie de Paris, 2018).

As urban mobility is one of the most important drivers toward smart and sustainable cities, it requires its proper means. Indeed, urban mobility systems should be capable of collecting information through sensing and monitoring; processing information; acting and controlling; communicating between sensors. Moreover, this should give them the capacity to predict problems; heal situations; and prevent potential failures (Debnath et al., 2014).

Table 2. Characteristics and factors of a smart city (Giffinger, 2007)

Smart Economy *(Competitiveness)*	**Smart People** *(Social & Human Capital)*
- Innovative spirit - Entrepreneurship - Economic image & trademarks - Productivity - Flexibility of labor market - International embeddedness - *Ability to transform*	- Level of qualification - Affinity to lifelong learning - Social and ethnic plurality - Flexibility - Creativity - Cosmopolitanism/ Open-mindedness - Participation in public life
Smart Governance *(Participation)*	**Smart Mobility** *(Transport & ICT)*
- Participation in decision-making - Public and social services - Transparent governance - *Political strategies & perspectives*	- Local accessibility - (Inter-)national accessibility - Availability of ICT-infrastructure - Sustainable, innovative & safe transport systems
Smart Environment *(Natural Resources)*	**Smart Living** *(Quality of life)*
- Attractivity of natural conditions - Pollution - Environmental protection - Sustainable resource management	- Education & cultural facilities - Health conditions & Individual safety - Housing quality & Social cohesion - Touristic attractivity

Urban mobility plays a central role in shaping the future of the smart and sustainable city. Indeed, it shapes together infrastructure, urban planning, and quality of life of individuals (Lopatnikov, 2017). Therefore, challenges facing cities impact urban mobility and the way it is designed. Urban mobility actors have to evolve in order to meet the new requirements of the new mobility paradigm that places, today, the traveler in the center (Banister, 2008).

I.2 The Anthropolis research chair

This thesis is conducted as part of the research chair Anthropolis (Anthropolis, 2018). It is a research project that aims at making engineering approaches of urban mobility more human-centered. The thesis focuses on design engineering approaches and tries to enrich them in both urban mobility contextualization and human-centered ways.

The industrial partners of Anthropolis are actors of urban mobility in the greater Paris region and they face several challenges related to innovation as part of urban mobility transformation to meet the evolving wants and needs of travelers.

I.2.1 The context of the chair

The Anthropolis research chair is the fruit of a partnership between the Institute for Technological Research (IRT) SystemX and the Industrial Engineering Laboratory (LGI) of Ecole CentraleSupélec. It is partially funded by industrial partners which are ALSTOM, ENGIE, Renault Group, RATP and SNCF.

The LGI develops models, methods and tools for the diagnosis, design, development, manufacture, launching, operation, recycling of socio-technical systems, such as urban mobility systems. This thesis is at the crossroads of the design engineering team works and the urban mobility research axis of the lab. SystemX, on the other hand, is one of eight institutes for technological research that have been established by the Government to enhance the country’s attractiveness. It is specialized in digital engineering of complex systems, meeting industries and territories’ technological and scientific challenges through open and collective applied research. The Anthropolis research chair is a part of Smart territories program of the institute.

The Anthropolis partners are motivated to work together, being aware of the fruits of R&D collaboration between urban mobility actors. Therefore, in setting the goal of the chair, the LGI has proposed that its research should be centered on the Human, arguing in this way:

“Innovation is born more and more of individual initiatives or spontaneous groups. Thus, it must be cultivated with a better understanding of the current evolution of the increasingly digital society, operating in networks and where sociotechnical interactivity has become a necessity. It is necessary to move continuously from the individual needs of each (of the user) to the systems of systems to satisfy them by integrating the concepts (systems, services, uses, etc.), with the management of the different interacting urban flows.”

This point of view is supported by the International Transport Forum (OECD, 2014, p:16). Indeed, in a workshop entitled "Designing Cities for People", it was pointed out that urban planning will need to adopt approaches that focus on the diversity of citizens and their needs, thus encouraging the development of new approaches to observe users and their quality of life.

To Sharon (2012, p:35), this kind of research projects generates value for its stakeholders when it helps:

- Uncover the needs of the user, different profiles of users, their situations of discomfort, identify the appropriate value to propose when it comes to developing a new product.
- Understand what works well and what does not work and how to improve it and see in competing offers when it comes to a new version of the product.
- Develop metrics to identify the success of use when the product is about to enter the market.
- Propose research questions to improve even more when the product is a success.
- Identify the problems of use and propose solutions when the product is a failure.

The "product" boundaries quickly become difficult to define once we start talking about urban mobility. Indeed, urban mobility includes several products and services which directly result a multitude of uses. The private car is driven in a high-traffic road network during peak hours, the bus to go to the suburban train station, the application that provides information on the journey to take to get from point A to point B, the self-service bike for a touristic hike, the trip in a tunnel with a hundred corridors to take a connection between the metro and the suburban train ... There will always be, in a system as complex as that of urban mobility, new products to design, others to improve, services to adapt, practices to reform, networks to optimize, etc. Anthropolis therefore tries to provide answers to questions that focus on travelers, users of urban mobility systems through three research axes: (1) User research: a traveler - centered approach of urban mobility issues. (2) Disruptive technologies and innovation: a technological watch of urban mobility. (3) Impact assessment: a measure of the impact of new solutions on business models and urban systems. As part of the first research axis, this thesis aims at bringing new insights that would help urban mobility actors to tackle the innovation challenges they are facing and target more human-centered solutions.

I.2.2 Innovation challenges of the chair’s partners

The five industrial partners of the Anthropolis chair are big companies that have decades of history in doing and excelling at developing urban mobility solutions. After interviewing them we discovered that, today, these companies feel the urge to move their businesses towards new paths that they never mastered before. Therefore, they need to acquire and adopt practices and approaches of innovation which are about going beyond their initial core business.

For B2B companies among our partners, it is hard to know the problems of the final user of the systems they design (e.g. a train). To develop their offer, they are constrained by technical specifications and do not have direct access to the raw user material collected by their business client. Therefore, today, they are developing their own knowledge about the final users of their products and services. For instance, ALSTOM has its own approach of digital mobility experience of passengers of its trains (ALSTOM, 2018). Moreover, the traveler knowledge becomes even harder to acquire and master when the company’s core business is not urban mobility but an energy provider. Indeed, the variety of sectors that a B2B energy company has to deal with is big. Therefore, it needs to have this knowledge on the traveler experience for its mobility solutions. ENGIE develops solutions for public transport, for example, among which there are passenger information systems and car sharing (ENGIE, 2018).

The core knowledge of the automotive industry is on driving a car, not on using the car as a mode of transport that interchanges with other modes in a door-to-door mobility experience. Therefore, car manufacturers who want to evolve toward a more integrated business with other urban mobility systems are acquiring the knowledge on these systems and position their offer as a system among systems. Moreover, the marketing practice of these actors is also evolving towards knowing better other mobility dimensions in a traveler experience perspective. For instance, RENAULT is now developing shared mobility solutions for the autonomous future of mobility (RENAULT, 2018).

For transport operators, in the context of the greater Paris region, the challenge is to assure a seamless, door-to-door experience of passengers using public transport. Beyond the operational performance such as reliability, safety and availability, transport operators have to provide cleanliness, comfort, information, and the right services for different profiles of travelers. Moreover, new shared mobility solutions such as ride-sharing or electric-scooters are becoming a part of public transport and need to be mastered by the operators. RATP and SNCF are already in the move of considering a door-to-door (RATP, 2018) and sustainable (SNCF, 2018) experience of public transport users and not only the aggregate of the line they operate.

When it comes to develop new solutions, urban mobility actors need to reflect on their previous projects. Moreover, a new solution when integrated in the market does generate changes in existing mobility systems. Therefore, it needs to be simulated to forecast the behavior of users and the global transportation system. However, the future behaviors and attitudes of travelers are not well known today. Anthropolis industrial partners are facing new challenges when thinking of the future of their respective businesses. Therefore, this thesis is set to help the Anthropolis partners to tackle some of them.

I.3 Research context

This thesis aims at being a bridge between design and transportation research fields. However, its core discipline is design research. For this reason, it will be positioned in the design research scope where its design object is urban mobility and its users are the travelers.

Early in the design process (Figure 2), designers develop a sense of problem knowledge. This constitutes the intelligence phase according to the Nobel Prize winner, Simon (1960). Recent research still has this view of design, where the problem setting phase has its sovereign role (Yannou, 2015). This phase is also called market, need, or problem analysis, where the requirements and the goals of the product life cycle are set (Pahl et al., 2007). This thesis aims at providing and validating a support for travel problem diagnosis by setting the problems travelers suffer from when using urban mobility systems.

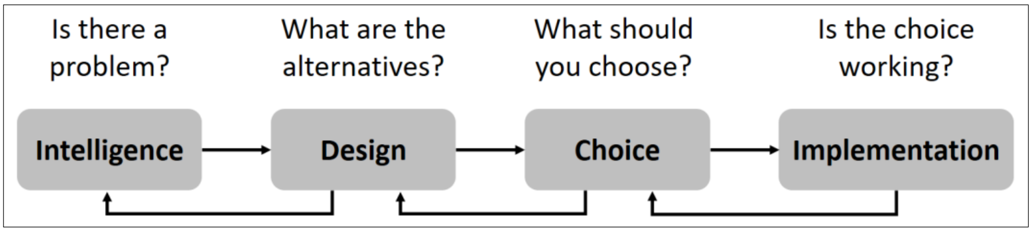


Figure 2. Decision-based design process (Simon, 1960)

Two main literature fields are investigated in order to address the picture of the traveler within complex urban mobility systems.

- The first field studies perspectives on urban mobility and sets its complexity factors (1.3.1).
- The second field lists different research approaches that have the human in the center of urban mobility design (1.3.2).

I.3.1 Perspectives on urban mobility

Depending on the point of view used to look at urban mobility, different definitions are used. Engineers likely consider the technical side of mobility and think about products and infrastructure. Transport planners think more of how they can make these operate effectively and efficiently and design future transport infrastructure. Sociologists and psychologists, on the other hand, would focus on understanding people in the way they move in cities. Economists see a demand on travel and a supply to meet it. All of these perspectives need to be taken into consideration to obtain a most complete picture of urban mobility.

Besides, different names have been given to the concept of urban mobility, or at least close concepts. In addition to transport, transportation and mobility, one can find “human transit” (Walker, 2012) for public transport or motility as potential mobility (Kellerman, 2012).

Kayal et al. (2014) define urban mobility as a *system* that meets the need of transport and land use (to include geography and infrastructure) in an efficient manner, and to take into account the dimension of sustainability, it incorporates economic viability, environment stability and social equity of both current and future generations.

In urban sociology, mobility differs from the notion of transport or displacement. Often, three elements are used to characterize mobility (Table 3). These three dimensions are turning around spatiotemporal movements of people within some urban environment, engaging social interactions and perceptions.

The spatial and physical vision of urban mobility includes the roads and rails, cars and trains, and the Information and Communication Technologies needed to make them operate efficiently. Moreover, people and institutions are needed to govern, operate, and do the transportation planning, regulation and pricing. Theses dimensions have been identified by (Stead, 2016) as the key research themes for sustainable urban mobility.

Table 3. Mobility through three dimensions

Dimension 1	Dimension 2	Dimension 3	Reference
Space	Time	Context	(Kakihara & Sørensen, 2001)
Physical settings, material spaces & design	Embodied performance	Social interactions	(Jensen 2013, p.6).
Networks, infrastructures & accessibility conditions	Displacements realized in time and space, from origin to destination	Capacity to be mobile in social & geographic spaces	(Kaufmann et al., 2004) (Kaufmann, 2011)

Following these dimensions, we will present first the technical side of urban mobility, then we will introduce the social, the market and the governance dimensions.

I.3.1.1 Technical urban mobility

Roads, rail, fuel stations, train stations, bridges, energy network, terminals and facilities etc. on one hand, buses, cars, trains, trucks, boats, trams etc. one the other hand, constitute the technical physical components of urban mobility. To complete that, Information and Communications Technology (ICT) (GPS, Internet of Things, mobile networks…) play an important role to foster the qualities of this technical system (safety, usefulness, fluidity…).

However, the aggregation of infrastructure, vehicles and ICT is not giving us the whole picture of the technical urban mobility system. In fact, trip-chaining (Primerano et al., 2008) connects each of both the elements of infrastructure and vehicles together. It brings out the necessity to have a global understanding that takes multi-modality into account and think of a global performance rather than those of a single bus line, highway, or hub separately. For instance, bus lines that are feeding a regional rail line may operate with good performance indicators (e.g. schedule respect, good frequency) but if they arrive all at the same time at the train station they would cause a congestion and deteriorate the train's performance indicators. The combined set of bus lines and regional train would then operate with a bad multi-modality efficiency indicator.

Nevertheless, studying multi-modality is not sufficient to complete the whole technical view of urban mobility. Actually, there are other urban systems connected to it such as households, industries, or workplaces (Wegener, 2013). Consequently, in urban planning, these are designed together with transportation infrastructure. Furthermore, the energy consumption of a city depends hardly on its transportation system. For instance, transportation represents more than 60% of the world's consumption of oil (IEA & OECD, 2015).

Systems Engineering brings out the links between the functional, the physical and the usage views of the system (could be a car, a station, a telecom facility, or even the whole mobility system) (Denis & Janin, 2010) (Jesty & Bossom, 2011). In fact, it uses Data & Physical diagrams to represent how data and physical elements (energy, documents, contact…) are being exchanged within the system and with external systems and actors.

Figure 3 shows an example of an Intelligent Transport System (ITS) that operates displacement information of passengers. It gathers data from two external systems (displacement coordination system & referential management system) and from passengers' displacement data (GPS data). It delivers data (e.g. traffic state) to both transport authorities through the indicators central and passengers through e.g. a smartphone application. This representation gives insight about the functions of the system and how data and physical flows move between different sub-systems and surrounding systems and actors. However, it reduces the users to simple entities with whom the system exchanges data and has a physical contact.

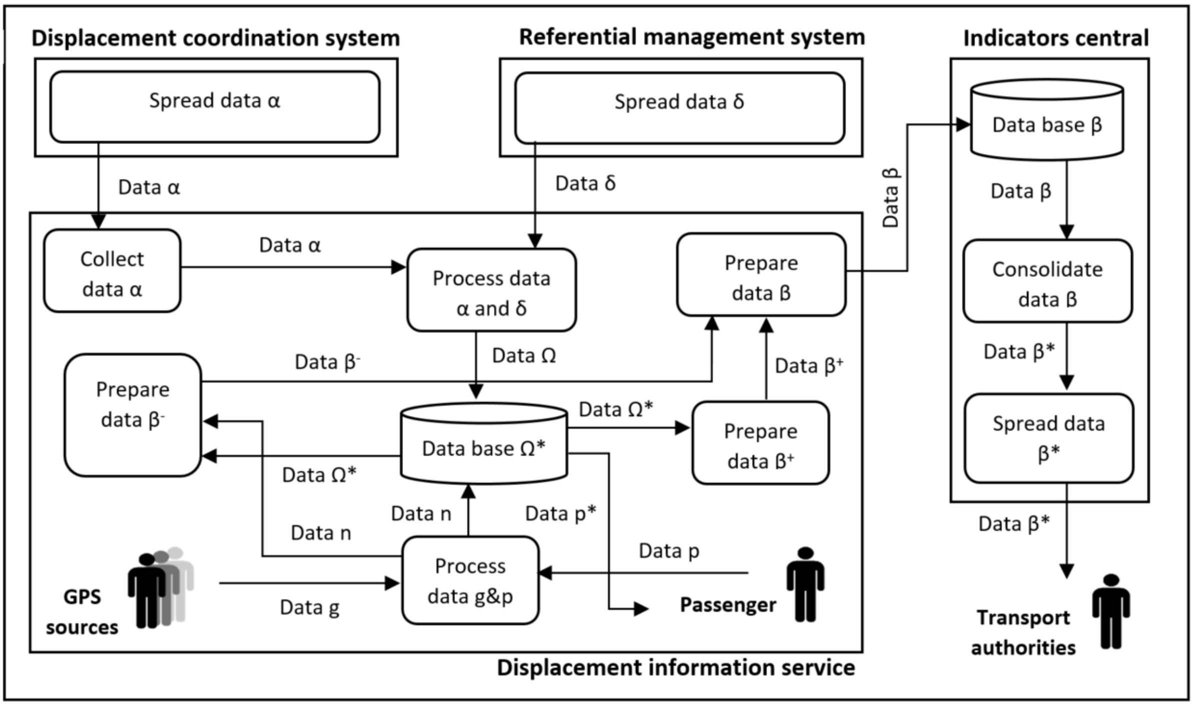


Figure 3. Systems Engineering model of an ITS (Denis & Janin, 2010)

I.3.1.2 Urban mobility market

The World Business Council for Sustainable Development (WBCSD, 2015) has developed a performance-oriented model of the mobility system as being a set of three markets (Figure 4): (1) the travel market where spatiotemporal activity creates travel patterns, (2) the transport market where travel patterns meet –theoretical- transport options in a transport patterns, (3) the traffic market in which transport patterns are confronted with the actual supply of infrastructure and their associated traffic management systems, information systems, etc. The supply of the urban mobility system uses spatial, economic and environmental resources on which, recursively, it has impacts when meeting the demand. The same phenomenon goes for the three markets. For example, the spatiotemporal travel patterns, in addition to social attitudes and cultural background, are the result of spatial passenger density which is conditioned by the availability of infrastructure. At the same time, the infrastructure is designed to fit theses travel patterns.

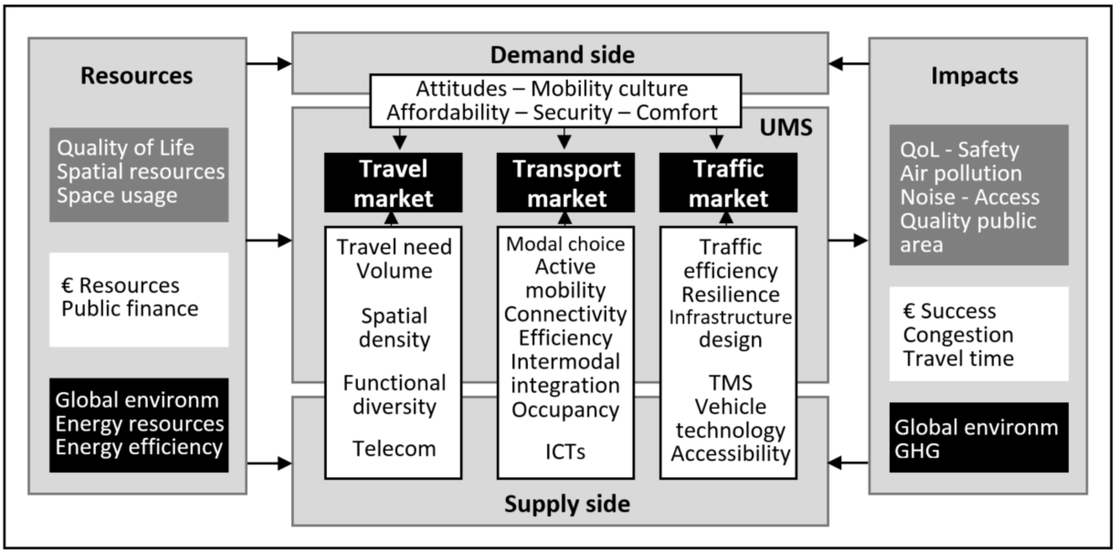


Figure 4. Urban mobility markets (WBCSD, 2015)

(Cascetta, 2009) defines the transportation system as a set of elements. The interactions between these elements produces both the demand for travel within a given area and the provision of transportation services to satisfy this demand.

There are many interactions between the components within the transportation system and between the activity system (the set of individual, social, and economic behaviors and interactions that give rise to travel demand) and transportation systems. For example, the level and spatial distribution of travel demand is defined, inter alia, by the location of both households and economic activities. On the other hand, the set of these interactions generates feedback cycles. For example, travelers who choose the most efficient (fast and cheap) path within the available means might congest it and thereby deteriorate this efficiency (transportation service performance).

(Gonzalez et al., 2008a) and (Hasan et al., 2013) gave more attention to the travel demand in its spatial aspect. Their approach covers all population displacement in the physical space, regardless of the duration and distance of travel, the means used, their causes and consequences. Taken in this way, mobility becomes a map of passenger concentration in an urban space (mobility patterns) (Gao, 2015). It gives insight of the most frequented places by profiles of people (e.g. using cars or public transport) or of all citizens together. Furthermore, these mobility patterns can be combined to actual city maps and give some hints to the reasons of the noticed concentrations.

Moreover, (Bassand & Brulhardt, 1981) identified three systemic properties in spatial mobility:

- The first one is totality; the spatial mobility as a whole is a totality carrying out specific functions that are distinct from those conducted by the various types of spatial mobility that compose it. For example, using the bus to get to the train station has for function catching the next train while the travel between home and work aims to get to work on time.
- The second property is the positive/negative or the reinforcing/balancing feedback. It is a distinction and decomposition of the feedback loops mentioned by Cascetta. For example, when an alternative itinerary to avoid congestion is announced, this could be a balancing feedback to balance the traffic jam in the road network. A reinforcing feedback occurs when congestion causes delays and delays accumulates travelers in the metro station which causes congestion, for example.
- The third principle is the diachronic functioning of mobility which generates itself over time. For example, if a traveler /commuter moves from home to work, he generates the need to move from work to home.

In summary, demand is characterized by attitudes and cultural background of users on one hand, and, by spatial distribution of socio-economic activities on the other hand.

Considering the supply and demand separately in representing the urban mobility has given us some information about how they interact. However, this perspective does not take into account neither the effect of legal and political dimensions nor the role of individuals and institutions in operating urban mobility.

I.3.1.3 Socio-technical urban mobility

According to (Auvinen & Tuominen, 2014), technological, social, economic, political, legal or environmental dimensions need to be considered in order to understand the complexity of urban mobility. They define the UMS (Urban Mobility System) as set of four main components which are; the infrastructure, the vehicles, the users and the governance (Figure 5). For example, from the environmental perspective, the infrastructure offering smart electricity grids and charging stations for cars and buses permits the development of emission-free and silent electrical fleets. Together with political support and standardization, this encourages responsible modal choice from users and finally generates a clean transport environment. For instance, people buying electric cars create a demand on charging stations and encourage the creation of new ones. However, if there is no charging station supply people won’t buy electric cars. All these interactions and positive loops permit the propagation of social values trough the global urban mobility.

In a wider perspective, the UMS is a component of a bigger urban system and interacts with e.g. energy systems and social structures. Hospitals and workplaces, for example, by the practice of telemedicine and teleworking, decrease the need of moving and, consequently, the transportation energy consumption. However, these new practices need involvement of people, commitment of companies, and the adequate technological and legal measures.

For Ottens et al. (2006), the main components of the UMS as a socio-technical system are aggregated into three classes: technical elements, social elements and actors. Where technical elements include all physical components and the software to operate those, the actors are individuals or organizations that are directly running the system, and finally the social elements influence the functioning the UMS. Every element is in relation with the ones that are of its kind and with the ones that are not. Beyond the functional relations (for instance bus providing information to bus station) and the physical relations (vehicles driving on roads), there are intentional and normative interactions. The intentional interactions are performed by actors where other elements are the object of their intention for some action e.g. a passenger has the intention to use a bike between metro station and his work. The normative interactions represent rules for running a technical element or an actor, e.g. a public transport operator obliges passengers to have valid tickets.

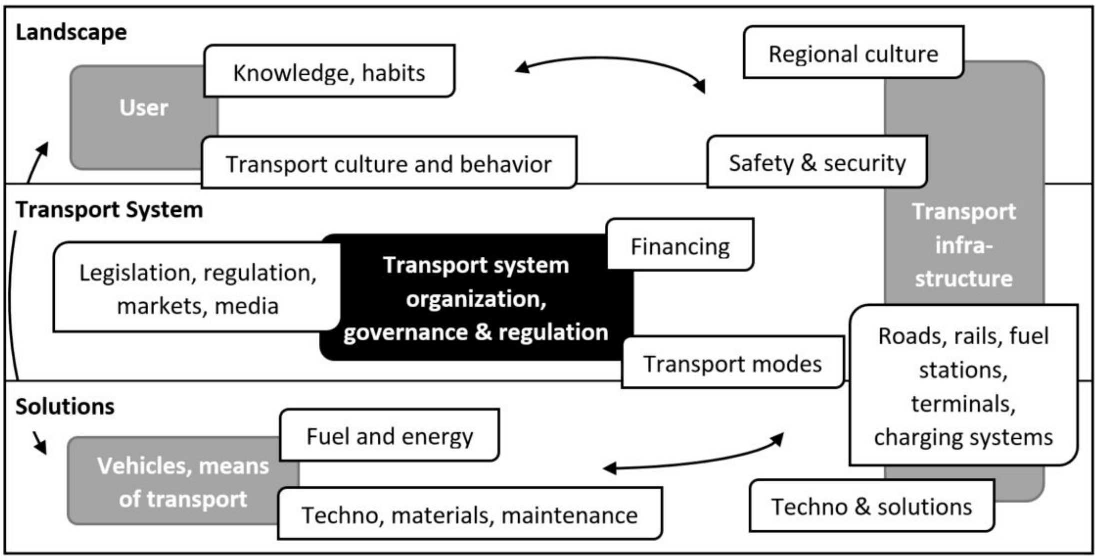


Figure 5. A framework to study the transport system (Auvinen & Tuominen, 2014)

From the socio-technical perspective, the user is a part of the UMS and contributes to its functioning as a consumer and as an actor. However, this perspective does not integer the governance upon different social elements and actors.

I.3.1.4 Urban mobility governance

Governance is crucial for promoting more integrated transport policy in many senses: horizontally (between different agencies or sectors involved in policymaking), vertically (between different tiers of government), spatially (between geographically adjacent agencies), temporally (between policies with different time horizons and/or implementation dates) and modally (between different systems and operators) (Stead, 2016).

IOG (2013) describes governance as the art of helping the achievement of organizational and societal goals, among several stakeholders, according to three dimensions: authority (who has the power of what), decision making (who decides what) and accountability (which do what).

The integration of different stakeholders in the decision-making process demands insights about how the urban mobility governance system works. A good governance gives coherence, consistency and relevance to measures made on how urban mobility would evolve. DeLaurentis (2005) models this as a System-of-Systems (SoS) problem. The main traits of urban mobility as a SoS are:

- Operational and managerial coordinated independence; e.g. a bus operates on a schedule dictated by the transport operator but must coordinate with other buses.
- Geographic distribution which is inherent to transportation systems.
- Evolutionary behavior; Measures of effectiveness for transportation are dynamic in nature, due primarily to delayed response to major inputs as well as inherent feedback mechanisms.
- Emergent behavior; e.g. in hubs, which is the connection between two modes or more, queues are emergent phenomena.
- Heterogeneity; institutions, users, vehicles, infrastructure etc. are different entities that composes urban mobility.
- Networks; e.g. road networks, hubs networks, car-sharing networks…
- Trans-domain; involving economy, sociology, psychology, geography, policy …

In order to visualize the different layers and dimensions representing the problem, DeLaurentis proposes the SoS-Lexicon Matrix (Table 4) where: (1) Resources are entities (systems) that give physical manifestation to the system-of-systems. (2) Economics are non-physical entities that give intent to the SoS operation. (3) Operations; application of intent to direct the activity of physical& non-physical entities. (4) Policies; external forcing functions that impact the operation of physical & non-physical entities.

Table 4. Transportation SoS-Lexicon Matrix with Order Estimates (DeLaurentis, 2005)

Size	Resources	Operations	Economics	Policies
(10^6)	Vehicles & Infrastructure (e.g. train, truck, runway)	Operating a Resource (car, bus, etc.)	Economics of building/operating/buying/ selling/leasing a single resource	Policies relating to single resource use (e.g. type certification, license, etc.)
(10^4)	Collection of resources for a common function (a train station, etc.)	Operating resource networks for common function (e.g. transport operator)	Economics of operating/buying/selling/leasing resource networks	Policies relating to multiple vehicle use (e.g. road traffic management, noise policies, etc.)
(10^2)	Resources in a Transport Sector (e.g. rail transportation)	Operating collection of resource networks (e.g.; public transport authority)	Economics of a Business sector (e.g. Automotive Industry)	Policies relating to sectors using multiple vehicles. (Safety, accessibility, etc.)
(10^1)	Multiple, interwoven sectors (resources for a national transportation system)	Operations of Multiple Business Sectors (i.e. Operators of total national transportation system)	Economics of total national transportation system (All Transportation Companies)	Policies relating national transportation policy
(10^0)	Global transportation system	Global Operations in the world transportation system	Global Economics of the world transportation system	Policies relating to the global transportation system

Parker (2010) gives an example of SoS spatial application on establishing networks between hubs to identify interfaces an apply standards to permit seamless connections between modes. That presupposes the presence of multiple transport means customized to specific situations. Therefore, sufficient information is needed for the correct decision between several options in real time (especially with the support of mobile technology). Ultimately it would drive a change in social habits and behaviors (Spickermann et al., 2013).

Sussman et al. (2005) consider, from the Regional Strategic Transportation Planning (RSTP) perspective, transportation system as a Complex Large-Scale Integrated Open System (CLIOS) focusing on both physical and institutional dimensions of complexity. They give higher importance to the involvement of stakeholders all along the design process. Indeed, setting the system's goals, representing its structure (subsystems and components) and giving it performance indicators define how the system would operate. For instance, the omission of some small private stakeholders – knowing they are developing new technologies shaping the UMS use, like new apps- may induce the lack of understanding change in the UMS behavior and its users depending on technology, and consequently distort the system modeling and performance setting. Indeed, (Schwanen, 2013) states that the urban mobility governance is ambiguous and generates the most complicated problems.

Moreover, (Lindenau & Böhler-Baedeker, 2014) stress the importance of involving the users in the decision making process of sustainable urban mobility planning,. This is to allow them to express their concerns and propose new ideas and encourage them to take ownership and raise awareness of sustainable measures. At the same time, authorities and operators gain insights of urban mobility problems from the user's point of view.

The Civitas project (Civitas, 2011) proposed a list of stakeholders to give a wide picture of whom can be involved in urban mobility decision making processes; (1) Primary stakeholders are ultimately affected by measures, either positively or negatively (e.g. citizens, various social groups or professional associations, city districts, business branches, individual organizations etc.). (2) Key Actors are those with political responsibility, financial resources, authority, with skills and expertise in transport and related domains, and those that are recognized by and have good relationships with local people (local champions). (3) Intermediaries; implement transport policies (e.g. operators, police etc.), those with permanent interest representations (e.g. associations, chambers, NGOs), and those who provide information and report on transport (authorities, transport operators, media etc.). Each of these actors plays a role in enriching and fostering the integration of measures and then permit a seamless mobility to users.

I.3.1.5 A comprehensive view on urban mobility

Based on the surveyed material, we propose a comprehensive view of urban mobility in Figure 4. Starting from the technical perspective on urban mobility we noted that it informs about the technical systems, the interactions that exist between systems, and the context of the city gave us an image of the environment where technical urban mobility operates. We have seen that systems engineering represents quite well the technical aspect of mobility but has limitations to model the response to the demand in the travel market.

Technical representation being only the supply side of the market vision, we need to describe the demand side and see how it interacts with supply. We then saw that it depends on socio-economical activities of individuals and their cultural background. Therefore, the spatiotemporal representation gave more insight on these travel patterns in the form of some systemic properties. The integration of both technical and social visions of mobility allowed us to capture the nature of interactions between users, institutions and the physical system. However, the functioning of governance above the socio-technical urban mobility was not explicit. Dimensions of governance confronted to the System of Systems problem setting gave us a comprehension of different levels of decision making and how the integration of stakeholders in its process is important.

This section aimed to represent the landscape of urban mobility through different perspectives. Table 5 summarizes them as complexity factors that should be taken into account while thinking of mobility solutions.

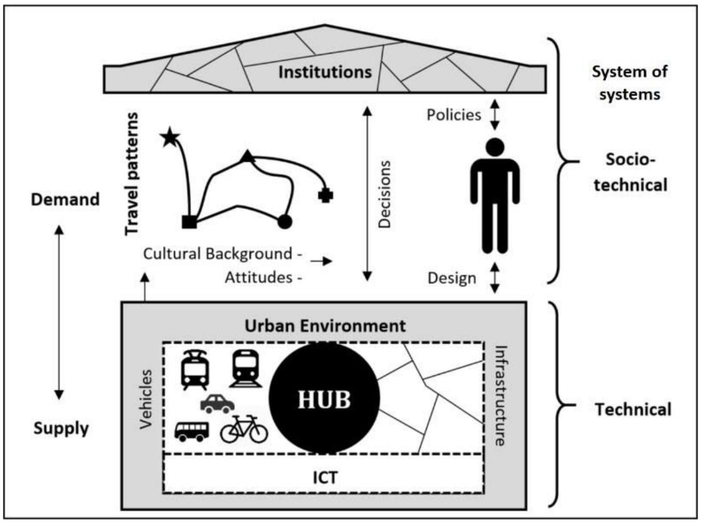


Figure 6. An overview of Urban Mobility

Table 5. Complexity factors of an urban mobility system

Vision	Focus	Complexity Factors	References
Technical	Multi-modality	Global performance of a transportation system depends on modal synchronicity	(Primerano et al., 2008)
	Urban context	The functions of a transportation system cannot be defined excluding the other urban systems	(Wegener, 2013)
Market	Travel-Transport-Traffic recursive relations	- The infrastructure supply shapes the travel patterns. - Travel patterns constitute the demand on infrastructure.	(WBCSD, 2015)
	Transportation demand generator	It is the socio-economic activity of passengers in urban areas that creates the demand on transportation supply	(Cascetta, 2009)
	Spatial mobility	- The function of a transport mean is different from the one of the whole transportation system - There are balancing and reinforcing loops within people's mobility - Mobility generates itself over time	(Bassand & Brulhardt, 1981)
Socio-technical	Multi-dimensional complexity	Technological, social, economic, political, legal and environmental dimensions of mobility are interrelated	(Auvinen & Tuominen, 2014)
	Technical and social elements with actors	There are intentional and normative interaction between urban mobility components, beyond physical and functional ones.	(Ottens et al., 2006)
Governance	Multi-dimensional governance	- Horizontal: agencies or policy makers - Vertical: tiers of government - Spatial: geographically adjacent agencies - Temporal: policies over time - Modal: systems and operators	(Stead, 2016)
	System of systems	- Managerial coordinated independence - Evolutionary and emergent behavior - Heterogeneous components - Complex networks - Trans-domain	(DeLaurentis, 2005)

I.3.2 Perspectives of urban mobility at the scale of travelers

The urban mobility complexity factors reviewed from literature can be retrieved in the real experience of travelers daily interacting with different urban mobility systems. When not managed properly these complexity factors generate travel problems.

I.3.2.1 Technical travel problems

Travelers suffer from technical problems of the systems they interact with. These problems can be either related to each mode, to multimodality or to the urban context. A train that is delayed is a technical travel problem related to "train" as a mode. Multimodality creates synchronization issues of two interrelated systems. For example, when a train arrives at a hub station, a bus in the same station is not informed and leaves travelers transiting by the station waiting for the next bus for longer. On the other hand, the systems underlying the functioning of mobility systems could generate problems. For example, in the absence of internet, a tourist struggles to find his/her ways in a city he/she does not know.

I.3.2.2 Demand-supply travel problems

Unbalanced supply and demand of urban mobility is translated at the scale of travelers in different forms of travel problems. If the demand is not well balanced through space this generates bottlenecks at the stairs for example (Figure 7). If the supply is less than the demand this generates crowds in peak hours for example (Figure 8). Congestion arises at roads networks that are connected to demand generators such as business areas.

Figure 7. Stairs bottleneck at La Defense (Paris)

Figure 8. Crowd at Denfert-Rochereau (Paris)

I.3.2.3 Socio-technical travel problems

As long as travelers are an active element in the functioning of urban mobility systems as socio-technical systems, they contribute themselves to create travel problems for other travelers. For example, in a shared mobility system such as free-floating bike service, if the travelers do not park correctly the bike they finish with, sidewalks are no more convenient for pedestrians (Figure 9).

Figure 9. Misused bike sharing system

I.3.2.4 Governance-related travel problems

A complex transportation system that is not well governed can generate several problems that affect travelers. For example, in the greater Paris region, some transportation hubs are operated by different companies. These do not use the same technology to operate their respective systems. Consequently, it happens that travelers do not find information about their next bus or train. In Paris Châtelet-les-Halles transport hub, the physical time tables are only accessible for travelers at the platform level.

Other forms of travel problems are observable in travelers' interaction with urban mobility systems under the four visions as presented. For example, small technical issues can happen when buying a ticket (Figure 10). The over-demand can generate violent behaviors of drivers (as social elements of a social-technical system) in a congestion for instance (Figure 11). Furthermore, it is not obvious to allocate some situations such as "bad weather condition" (Figure 12) to one of these four visions.

Moreover, social networks are an abundant source of travel problems expressed by travelers themselves or by transport operators. These tell more about how travelers experience these problems rather than observing them through the lens of complexity factors we identified so far. Indeed, when a traveler expresses his/her problem, there is a subjective part of it that represents the projection of a problem on the plan of a traveler. For example, in *"I never find a seated place. I have back issues and need to sit"* the subjective part of it is that the traveler gives an information about his/her physical condition.

Figure 10. Automaton out of order

Figure 11. Angry driver (HVSL, 2017)

Figure 12. Bad weather conditions [Vienna]

Beyond travel problems at the scale of the traveler, the complexity of urban mobility generates challenges in the design process of mobility solutions.

I.3.3 Challenges in designing urban mobility

Urban mobility is a complex system where the users play an important role defining its dynamic and intervening in its performance. Starting from the technical dimension of the UMS, introducing the user, then a market view including both, finishing with a socio-technical integration of all UMS's components, several complexity factors have been identified.

Attempts have been made to tackle the complexity factors by some research works in the design community. Trying to model a bike sharing Product Service Systems (PSS) through use cases, (Hollauer et al. 2015) introduced: stakeholders, system's goals and stakeholders' objectives, functions and sub functions, infrastructure, hardware and software, interactions, and cycles. They faced challenges such as defining the relevant level of details, the expanse of stakeholders' integration in the system, or picking general key performance indicators (KPI) for the PSS.

In order to compare different electric vehicle (EV) technologies, (Barbieri & Campatelli 2015) used scoring matrix and axiomatic design. They defined multiple variables related to the technology used in the vehicle (e.g. feasibility, upgradability) and variables related to the users such as satisfaction and delighters. They were challenged by the qualitative nature of user's variables. For example, recruiting the appropriate sample (in size and nature) brought out questions such as: how likely the respondents would use an EV, how many, from which geographical area etc.

Vidal & López-Mesa (2006) proposed to apply engineering design methods such as life cycle assessment, life cycle cost and risk analysis in order to develop transportation infrastructure sustainability KPIs. They faced an issue in defining the boundaries and therefore the interactions of the infrastructure with the other TUMS components.

To summarize, issues of sampling, scaling, setting performance indicators, gathering and analyzing qualitative data, involving stakeholders, and setting the boundaries of the system to design are not obvious when it comes to design a system at the scale of a city which is anchored in the urban life. Therefore, as long as the common core of these challenges is the traveler, adopting a human-centered design approach could be of some help.

I.3.4 Approaches of Human-centered urban mobility

It is an ambitious purpose to address different perspectives to understand expectations in a human centered way, in order to offer suitable solutions to urban mobility problems. In this section, an attempt is made to touch upon multiple perspectives from which the human has been looked at in an urban mobility context.

We first present the general concept of need in urban mobility. Secondly, we introduce the perspective of quality of life and how it can be used to evaluate the mobility performance. Thirdly, a description of mobility as a set of tasks, thoughts or feelings is provided. Fourthly, different representations of travelers as groups are presented. Finally, some approaches that combine multiple perspectives are reported.

I.3.4.1 Needs in urban mobility

Max-Neef et al. (1989) identify nine fundamental human need classes: subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom. These are defined in relation to four existential satisfiers: being, having, doing and interacting. A matrix built according to the two dimensions (needs and satisfiers) can be used as a tool to analyze the level of satisfaction of a given group or society.

In this model, urban mobility is represented as a satisfier ((Guillen-Royo, 2016), p. 91), at the same level as population and lifestyle, economic development, energy, tourism, spatial development, environment, and agriculture. The matrix covers the spectrum of human needs for a society or a community and does not focus on specific aspect of human activities such as mobility.

On the other hand, urban mobility can be assessed, within a local space, as a 'multiple satisfier' i.e. see how many cells it covers in the needs matrix. For example, (Horton et al., 2007) assume that cycling is a multiple satisfier. Indeed, cycling enhances the user's freedom (e.g. *interacting)* because it gives him more spatial plasticity, understanding *being* because it makes him more curious by giving him the possibility to explore wild places, *having* identity because it makes him belong to the cyclists' community etc.

Another dimension may be added to the previous. It is a hierarchy of needs (Maslow, 1943). According to Maslow, people care about particular set of needs (self-actualization and esteem) only if lower-level needs (physiological, safety, love and belonging) are satisfied. (Van Hagen & Bron, 2014) uses

Maslow's hierarchy on the train journey. Indeed, he assumes that people do not take a transport mean if it is not safe and reliable (available, on time). If these trust conditions are fulfilled, they would think of a fast and easy to use transport solution (information available, easy to access). Finally, at the top of the hierarchy, they would prefer a physically and emotionally pleasant mobility experience.

From another perspective, (Walker, 2012) argues that urban mobility should be designed to fulfill the lower-level set of needs first, i.e. the drivers of demand on urban mobility such as getting home to sleep, go to the supermarket to buy food or go safely to work. This raises the question of what satisficing urban mobility is. This is the object of Quality of Life (QoL) studies.

I.3.4.2 Quality of Life and urban mobility

QoL refers to well-being. It can be either the objective conditions of living of individuals (OWB) or the subjective representation of people's own life (SWB) (Table 6).

Table 6. Subjective vs objective well-being

Well-being	(Diener, 2000)	(Alatartseva & Barysheva, 2015)
Objective OWB	Health, education, jobs, social relationships, environment, security, civic engagement and governance, housing and leisure	Related to what is available in the global environment of individuals, regardless of what they think of it
Subjective SWB	- Life satisfaction (global judgments of one's life) - Satisfaction with important domains (e.g. work satisfaction) - Positive affect (experiencing many pleasant emotions and moods)	Deal with respect and self-respect, confidence, satisfaction, harmony, harmonious physiological and psycho-emotional state, awareness of the purport of life and the person's own meaning and significance in the social and political systems and in the universe

Furthermore, (Tay et al., 2015) and (Glatzer, 2015) focus on satisfaction and happiness (positive side) and worries and pains (negative side) of QoL. The positive side gives insight about how people are happy (e.g. what makes them happy, what are the moments when they are happy) and what are the factors influencing their happiness. The factors may be useful for a government, a company, a person wishing to improve people's lives. In contrast, the negative side gives information about where to place efforts to neutralize the negative feelings of individuals and groups.

The measure takes into account all individual factors (e.g. temperament, personality, values and goals, marital status, wealth, spirituality) and collective factors (culture, policy, weather). On the other hand, several possible biases are reported, such as the mood of survey respondents or memory deficiencies while completing questionnaires (Diener, 2000).

Steg & Gifford, (2005) consider the impact on QoL is an important indicator to assess sustainable urban mobility solutions. They propose 22 QoL indicators combining both subjective and objective aspects of well-being. For example, one can understand how a solution enhances the feeling of safety or how it impacts the privacy (e.g. in a car sharing platform).

Meanwhile, Bertin et al., (2016) considered another perspective of well-being in an experiment with car drivers. They evaluated the impact on well-being of a new car. In order to measure anger and stress, they used physiological data entries such as heart rate, blood pressure etc. In this approach, only few well-being aspects were selected. These are directly related to the use of a product. So, the purpose of this research was not to cover all the QoL aspects mentioned above, but to measure, in a restricted context (in a car) the well-being of one person using a product. However, this physiological manifestation of stress and anger is not only related to the car driving but can be influenced by external factors such as the weather or the behavior of other drivers.

This kind of evaluation belongs to the domain of expertise of human factors which focuses on task performance.

I.3.4.3 Performing tasks as a traveler

Models of human factors and ergonomics place the user -of a product or a service- in the center and represent the factors (individual, social & cultural, task, product design, infrastructure, management) which influence the completion of a task in different layers (Benedyk et al., 2009).

In the urban mobility context, the user accomplishes a series of tasks using different transport products and services in order to complete his mobility goal. The spindle of hexagon (Figure 13) can represent a set of tasks during the journey (Woodcock et al., 2013). The journey can be influenced by factors such as the design of the vehicle, the transport infrastructure, behavior of other passengers, or the investment policy on the transport system (Woodcock et al., 2013). Each task can be decomposed into sub tasks for deeper analysis (Stephan Hörold et al., 2012).

In the automotive context, Green (2012) focuses on the profiles of the drivers and how do they drive. The information about the drivers should be statistically significant in order to allow the manufacturers to design the appropriate types of vehicles. For example, the anthropometrical data will allow them to specify in-vehicle space (e.g. chair height, back angle…). On the other hand, the drivers' behavior can take different aspects (Michon, 1985). It can be modeled with a simple task description (stand still, move backward, stop, accelerate) with e.g. speed/gear shift information. Or a deeper cognitive analysis can be added, like goal-finding parallel with tasks (the goal is to stand still, and the car is moving then set stop as a sub goal). Another dimension of task description is to describe the visual scale (observe a warning light turn on, watch a moving car, change the focus to the speed indicator…).

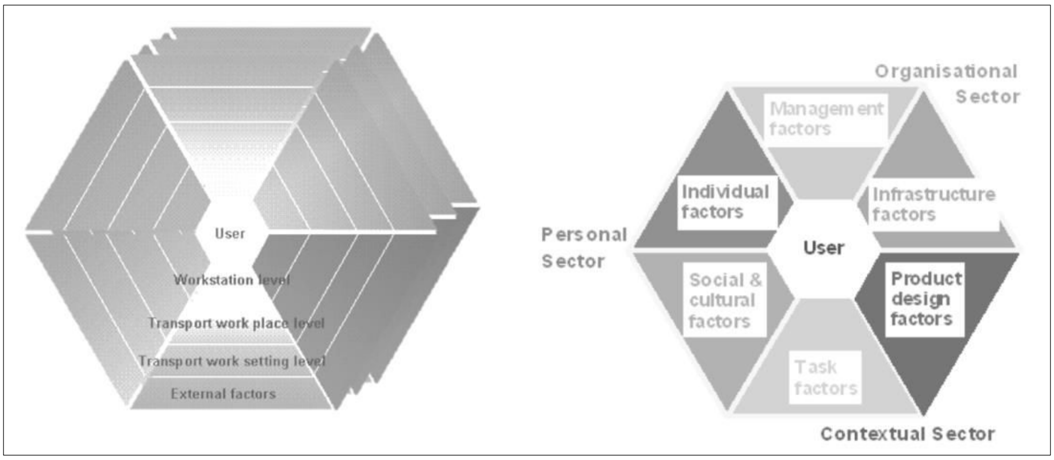


Figure 13. Human Factors Hexagon (Woodcock et al., 2013)

Task description and analysis helps to measure performance (break movement time, acceleration response), identify human skills to perform a task (reflexes, cognitive capacities…), identify loops between tasks (deceleration vs. acceleration), sort the tasks and cluster them. This allows to identify some behavioral patterns to know how to organize information, how fast to present information or how not to overload the working memory of the user.

I.3.4.4 Cognition and mobility

Young, (2008) states that mental models give a deep understanding of people's motivations and thought-processes, along with the emotional and philosophical landscape in which they are operating. A mental model can be represented as a sequence of thoughts, actions and feelings that aim to achieve a goal.

Chamaki, (2010) used Young's model to represent people taking the train. He subdivided the journey into three phases; setting off to train station, waiting on the platform and boarding the train. Each phase contains tasks, and each task contains actions, feelings and thoughts. For example, in the setting off to train phase, there is: check time, leave home, journey to the station and arriving to station. As an action we can find "determine travel destination", as a feeling "concern over train delay and the crowd" and as a thought "plan day ahead in mind". The data used to build this model is actually the output of several interviews that allowed the author to cluster the results into personas and build for each one a mental model.

The value of this schematization is to allocate the existing products and services contributing to achieve each task. Then a deeper analysis can be conducted to understand how each solution is valuable to the user.

Used in urban studies, another aspect of mental models is the representation of the environment in the human's mind. Indeed, (Mondschein et al., 2010) call this representation "cognitive map" which includes places and routes identity, locations, distances and directions. The cognitive map is a result of a spatial learning process. Individuals have different level of qualities of cognitive maps because of several factors such as: memorization and info-processing capacity, motor capabilities, topological knowledge, socio-cultural factors etc. Thus, the more an individual has a complex, rich and diversified map the easiest his/her mobility experience is. This is due to, inter-alia, his capacity of estimating accurate travel duration and the right mix of modes to avoid traffic or crowded places.

One more cognitive research value in urban mobility is identifying the passenger information need. Stephan Hörold et al., (2012) have developed a framework for that purpose. They confronted, along the journey tasks, the available information in the transport system to be evaluated and the knowledge of the passengers. But they needed to know the status of this information (needed or available). So they made a classification: location (actual geographic position, stop point information, direction to stop points), time (departure, arrival, real time), connection (route information, number of transfers, means of transport), ticket (price, validity, terms of use), vehicle (accessibility, load factor, eco-friendliness), network plan (number, name of stop point, direction), disturbance (reasons, impact, duration).

This information classification has generated 87 information types, which were crossed with the 94 tasks of the journey. The produced matrix served as interview basis. This passenger information mapping served to know which tasks were performed, when and where, which tasks require which information, and who needs which kind of information. Moreover, it helped different transport stakeholders to deliver the right information at the right place and to decide which characteristics the information has to fulfill.

Moreover, (Nickpour & Jordan, 2012) conducted a research on psychological barriers to accessibility. They consulted the users of a bus service, in order to understand what made people not using the public buses. They organized focus groups, audits, interviews and observations. Five main factors have been identified; (1) Uncertainty e.g. about the weather or interactions with the other users. (2) Overcrowding at peak hours where e.g. wheelchair users find difficulties finding a place. (3) Negative experience with drivers if they drive violently or do not stop at station for example. (4) Negative behavior of other passengers such as annoying loud conversations or people pushing disrespectfully. (5) Off putting stories that are violent or frightening about the bus usage.

I.3.4.5 Urban mobility and social interactions

Up to now, we have seen how different approaches tried to understand urban mobility at the scale of individuals. In fact, there are sociological and demographical differences between individuals in their practice of urban mobility. For example, there are commuters; people drawn by the larger number of available jobs in the metropolises, and there are city users; those attracted by the concentration and better quality of goods and services in urban centers (Colleoni, 2016).

Urban sociology is the science that addresses issues related to collective practices of mobility, or mobility as a totality (Vincent-Geslin et al., 2016). One of its areas of investigation is how urbanization transforms flows of populations and mobility habits. For instance, the continuous extent of housing, businesses and services generates a need of accessibility which increases mobility and a need of public and private means. Problems of accessibility could either have a positive or a negative impact on the social life of individuals. In fact, accessibility allows people to participate in the economic, political and social life. In this way, mobility constitutes a lens through which one can read society (Urry, 2000).

However, to understand a global and complex issue such as mobility practices, it might be necessary to subdivide the problem by considering sub-categories of people by e.g. sampling and clustering under some criteria. For example, one can describe the population by socio-demographic characteristics such as age, ethnicity, gender, household income and size, occupation, vehicle ownership, etc. Or by travel characteristics such as access to public transportation, alternative mode of travel, duration and frequency of travel, transfers, trip purpose, etc. (Neff & Pham, 2007).

Another way to represent social categories for analyzing urban mobility is to use persona modeling. It is a simplification of distinctive social, affective, and cognitive information. Indeed personas are hypothetical archetypes of an actual population (Tara Smith, 2011). The main information describing a persona is; (1) His/her identity (name, age, marital status, profession, diploma…). (2) His/her environment (living conditions, family, elements from social life…). (3) Preferences (personal opinions, friends, scenarios of using a product/service…).

Pontis (2013) has represented, in a so called ethnographic information design, archetypical commuters (communities) on a metro line all along an archetypical day (Figure 14): city workers (women and men wearing suits and smart clothes), builders and painters, tourists (families, couples, mixed groups), and youngsters (school children, mixed groups). Each category has some specific characteristics and behaviors. For example, highly frequent commuters (e.g. city workers) seem to plan their position on the platform. For instance, they choose the longest queue because they know the busiest stations and wait for them to secure a seat after people get off.

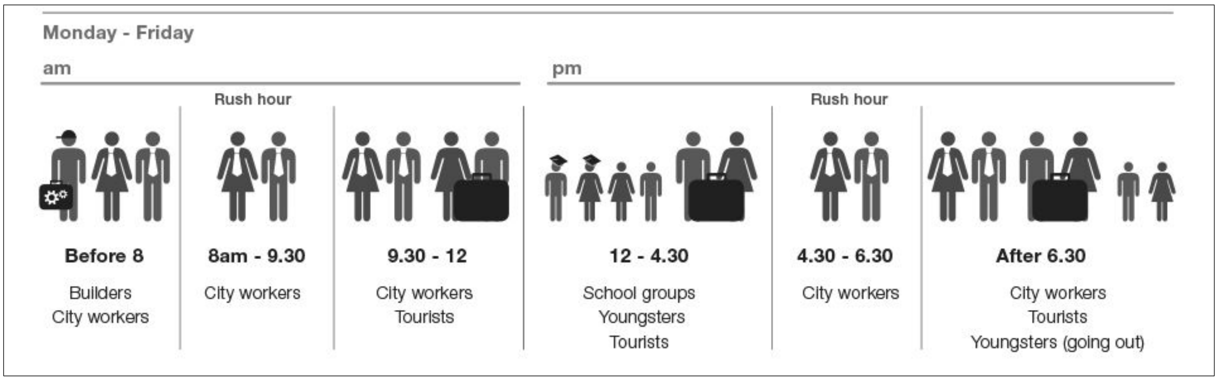


Figure 14. Ethnographic information of a metro line commuters (Pontis, 2013)

Moreover, (Nunes et al., 2016) introduce the concept of Temporary User-Centered Networks (TUNs) in order to identify opportunities of collaboration between users to facilitate the diffusion of knowledge across the urban mobility system in real-time. For example, it could improve the visibility of the service status, enhance the relevance of routing choices among users or connect the community of cyclers. TUNs represent the *materialization of spatiotemporally dependent ties between users*. Actually, it uses two affinity measures to do that; journey *similarity* and journey *substitutability*. The first one stands for the portion of simultaneous journey of two users sharing similar paths. The second one represents the portion of simultaneous journey of two users with different paths, but they serve at least two of the same potential origin–destination pairs. With real-time data, this model would give insights of relevant shared mobility interests between users and give birth to useful innovative solutions.

I.3.4.6 Multi-perspective approaches

Multi-perspective approaches allow connecting different viewpoints on urban mobility and obtaining and integrated picture of what a traveler is, does and has while he/she is mobile.

Woodcock, Berkeley, et al. (2014) have done a research of this kind as part of the EU-FP7 project METPEX (MEasurement Tool to determine the quality of Passenger EXperience). The objective of this project was to develop a tool to measure the whole journey passenger experience. The intention is to take into account human factors (physiological, perceptual, cognitive, sensory and affective), as well as socio-economic, cultural, geographic and environmental factors. To do this, they broke down a typical passenger journey into eight stages which is to be adapted to different user groups; journey planning, preparation of the journey, movement from origin to the transport gateway, interaction with transport service, traveling on the vehicle, transport interchange, and egress from the service to the destination (Woodcock, Osmond, et al., 2014). The tool defines 450 variables associated with specific journey stages. These variables are meant to be used depending on the intent a transportation stakeholder is willing to achieve. For example, if a policy maker wanted to analyze the city performance according to the quality perceived by different profiles of users, he would use a set of indicators per user group. For instance, the low-income category of users is defined by three indicators (LOW1, LOW2, LOW3). Each indicator is calculated on the basis of a set of variables (among the 450). If LOW2 stands for comfort, then the associated variables are: level of noise, level of crowding, air temperature and ventilation inside vehicles, cleanliness of vehicles, notification on timetabling changes, and level of assistance available during journey (Marco, 2015).

(Josset, 2016) investigates behavior change about congestion issues taking a dual perspective of behavioral economics and sociology. Josset conducted three experiments as part of the MOBIDIX project (MObility Digital economiX). The objective was to check the effect of an alternative mobility framework (e.g. car sharing), and especially what conditions would allow a sustainably gain against a dominant framework already in place. The first experiment was about strengthening certain signals (e.g. an awareness video to the daily problems of mobility) corresponding to the alternative framework and see an increase in engagement (at least declarative) of participants. The second experiment tested the effect of feedbacks of mobility behavior, showing the participants their daily trips patterns (location, time) using a geo-tagging device. The third experiment tested the effect of different incentives (monetary, competition, social, representations ...) on the daily statement of good practice (carpooling, biking, telecommuting …) of a group of 66 participants. The results discussed issues about the place of the individual in transport schemes, the use of time or well-being as a measurement indicator of mobility practices and, finally, how collective representations enable coordination.

Chronos & Attoma (2009) propose a sociological and industrial design reading to imagine new mobilities, making the bet of an autonomous and responsible user. They start from the fact that the usage of mobility is singular depending on socio-economical profiles of users, so the offer should be as diverse and redundant as possible. However, the actual state of the urban mobility system imposes cognitive and physical limitations to commuters so that they need to be reactive, adaptive, improvisational, and tolerate this non-comfort. For instance, these limitations are represented through a cognitive path of the commuter. It includes the cognitive charge that he or she's facing everyday (e.g. anticipation of interchange, simulation of path, attention to time…). To face these limitations, the users have resources such as smartphones or signage.

Liu et al. (2018) takes a multidisciplinary view on the cycling experience. They separated literature's views on the topic into three different dimensions. The first dimension is social. It is captured through qualitative methods where the cycler expresses his/her feelings in their interaction with other urban dwellers. The second one is sensory and embodies energy expenditure, risk perception, smell, sound, vision, etc. The third dimension is spatial. It includes mental maps, landmarks, wayfinding, spatial identity, etc.

I.3.4.7 Human-centered urban mobility

Table 7 summarizes the different perspectives we have analyzed in this section and shows how the human is taken into account in modeling urban mobility.

These different human-centered perspectives give a holistic picture of how a traveler experiencing his/her urban mobility can be modeled. Each perspective is a projection of the traveler experience in a dimension that characterizes the traveler as a human. There are urban mobility solutions that adopt such human-centered approaches in their design as described in next section.

Table 7. Human centered urban mobility perspectives

Perspective	Integration of human centered perspective	References
Methodology	Practically learn from the user and make him impact design decisions	(Steen, 2011)
Needs	Describe how mobility satisfies basic human needs Measure mobility performance on hierarchical human needs satisfaction Prioritize needs to be satisfied while developing a transport solution	(Guillen-Royo, 2016) (Van Hagen & Bron, 2014) (Walker, 2012)
Quality of Life	Measure solution performance on impact on quality of life globally / experiencing mobility	(Steg & Gifford, 2005) / (Bertin et al., 2016)
Performing tasks	Describe the environment of mobility such vehicle design, infrastructure, other passengers, or policy Describe mobility by task analysis Make drivers profiles statistically	(Woodcock et al., 2013) (Stephan Hörold et al., 2012) (Green, 2012)
Cognition	Describe the journey as a set of feelings, thoughts and actions Model the user's environment mental map Identify the passengers' information need Identify the psychological barriers to accessibility	(Chamaki, 2010) (Mondschein et al., 2010) (Stephan Hörold et al., 2012) (Nickpour & Jordan, 2012)
Social interactions	Represent socio-economic activity profiles of users Describe the impact of urbanization on mobility Use travel characteristics to make passengers archetypes Represent ethnographically commuters' profiles Identify opportunities of collaboration between users Predict pedestrian crowd behavior	(Colleoni, 2016) (Vincent-Geslin et al., 2016) (Neff & Pham, 2007) (Pontis, 2013) (Nunes et al., 2016) (Fridman & Kaminka, 2010)
Multi-perspective	Measure the mobility experience on human (physiological, perceptual, cognitive, sensory and affective) socio-economic, cultural, geographic and environmental factors. Experiment the mobility behavior framework change to external signals. Read physically and cognitively commuters' mobility to imagine new mobilities.	(Marco, 2015) (Liu et al., 2018) (Josset, 2016) (Chronos & Attoma, 2009)

I.3.5 Embedding human-centered approaches in mobility solutions

Observing urban mobility solutions can give an idea of how designers adopt or not human centered approaches. Here are examples of solutions referring to each of the perspectives described in the previous section.

I.3.5.1 Methodology: asking user's feedback

To continuously improve its service, Uber routinely asks its customers for feedback. Apart from the feedback a rider can give about his/her driver, there is another way of how Uber gets what its users think of its services. Figure 15 shows an email asking a rider to share his thoughts about Uber. The questions in this type of surveys are not only Likert-styled. Indeed, the respondent has to write few words about his experience. For example, he is asked to complete sentences such as "I would use Uber more if …".

The classical Likert-styled satisfaction surveys do not reflect the very specific vision of users, because they come with preconceived qualities that they want to assess. These qualities are not always relevant for users, they are rather shaped by a technical-centered goal (Boy & Narkevicius, 2014).

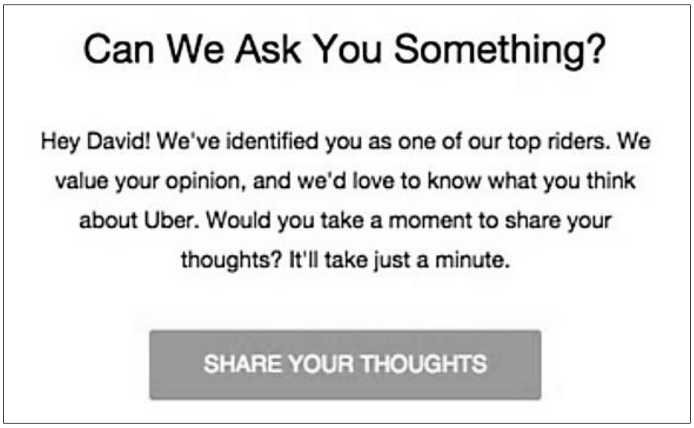


Figure 15. Uber asking customer feedback (Drift, 2016)

I.3.5.2 Needs: knowing the special needs of users

Some buses include a device that is designed to lift a wheelchair and its occupant into the bus. It permits people with disabilities to more comfortably access public transport (Figure 16). The user gets on the horizontal platform and the lift operates the movement of getting in the bus.

Classical solutions for allowing wheelchair access to public transport means (buses or trains) such as bridges, plates or ramps demand from the user to perform a movement by him/herself or ask for help to do so. The bus wheelchair lift makes this task effortless, knowing special needs of the users.

Figure 16. Bus wheelchair lift (ADA, 2012)

I.3.5.3 Quality of life: the joy of Art

Pieces of art such as tiles, paintings, decorations are meant to make the mobility experience more colorful and joyful. One can find them in trains, stations, tunnels, on roads, or other urban spaces (Figure 17 to Figure 20). These forms of art transform urban spaces into a more joyful and enjoyable environment for urban dwellers and can have some effects on their behavior (cars slowing down, increased patience).

The grey and dull colored design in some urban areas influences negatively the mood of travelers and how they perceive mobility systems. Art plays a positive role in restoring the overall quality of life within a city (CityRepair, 2016).

Figure 17. SNCF Transilien Train

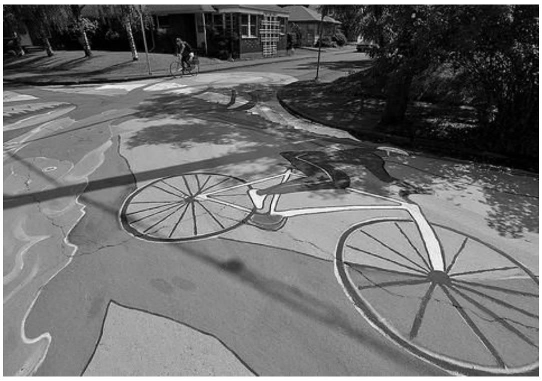


Figure 18. City repair art (CityRepair, 2016)

Figure 19. Stockholm Metro Tunnel

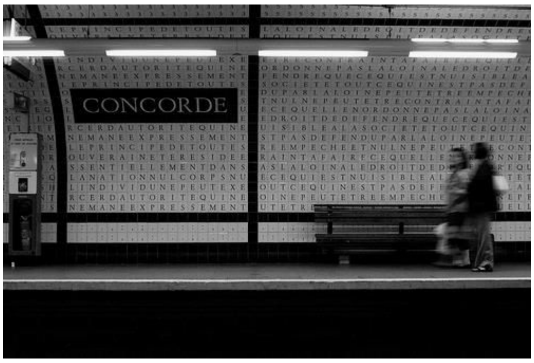


Figure 20. Paris metro station

I.3.5.4 Performing tasks: easy gear shifting

The paddle shifter is an automobile transmission device that does not change gears automatically. Rather, it facilitates manual gear changes by dispensing with the need to press a clutch pedal at the same time as changing gears or to move hands from the wheel. It permits a semi-automatic driving mode with keeping control on the acceleration experience in a more handy way (Figure 21 and Figure 22).

The full manual gear shifter needs, from the driver, to press a pedal in order to achieve the gear shift. Moreover, the place of the stick shift obliges the driver to move his/her hand from the wheel to attain it and bring it back. So, the task of shifting the gear demands two parallel movements that may reduce the driver's attention. On the other hand, the full automatic dear shifting mode, do not demand any action from the driver. However, the fact of submitting this task to a program takes off the control of the driver on the acceleration and may diminish the driving pleasure. The paddle shifter makes the task of gear shifting easier for the driver (no need of pedal and moving the hand).

Figure 21. Manual gear shifter

Figure 22. Semi-automatic gear shifter (TRCG, 2015)

I.3.5.5 Cognition: showing the right exit

Figure 23 and Figure 24 represent two smartphone apps that indicates the exit to take, and also which metro door is the closest to this exit, depending on the address he/she is heading. The graphics make their use easy while the user does not need to read all the text provided in a station. For example, there is the metro plan with the door to take highlighted and the graphic itinerary between the exit and the address of the destination.

The classical apps provided by the transportation operators only informs the user the connections and the estimated time from the starting point to the destination. So, when he/she arrives in front of the multiple exits in a station he/she feels lost and needs to ask the crowded information point or the other rushing passengers. This makes his/her arrival frustrating. To summarize, these two apps complete the information traveler needs to achieve his/her travel autonomously and fluently, taking care of a cognitive gap.

Figure 23. The right exit (MSP, 2016)

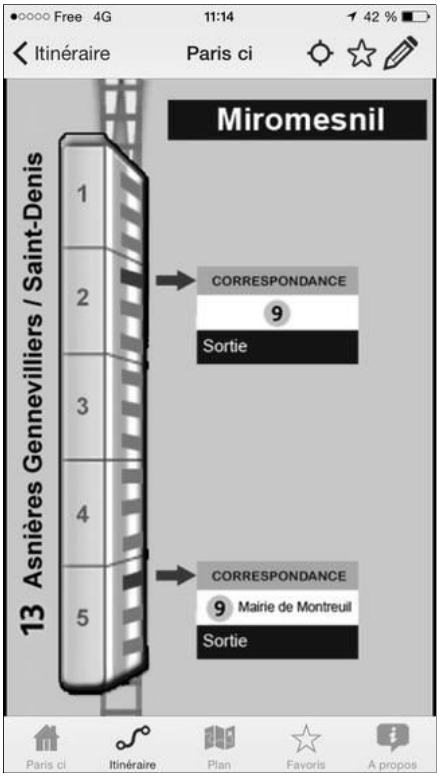


Figure 24. The right door (PungApps, 2016)

I.3.5.6 Social interactions: hacking safety instructions

A New York artist replaced the safety instructional stickers in subway trains by new ones. He called the series “Life instructions” because they offer snippets of philosophy that helped him turn his life into a more positive direction and positively influence people around him (Figure 25 and Figure 26).

The design of the internal environment of a public transport contains artefacts fulfilling multiple functions, such as safety or providing information to passengers. However, it does usually not include components that contribute to traveler’s happiness with his/her fellow travelers. Through such acts of creativity, this artist extended the function of instructional stickers to make passengers smile and experience their trip better together.

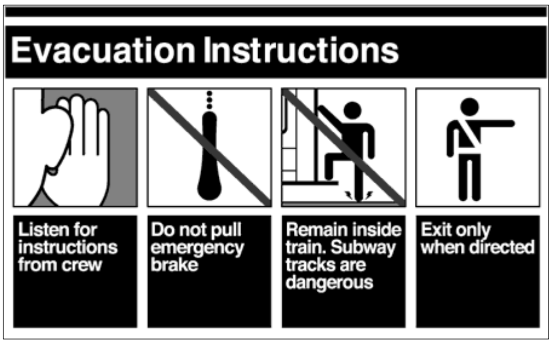


Figure 25. Original safety instructions

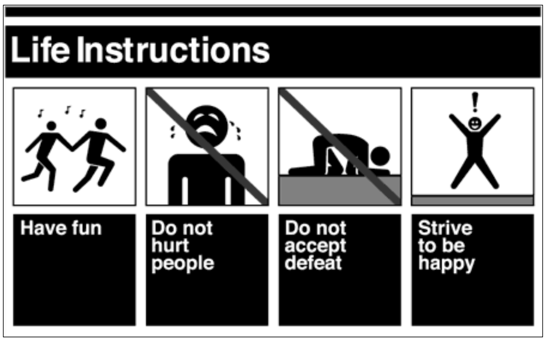


Figure 26. Hacked safety instructions

One can think of other basic systems with a comparable purpose as the solutions we glimpsed. For example, a chair in a subway station is meant to make the waiting time of travelers less 'painful' (more comfortable). Time tables are meant to give the information to schedule their travel and make decisions to save time. Street lightning increases road visibility and driving comfort (other examples: heating/cooling and physical comfort, seatbelt and safety, the Wi-Fi in stations and connectivity, a roof in a bus station and bad weather protection etc.)

We briefly saw in this section different ways to improve the traveler experience through design. Understanding and modeling the traveler experience involves the use of human centered approaches, which can be applied to develop relevant urban mobility solutions.

I.3.6 Summary and research question

In this section, we frame the key concepts on which the traveler experience is based in order to build the design research question of the thesis.

In design research, the phase of problem setting in the existing systems is vital to identify what users suffer from. In urban mobility, this form of diagnosis is harder to perform than in dealing with simple artefacts. This is due to the complexity of urban mobility as being the field where travelers interact together with multiple products and services in a door-to-door experience.

Figure 27 brings together different facets of urban mobility and human centered approaches, proposing a first representation of the traveler experience. Travelers plan their trip before taking a mode of transport among the possibilities that are offered to them. Before getting to some destination to fulfill some need (e.g. work, shopping), they have to perform several tasks, interacting with multiple technical systems depending on their modal choice. If they choose to go by car, they are exposed to congestions (roads and other cars). If they choose to go one foot or bike, they are exposed to weather. They are cognitively loaded during their trip in finding their way and thinking of the destination. Some urban systems offer to travelers some features such as music and art to mitigate their struggle.

The complexity of the traveler experience makes it hard for mobility big industrial companies, in the person of designers, to master all the facets of travel problems that travelers suffer from. Indeed, they are restrained by the vision of designing their current product or service. It is then hard for them to see the big picture that involves multiple systems they need to consider in offering a seamless traveler experience.

Therefore, designers need a support in assimilating the traveler experience to diagnose travel problems of the current products and services in which they would introduce better solutions.

This thesis aims at answering the following research question:

How can traveler experience be modeled to feed travel problems diagnosis?

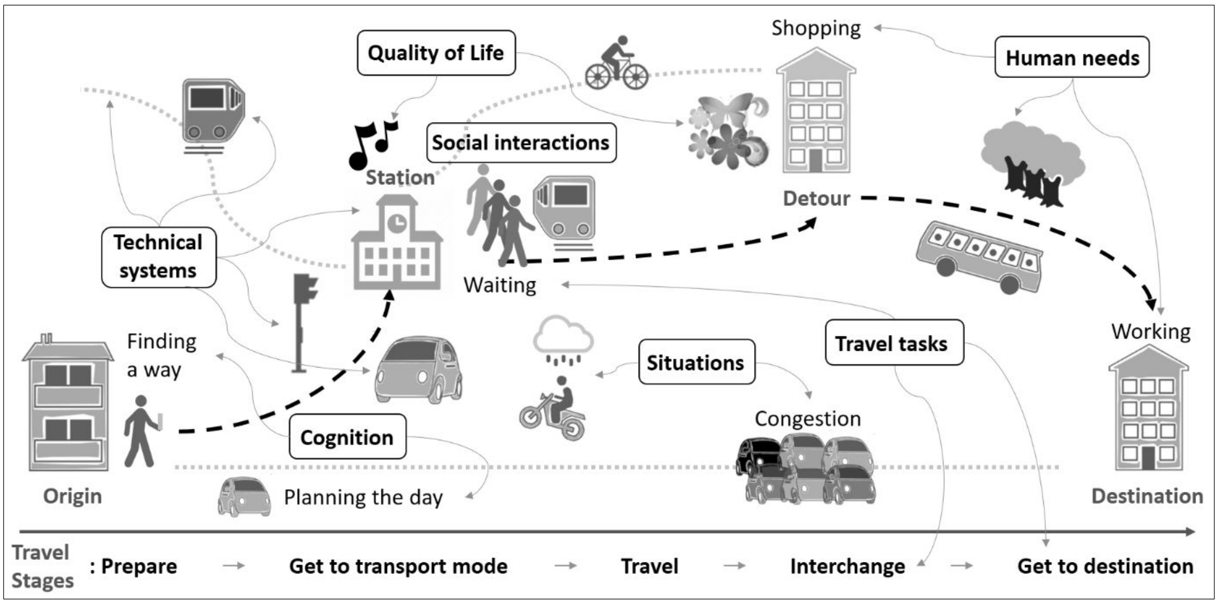


Figure 27. Urban mobility and human centered approaches

I.4 Research methodology

According to Creswell (2009), a prior step before choosing the research approach, to answer a research question, is to be aware of the knowledge claim and of the possible methods. He proposed four knowledge claim positions grounded in a philosophical understanding of knowledge (Table 8). A knowledge claim is a set of assumptions about what is to be learned, how, the process, and the value of the study.

Table 8. Alternative knowledge claim positions (Creswell, 2009)

Position	What	How	Process	Value
Post positivism	Determination of effects' causes	Reduction of knowledge into variables	Empirical observation & measurement	Theory verification
Constructivism	Understanding the world around	Assembling of multiple participant meanings	Social & historical construction	Theory generation
Pragmatism	Consequences of actions	Problem-solving - centered	Pluralistic, mixing methods	Situation improvement
Advocacy	Constraints and structures	Including marginalized viewpoints	Collaborative & iterative	Change-making

He associates the quantitative approach to the post positivist position insofar as quantitative research aims to validate hypotheses and deals with measuring and defining variables. On the other hand, qualitative research better fits in the constructivist and advocacy position because it concerns theory building and recognizes that knowledge is generated from people's points of view. Finally, pragmatic position deals with both qualitative and quantitative research since its goal is to make concrete improvements and needs both to get knowledge from people and to put into variables in order to observe the evolution of the improvement.

This thesis has both constructivist, pragmatic, and positivist positions. Indeed, it intends to understand the traveler experience of urban mobility systems through travelers' visions of travel problems (constructivist), to empirically evaluate this model (positivist) for its improvement of the quality of travel problems that one can gather (pragmatist).

These positions being interdependent regarding the aim of the thesis, they need a research protocol that handles best their cyclicity. For these reasons, this thesis is built on an Action Research protocol.

I.4.1 Action research protocol and research questions

Action research is a form of action inquiry that employs recognized *research techniques* to inform the action taken to improve *practice* (Tripp, 2005). In our research:

- The *practice* is a theory building qualitative research. Starting from literature, observations, and interactions with travelers, it aims at making an abstraction effort and induce a model that would be able to describe problems travelers experience using urban mobility systems.
- The *research techniques* are tailored to each of the stages of the research process. They concern different fields, use cases, travel stages, transport modes, innovative services, which all are the source of data that will feed the modeling cycles (Table 9).

The process of action research is cyclic with three stages in each cycle: planning, implementing, and evaluating. The planning stage poses the spatial-temporal settings and sets the sources of data. The second stage is dedicated to action. The last stage is when both research and action are evaluated in order to propose improvements for the next cycles.

The first cycle is preceded by a reconnaissance phase. It is a pre-requisite where the current professional and research practices are reviewed, the initial thematic concern is set, and the context in which action research is conducted is defined. That is what we presented so far. We investigated literature, made some field observations, and interviewed the chair's industrial partners, regarding the core thematic concern over which this research was built; "Human centered urban mobility". We also have identified some challenges for which we set a research question.

Q1: How can traveler experience be modeled to feed travel problems diagnosis?

The first cycle planned the literature to be investigated, what and where to observe travelers, who to interview and what questions to ask. The action consisted of visiting transportation hubs and make daily observations of how people use mobility systems, interviewing colleagues about their daily mobility and organizing workshop to collect travelers' mobility stories. After proposing a model of traveler experience, we evaluated it in the form of a case study to see what insights it could generate when applied in diagnosing an existing mobility system. The evaluation pointed out the need for a deeper understanding of travel problems and recommended a path for the next cycle. It proposed a new research question.

Q2: What are the problems travelers experience using urban mobility systems?

To plan the second cycle, we chose the research method which was grounded theory building. We then set its protocol form the beginning until the end. The action consisted of making the interviews, recording, transcribing, and coding them. The evaluation consisted of two case studies that were connected to the first cycle. The outputs of both the first and the second cycle were translated into a stimulus as a travel problem generation support to be evaluated in a third cycle. We had then the third research question:

Q3: What is the effect of a traveler -centered stimulus on travel problem generation effectiveness?

The third cycle involved setting an experiment protocol in its planning phase. This includes selecting participants and setting the variables and metrics to make the experiment. The action phase was in the form of animating, measuring, and monitoring the experiment's process. The evaluation consisted of inspecting the results and proposing improvements on the stimulus.

The final cycle of this thesis was not a natural continuation of the third cycle. This cycle had a different purpose compared to the three other cycles. Indeed, another way to building a bridge between design and transportation is to feed transport modeling and simulation with traveler experience insights. These two were the topics of two other PhD students of the research chair. What the traveler experience model brought as "traveler specific attributes" were used in an optimization model and an agent-based simulation of an autonomous vehicle service in order to improve their relevance to travelers. In other words, it intended to make them more "human-centered". Then the next research question arose.

Q4: How can specific traveler attributes improve transport modeling and simulation?

The planning phase of this cycle consisted of preparing an online survey to collect the opinion of travelers of the greater Paris region on autonomous vehicles and their preferences regarding their current mode of transport. In the action phase, we deployed the survey and completed the less populated profiles with asking people on the street. The evaluation was in the form of using the results of the survey in remaking a model of optimization and agent-based simulation using subjective travel attributes.

Table 9. Research techniques involved in the thesis

RQ	Techniques	Outputs
-	Desk research Self-observation Interviews	- Urban mobility complexity factors - Human centered urban mobility models & innovation examples - Traveler experience key concepts
Q1	Workshops Interviews Observations Case study	- Problems narratives - Initially coded problems - Categories within the conceptual model - Inferred causality examples
Q2	In-depth interviews	- 3 cities travel problems narratives - Travel problems categories
Q3	Experiment	- Proof of value on travel problems variety and novelty
Q4	Survey Case study	- Travelers preferences on autonomous vehicles - Modeling and simulation integration

I.4.2 Research methodology in design research

The two main objectives of design research is to (Blessing & Chakrabarti, 2009, p:5):

- Formulate and validate models and theories about design with all its facets.
- Develop and validate support founded on these models and theories to improve design practice.

The projection of these objectives on the scope of this thesis is:

- Formulate and validate a traveler experience and a travel problem models regarding urban mobility complexity factors and what travelers think of their problems.
- Develop and validate a stimulus and traveler specific attributes to improve travel problem generation and optimization models and agent-based simulation.

A design research follows a design research methodology (DRM) framework, fully or partly (Blessing & Chakrabarti, 2009, p:15). This starts with *research clarification* by describing the existing (literature analysis) and setting the research goal. Then, follows the *first descriptive study* where the existing situation is described more in details deploying more elaborated methods such as observations and interviews. The gap to be filled is more clearly defined to proceed to a *prescriptive study*. The output of this phase is a support that should improve the existing situation starting with the synthesis of what has been learned from the first descriptive study. Finally, a *second descriptive study* is conducted to evaluate the impact of the support using empirical protocols.

This thesis was deployed according to the DRM framework (Figure 28). Research clarification started with general urban mobility and human centered literature along with first observations and interviews with the chair's partners. This allowed us to set two research goals: the first one is on improving travel problem diagnosis in early design phases, and the second one is on improving transport modeling and simulation introducing relevant traveler -centered variables. The descriptive study consisted on developing a traveler experience conceptual model using literature and varied methods. This stage was improved be a grounded theory study, improving some aspects of travel problem understanding. The prescriptive study used the outcomes of the two studies and developed a stimulus aiming at improving travel problem generation in a focus group format. The last stage evaluated, on the one hand, the effect of the stimulus on the quantity, the variety, and the novelty of travel problem generation. On the other hand, traveler specific attributes were evaluated regarding their improvement of an optimization model and an agent-based simulation.

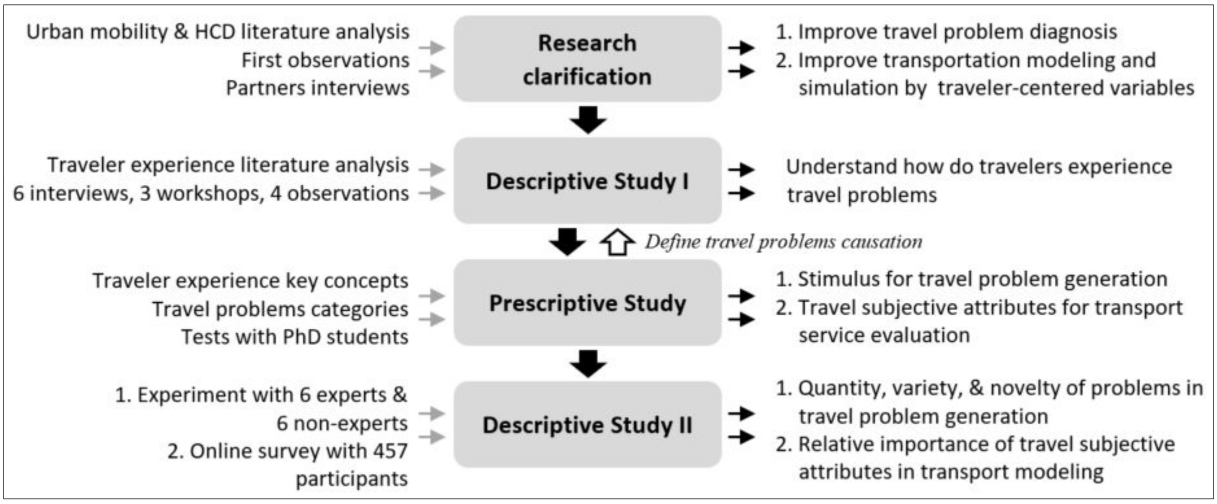


Figure 28. Design research methodology framing of the thesis

I.5 Structure of the Manuscript

This dissertation is structured as a collection of articles, all of which have been, or are about to be, submitted to peer-reviewed journals. We tried our best to reduce any redundancy between the chapters of this manuscript. However, we kindly ask for the reader's understanding on this point.

We now present the way the contents of this dissertation map the research questions presented in section I.4.1 of this first chapter. We then provide a brief summary of each chapter. Figure 29 summarizes how the five chapters of this dissertation are structured accordingly to the research questions, offering an overview of the contributions as well. The first chapter of the manuscript introduced the general, the industrial and the research context of this thesis. We now introduce each chapter from II to V.

Chapter II: Modeling traveler experience for designing urban mobility systems

Travelers interact with a large number and variety of products and services during their journeys. The quality of a travel experience depends on a whole urban mobility system considered in space and time. This chapter outlines the relevant concepts to be considered in designing urban mobility. The goal is to provide a language and insights for the early stages of a design process. A literature review sheds light on the complexity of urban mobility from technical, socio-technical, and user experience (UX) perspectives. Observations of experiences in urban areas provide data for describing and understanding travel experience patterns and issues. The chapter proposes a conceptual model to describe and analyze different facets of traveler experience, and categorizes problems that travelers face when they interact with an urban mobility system. A case study illustrates the use of the conceptual model in identifying travel problems for a demand-responsive transport (DRT) service.

Chapter III: Understanding travel problems – A grounded theory approach

Urban travelers experience problems when they use different products and services along a door-to-door journey. These problems are of different nature and might be perceived differently by travelers. Existing research has focused on travel problems for a specific traveler profile or transportation mode. However, neither archetypes of travel problems nor their possible causal relations were investigated. This chapter proposes a travel problem categorization including a causality scheme. The goal is to provide a tool that can be used to diagnose urban mobility systems' problems. Nine open-ended interviews with a maximum variation sample of interviewees were used to provide narratives on urban travel problems. Using a grounded theory methodology, the chapter proposes a taxonomy of travel problems and how each category can be a cause or a consequence of another category. It presents two case studies to show

how the proposed tool can be used in decomposing a complex travel problem statement and enriching a simple one.

Chapter IV: Simulating travel usage problem generation – An urban mobility case study

Designers improve urban mobility solutions by investigating archetypal usage problems in existing mobility systems. User-centered design methods help accomplish this task, but lack effectiveness when not supported by appropriate tools. Here we posit that the use of a traveler -centered stimulus improves the effectiveness of travel problem generation. To test this hypothesis, an experiment is conducted with two control groups as a baseline for non-stimulated problem generation and two experimental groups that are provided with a traveler -centered stimulus. The two sets are composed of one group of urban mobility experts and one group of non-experts. Results show that stimulated groups generate novel ideas with a greater variety covering most of the traveler experience dimensions than non-stimulated groups.

Chapter V: Traveler specific attributes in transport modeling and simulation of AVs

Modeling transport systems is usually based on variables that are projected on time and space. For instance, simulation and optimization models rarely go beyond cost, time and space as determinants when analyzing travelers' choice regarding their transport mode. This chapter shows how the knowledge of traveler experience helps to determine relevant variables that subtend travelers' willingness-to-use a mobility service. We exemplify the approach for a shared autonomous vehicle service. An online survey was carried to collect data on travelers of the greater Paris region and their position regarding autonomous vehicles. On the one hand, the chapter identifies profiles of travelers that are more likely to accept autonomous vehicle technology. On the other hand, it identifies subjective criteria of travelers behind their willingness-to-use a shared autonomous vehicle service depending on their current mode of transport. The chapter shows how traveler specific attributes are relevant to studying a mobility system and how these can enhance the accuracy of agent-based models and the traveler preference dimension in optimization models.

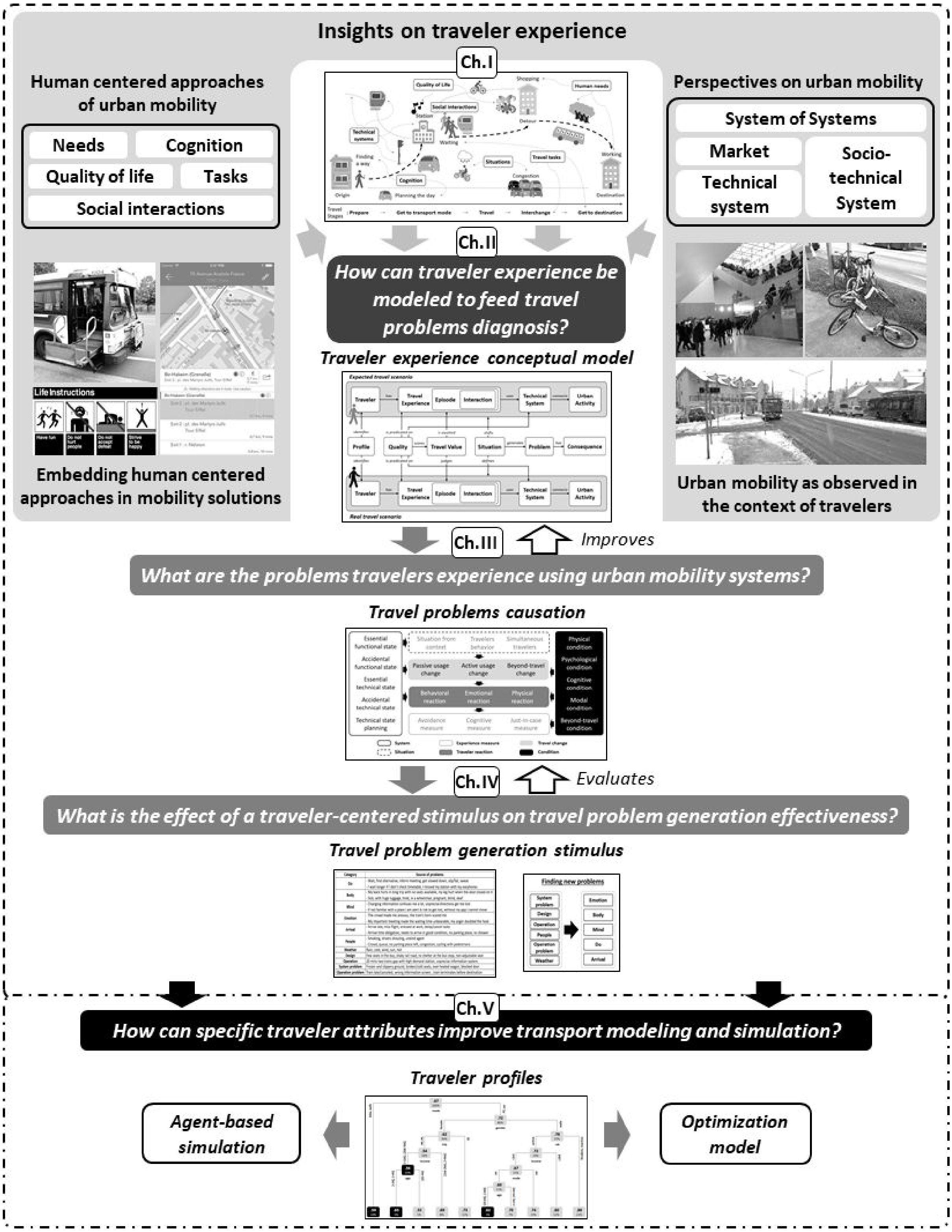


Figure 29. Thesis research framework

Chapter II

Modeling traveler experience for designing urban mobility systems

Travelers interact with a large number and variety of products and services during their journeys. The quality of a travel experience depends on a whole urban mobility system considered in space and time. This chapter outlines the relevant concepts to be considered in designing urban mobility. The goal is to provide a language and insights for the early stages of a design process. A literature review sheds light on the complexity of urban mobility from technical, socio-technical, and user experience (UX) perspectives. Observations of experiences in urban areas provide data for describing and understanding travel experience patterns and issues. The chapter proposes a conceptual model to describe and analyze different facets of traveler experience, and categorizes problems that travelers face when they interact with an urban mobility system. A case study illustrates the use of the conceptual model in identifying travel problems for a demand-responsive transport (DRT) service.

Keywords – System design, traveler experience, travel problems, service

A modified version of this chapter has been accepted in "Design Science" Journal

II.1 Introduction

The proportion of people living in the world's urban areas is expected to rise in the coming decades, to reach 66% by 2050 (UNDESA, 2014). This growth generates increasingly challenging situations for urban travelers, such as traffic chaos, insecurity, poorer quality of life, limited parking space, air pollution, and noise.

An urban mobility system is a solution that satisfies the derived demand of people who need to perform an activity at some destination (Banister, 2008). The way in which this need is met is how travelers experience their door-to-door journey (Susilo & Cats, 2014).

Urban mobility systems (UMSs) are still designed as aggregations of products and services that are not operating in traveler -centered harmony to offer a seamless mobility experience (Preston, 2012). For example, in the Paris area, there are several transportation operators for different lines. At the exit of a train station, it is frequent to find information about one operator's bus lines but not others. One of the reasons why such problems persist is that each line is designed and operated separately from the others (Al Maghraoui et al., 2017a). The same problem arises for the interchange between private cars and public transportation (e.g. park-and-ride facilities), or the need to have different smartphone apps for planning and monitoring a single trip (e.g. one for bus real-time schedule and one for multimodal transfers).

The complexity of urban mobility systems poses challenges in their design process, models, knowledge or expertise (Sussman et al., 2005). There is therefore a need for a common approach for stakeholders involved in the design process of such systems to operate in designing a satisfactory traveler experience (Civitas, 2011). Consequently, companies adopting such an approach are more likely to have a better innovation performance (Faems et al., 2005). Moreover, design practice comes with an amount of complexity related to the information available on the problem to be solved, users' wants and needs, context evolution and, above all, the decisions a designer has to make among design possibilities (Stolterman, 2008). Thus what makes the situation even more challenging for urban mobility designers is that they must handle design complexity in addition to UMSs. For example, if we want to identify user profiles for metro lines within an urban area, the users to be studied are all the people transiting by these lines plus the urban dwellers using the metro stations, and maybe also those affected by its noise and vibrations in adjoining neighborhoods.

A model proposed by Simmons (2005) handles some of this complexity by using the concept of *usage*, which encompasses information on the user and the interaction between the system and the user, and information on the environment in which this takes place. Furthermore, it can move from detailed interaction, at the scale of a task (e.g. pushing a button to open a train door) to abstract levels (e.g. using a bike-sharing service). On the other hand, the diversity of interactions a traveler might have with a UMS is contained within the concept of *usage scenarios* and *use cases* drawn from Universal Modeling Language (UML) (D'Souza & Wills, 1999).

A traveler interacts with many products and services while heading to some destination: the traveler may be the user of a smartphone application to program the journey or check the schedule of a bus, for example. He/she enters the metro station and interacts with the ticket machine, then boards the metro train. He/she reads information panels at the station's exit. In this chapter, the point of view is focused on the user to include all products and services used throughout a journey.

This chapter addresses the following research question: *How can traveler experience be modeled to feed travel problems diagnosis?*

Firstly, a literature review is made on different perspectives of urban mobility systems and traveler experience. Second, a conceptual model is proposed as a model of traveler experience to help identify travel problems within an urban mobility system. Third, to test the potential of the conceptual model, a case study on a demand-responsive transport (DRT) service is illustrated. Finally, a discussion and perspectives for the design of urban mobility systems are included.

II.2 Urban mobility systems

The complexity of an urban mobility system (UMS) encompasses different factors in several dimensions. A UMS comprises a large number of diverse, evolving stakeholders, physical components, information, and travelers, all interacting with each other in an urban context. Another form of complexity stems from the diversity of use combinations: UMSs serve throughout the day and night in a shared form of use. To represent these forms of complexity, the technical aspect of urban mobility is first presented as a technical UMS (TUMS). It is followed by the market perspective, considering a TUMS as a supply responding to and generating a travel demand. The socio-technical perspective of urban mobility is then introduced to merge the supply and the demand into one system.

II.2.1 Technical perspective

The technical physical components of urban mobility are composed of infrastructures: roads, rails, fuel stations, train stations, bridges, energy and communication networks, terminals and facilities, etc., and vehicles: buses, cars, trains, trucks, boats, trams, etc. Information and communications technology (ICT) (GPS, Internet of Things, mobile networks, etc.) also play an important role in ensuring the qualities (safety, usefulness, fluidity, etc.) of these technical physical systems (Kitchin, 2013).

Travelers taking multimodal trips connect the elements of infrastructure, vehicles and ICT (Gallotti & Barthelemy, 2014): this brings out the need for a global understanding taking multi-modality into account and considering global performance rather than that of a single bus line, highway, or hub. For instance, bus lines feeding a regional rail line may operate with good performance indicators (e.g. good timekeeping, good frequency), but if the buses all arrive at the same time at the train station they will cause congestion. The TUMS including bus lines and the regional train will then operate with a bad multi-modal efficiency indicator.

Travelers may chain multiple trips during the day (Primerano et al., 2008) connecting the TUMSs to other urban systems, such as households, industries, or workplaces (Wegener, 2013). Thus it is the activities that travelers pursue in these systems – the origins and destinations of travel – that generate the demand on TUMSs (Banister, 2008). Whence the usefulness of studying the market perspective of urban mobility.

II.2.2 Market perspective

The World Business Council for Sustainable Development has proposed a model of UMSs as a set of three markets (WBCSD, 2015): (i) the travel market represents the spatial-temporal presence of travelers in urban systems performing their activities, which generates travel patterns, (ii) the transport market is where travel patterns meet the supply of vehicles and transport solutions (including cycling and walking), which generates transport patterns, and (iii) the traffic market is where transport patterns meet the supply of infrastructure, its information and management systems. Within these patterns, some recursive phenomena occur (Cascetta, 2009). For example, travelers who individually choose the most efficient (fastest and cheapest) UMSs might collectively congest them and thereby deteriorate the very two criteria on which they chose them in the first place.

These mobility patterns (Gonzalez et al., 2008), superimposed on actual city maps and sociodemographic data, attitudes, preferences, etc. (Lucas, 2013), can explain some of collective travelers' behaviors (e.g. reasons underlying traveler distributions within a geographic area). In summary, demand is characterized by both spatial distribution of social and economic activities, and by attitudes and cultural backgrounds of travelers.

Considering the supply and demand separately in representing urban mobility explains how they interact. However, this perspective does not consider either the effect of legal and political dimensions, or the role of individuals and institutions in operating urban mobility.

II.2.3 Socio-technical perspective

According to Auvinen & Tuominen (2014), technological, social, economic, political, legal and environmental dimensions need to be considered to understand the complexity of urban mobility. They define a UMS as a set of four main components: infrastructure, vehicles, travelers and governance. For instance, from the environmental perspective, the infrastructure offering smart electricity grids and charging stations for cars and buses permits the development of emission-free, silent electrical fleets. Together with political support and standardization, this encourages responsible modal choice by travelers, and ultimately generates a clean transport environment. For instance, people buying electric cars create a demand at charging stations and encourage the creation of new ones. These loops permit the propagation of social values through global urban mobility.

In a wider perspective, UMSs are components of the system of the city, and interact, for example, with energy systems and social structures. Hospitals and workplaces, through the practice of telemedicine and teleworking, decrease the need for mobility, and consequently transportation energy consumption. However, these new practices need the involvement of people, the commitment of companies, and adequate technological and legal measures.

For Ottens et al. (2006), the components of a UMS as a socio-technical system are: technical elements, social elements and actors. Technical elements include all physical components and the software to operate them, actors are individuals or organizations that are directly operating the system, and social elements influence the functioning of the UMS. Beyond functional relations (e.g. buses providing information at a bus station) and physical relations (vehicles driving on roads), there are intentional and normative interactions between these components. Intentional interactions are performed by actors where other elements are the object of their intention to take an action (e.g. a traveler has the intention to use a bike between metro station and work). Normative interactions represent rules for governing a technical element or an actor, e.g. a public transport operator obliges travelers to have valid tickets. Thus, from the socio-technical perspective, the traveler is a part of the UMS, and is involved in its operation as a customer and as an actor.

The dimensions listed above show how diverse are the interactions a traveler might have with UMSs while living his/her urban life, traveling from activity to activity. A closer look at how the traveler experiences his/her trip at an individual scale uncovers new aspects.

II.3 Traveler experience

The traveler experience of UMSs is not only about describing how travelers interact with the different components: the spatio-temporal dimension of the journey also induces some dynamics on the traveler's emotional, cognitive, and physical state.

II.3.1 Journey through time and space

UMSs are designed for different travelers who interact with their components, individually or collectively, or at different times of day, and with different itineraries. The EU-FP7 project METPEX (MEasurement Tool to determine the quality of Passenger EXperience), describes the 'traveler experience' by decomposing the journey into different typical stages (Woodcock, Osmond, et al. 2014). The journey is decomposed into (i) assessment of the need for mobility; (ii) planning stage (time, modes, routes, etc.) and the gathering of the artefacts needed during the journey (tickets/car papers, entertainment artefacts, etc.); (iii) movement from the origin to the transport gateway/car; (iv) interaction with the transport service (payment, ingress, etc.); (v) traveling in the vehicle; (vi) interchanges, which include finding the location of the next means of transport, schedule information, buying new tickets, etc. Finally, egress from the service at the destination concludes the journey.

Along their journeys, travelers value different things. Stradling et al. (2007), Woodcock, Berkeley, et al. (2014), and Susilo & Cats (2014) identified from travelers themselves: price, journey and service speed, protection against weather while waiting and traveling, reliability (punctuality and regularity), availability (frequency and stop locations), physical environment, vehicle quality, cleanliness both at stations and on board, quality on board, fellow travelers' behavior, seat availability, seat comfort, crowding both at stops and on board, station facilities, information accessibility, safety and security (at stops and on-board), ticket use and purchase simplicity, and connectivity (network and easy transfer). Joewono and Kubota (2007) identified from literature similar groups of criteria set as a mean to evaluate user satisfaction broken down into 54 attributes. At this level of detail, some attributes overlap with others such as level of emission and air quality, where level of emission is more an environmental technical attribute that should be calculated rather than evaluated by a transportation service user.

To analyze the journey experience, Susilo et al. (2015) consider three variables for each activity based on an activity representation of travel as already seen. The first one is *personal doing*, such as packing belongings, exiting home, walking to station, or crossing the street for some preparatory activity, for example. The second one is *personal thinking*, such as thinking over the day's schedule, observing people waiting, or wondering about waiting time. The last one is *personal feeling*, such as being worried about hygiene in a bus, bothered by the noise of a train arriving, or anxious about the weather.

These three personal dimensions vary over time: depending on the travel stage and the circumstances of travel, the traveler experience is never stationary. For instance, Van Hagen & Bron (2014) set an *emotional curve* over different train travel stages. Each level of *pleasantness* takes a value over time and according to some emotional instance (e.g. enthusiasm, stress, annoyance, rest, freedom, uncertainty, etc.). Lancée et al. (2017) introduced *commuting mood* as a metric of happiness variation throughout different travel means. Abenoza et al. (2018) linked overall satisfaction with a door-to-door experience to the stage by stage satisfaction through the lens of duration.

II.3.2 User experience journey

The International Organization for Standardization (2010) defines user experience as a "person's perceptions and responses that result from the use or anticipated use of a product, system or service". This definition considers the essence of UX as the subjective perception of the user. Hassenzahl & Tractinsky (2006), on the other hand, see in UX a subjective, situated, complex and dynamic encounter between the user and the designed system. Subjectivity here plays only the role of instantiating the interaction. It is not only a user's perception but also *usage* elements including the system to be designed and the context of interaction.

Law et al. (2009) also include in the *experience* framework what happens before and after the interaction. Furthermore, they insist that what is to be designed is not only an artefact or a service but a *system* that includes everything the user interacts with. In this respect, the scope of a traveler experience with a UMS can take multiple forms. The system's boundaries can be set according to several dimensions such as time, space, travelers, or as a set of artefacts/services and the connections between them. One important subjective dimension is *emotions*. Jokinen (2015) points out the importance of task performance on a user's emotions and vice versa. How the experience happens affect a user's emotions, but the emotional state of the user also affects the experience. Recursively, Desmet (2012) further details this reciprocation between the user's experience and emotional state by breaking down the sources of emotions. These are: the system, the meaning of the system to the user, the interaction, the activity facilitated by this interaction, the effect that the system has on the user, and other people involved in the interaction.

What has been identified as travel value categories in the METPEX project are the locus where a solution is most likely to be successful. Different names are given to this concept, such as jobs to be done, needs (Johnson et al., 2008), blue ocean (W. C. Kim & Mauborgne, 2004), or value buckets (Yannou et al., 2013). For instance, if many travelers value cleanliness, then an opportunity to achieve market success will be to improve cleanliness in UMSs if they are dirty. As a result, the travelers will be satisfied in that respect.

In a holistic approach, Kremer et al. (2017) consider UX as a process that flows over time, called *UX journey*, of which a designer can grasp multiple facets. This includes questions that the user asks, physical and cognitive interactions, system components, alternative interactions for special-needs users, emotional curve (positive and negative), problems, possible measurements, context aspects, and innovation potential.

Urban mobility systems have a considerable number of complexity factors. Different issues emerge from perspectives in the literature centering the vision on the traveler . The technical standpoint shows the variety of physical components a traveler might interact with during a single trip, and how these components are interrelated. The market vision brings out the recursive interaction between supply

(UMSs) and demand (travelers). The socio-technical position uncovers the position of UMSs within a city and traveler's activities in other urban systems as actors rather than customers. The literature on travelers' journeys through time and space shows how relevant it is to consider the perspective of travelers to connect all the visions on UMSs. Still, it does not cover the door-to-door experience as a whole: when a journey is deconstructed stage by stage, it does not inform on, for example, how a travel problem can affect the rest of the journey or even the day or habits of travelers experiencing it. Traveler experience encompasses a multimodal journey where the traveler, within a single trip, might for example use a bike and a train, and walk.

II.4 Research method

The study aims to provide a model of traveler experience that feeds the early phases in a design process for urban mobility systems with insights on travel problems. Qualitative action research was chosen: Loftland & Loftland (1984) state that qualitative research is suitable for "defining structures and looking for reasons", which is the object of this research. Accordingly, a conceptual model was designed to structure the interaction between travelers and urban mobility systems and bring out the problems travelers experience, pointing out their reasons.

The cyclic nature of action research involving different research methods allowed this research to evolve, through 18 months, from a conceptual framework based only on desk research and interviews, to a structured conceptual model supplied with insights from interviews and observations (Figure 30). Lucas (2013) states that action research is an effective way to promote technological innovation and social learning and is therefore relevant for urban mobility issues. Being inherently collaborative, involving repeated knowledge interactions and exchanges between the researcher and the object of research, action research narrows the gap between urban mobility models and the actual vision of travelers.

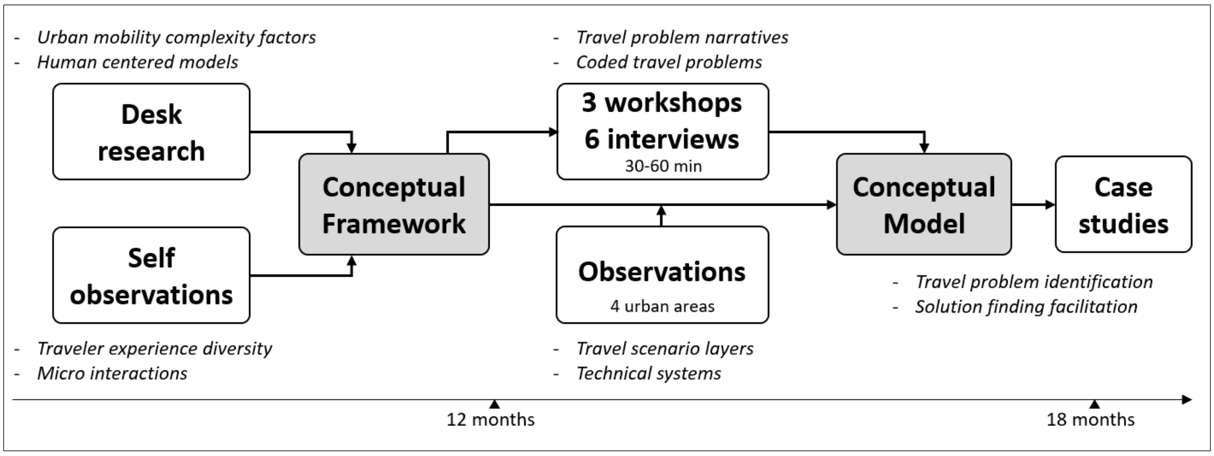


Figure 30. Action research process for designing the conceptual model

II.4.1 Desk research

Glass (1976) pointed out that desk research (or secondary research) by reviewing scientific results is relevant for learning from previous research and bringing new perspectives. Of course, the limited set of references cited in this literature review cannot do justice to the vast amount of literature on urban mobility. However, the pragmatic nature of this research makes the perspectives given on UMSs *diverse enough* to position the system to be designed, and bring out some of its complexity factors that need to be considered by a designer. More than two hundred papers were thus reviewed to set a framework for urban mobility in design and user experience. First, the literature on urban mobility was explored using different key words referring to it (urban mobility, transport, transportation, public transit, etc.). The focus was then narrowed to look for human-centered perspectives (e.g. human factors, urban sociology and psychology). This thorough review revealed a lack of literature on UMSs as an object of design. Observations, interviews, and workshops were therefore conducted in parallel on travelers and UMSs to fill this gap.

II.4.2 Observations

Observations are relevant for generating data on human behavior in some contexts (Sanoff, 2016, p.77-89). Interaction of travelers with UMSs and their environment was accordingly captured by this method. First, self-observations were recorded in the form of diaries and photos where different travel episodes, UMSs, and activities are related. This provided a dynamic picture of travel flow over time and uncovered the hidden micro-interactions of traveler experience concerning not only physical artefacts, but also interactions with fellow travelers, activities during the trip, planning the activity to be done after the journey, etc. More localized observations in four different transport hubs in the Paris area provided data on subsystems forming a multimodal physical space, identifying artefacts, crowd phenomena, travelers' actions and reactions, and situations a traveler may face in his/her travel routine in such places. A form of participant observation (Atkinson & Hammersley, 1994) was also conducted, traveling in different means of transport and relating travelers' issues in vehicles. Observing travelers, UMSs, and their interactions enabled us to detail the conceptual framework induced from desk research by creating new entities in the conceptual model, and to break down others. For instance, gathering different artefacts and interactions from different contexts enabled us to create different layers of *travel scenarios* (*interaction*, *episode*, and *travel experience*) to grasp the diversity of the variables without losing the abstraction that links travelers to UMSs. However, the projection of the journey on travelers' minds could not be captured without interviewing the travelers and asking them to express their experience using their own vocabulary.

II.4.3 Workshops and interviews

To grasp the perspective of a subject living an experience, interviews are needed (Kvale & Brinkmann, 2009). Thus, as the traveler was at the center of this research focus, to complete the picture, six semi-structured and in-depth interviews (30min - 60min) and three workshops were conducted. Participants were asked to talk freely about their experiences and recount problems they faced in their daily commute and/or in weekend trips. The goal was to capture concepts and predicates they use in their narratives. In the structured parts of the interviews and workshops, participants were also asked specific questions aiming at uncovering why the situations they described were problematic, and their narratives were coded within the conceptual framework. This form of inquiry enabled us to create the *travel problem* conceptual model entity, and to describe it using the pattern identified in participants' narratives.

II.4.4 Case studies

To evaluate the performance of the conceptual model in addressing the research question, several case studies were carried out. Two dimensions were chosen among all the performance variables a conceptual model could be evaluated for (Vrande et al., 2010).

1. *Travel problem identification*: the capacity to provide multi-perspective insights on the problems travelers experience interacting with UMSs.
2. *Solution-finding facilitation*: the capacity to transform the problem formulation into solutions (in the form of functions, for example).

The case study that was chosen for this chapter was an on-demand bus service operated by a public transport operator of Paris Metropolis. It is a service that allows a traveler to book a bus for an itinerary within an interval of time. The conceptual model is applied partly (using some of its concepts) to diagnose some of the service's problems. The data were collected from observations and by interviewing a bus driver who was the oldest agent and knew most of the users. The interview lasted 3 hours, and 5 rides were observed between 7 bus stops.

II.5 Proposition of a Traveler eXperience Conceptual Model

Based on the perspectives on urban mobility and user experience from the literature, observations, and interviews, a traveler experience conceptual model (TXCM) was designed. A first conceptual framework was set as basis for conceptualization (Author, 2017). Core concepts for the conceptual model were identified, namely: the *traveler,* the *system*, the *interaction*, the *situation*, and the *value* the traveler expects from the system. In this sense, the conceptual model goes further than these core concepts by detailing them, and by adding new concepts to clarify the big picture. Table 1 shows the definitions of each concept in the conceptual model, and Figure 2 illustrates how they are interrelated.

II.5.1 Assumptions

The conceptual model is one answer to the research question of design support and is based on various assumptions that delimit its scope and capacity.

- The conceptual model is not the pure subjective projection of traveler's interactions with technical systems: the subjective dimension only appears in the expected travel scenario, the scoring of travel value, and the predicates of quality.
- The conceptual model does not allow measurements such as travel problem severity or technical system performance. Instead it proposes concepts and variables that can be used to create measurements.
- The conceptual model is based on the literature, observations, and interviews with travelers. Hence its capacity to feed early design phases of UMSs was not captured from designers themselves. It is based on identifying gaps in the literature and real problems experienced by travelers.

It is up to the user of the conceptual model to set the boundaries of the system to be modeled and the travelers to be considered. The scaling of the system is also set by the user. For example, he/she can focus, at the elementary level of *interaction*, on how a stair of an escalator is climbed, and consider as a *travel episode* the whole escalator climb, which would be one episode in a metro station *travel experience*. An alternative is to consider the whole escalator climb as an *interaction*, the metro station transition as an *episode*, and the *travel experience* all three *episodes* metro-station-bus combined. The episodes occurring after and before these three can be included in the scope of the *travel scenario*. In this way, the details described by the conceptual model will depend on how the user handles the scoping. Likewise, if the user takes the scoping from the spatial dimension, the technical system can be a simple artefact such as a bus ticket, or a train station with all the subsystems it contains. Broader than a station, a technical system can also be a whole geographical area.

II.5.2 Model

The concepts in the conceptual model are described by a definition (Table 10) and the connections it has with the other concepts (Figure 31 illustrates some of the connections).

The output of the conceptual model as it appears in Figure 31 is the contrast between the two scenarios (*expected* and *real*). However, from a methodological point of view, the problem narrative is the input to the conceptual model. Put this way, the travel problem formatted through the conceptual model is a consequence of a situation that shifts a travel scenario from expected to real. We can therefore understand the manifestation of the problem through the other concepts. In this way, insights on the causes of travel problems can be identified, so facilitating solution finding.

Summarily, a *traveler experience* is a process that happens in time and space when a traveler moves from one urban activity to another using different technical systems. It can happen through different travel scenarios. When a situation happens, it shifts a travel scenario from what the traveler expects to what happens for real, and this may generate a travel problem if the outcome is perceived as negative.

In the TXCM, a *real* travel scenario happens to the traveler in his/her real experience of traveling. It can be once in time and space, or an average scenario that describes what often happens in the daily commute, for instance. An *expected* travel scenario, on the other hand, is how a traveler expects his/her journey to happen. For example, if the traveler expects to arrive at work at 8:00 am for a meeting at 8:10 and the train he/she takes is 20 minutes late, then the problem will be that he/she arrives 10 minutes late for the meeting without having had any time to prepare it. Another example is when a traveler expects to arrive on time for a date, but before boarding the bus realizes that he/she has forgotten his/her transport pass and needs to go back home to retrieve it because he/she needs to take a metro after the bus, or else decides to pay for the tickets.

Table 10. Traveler eXperience Conceptual Model concept definitions

Concept	Definition
Traveler	A person who moves from one *urban activity* to another and has a *travel experience* with one or more *technical systems*. He/she expects a *travel value* through which he/she perceives the *quality* of his/her *travel experience*.
Profile	The vector of attributes that describe a *traveler*. It does not depend on the *travel experience* to be assessed.
Travel Experience	A set of *travel episodes* that connects two or more *urban activities.*
Travel Episode	A set of *interactions* that connects one or more *technical systems.*
Interaction	The elementary relationship between *technical systems* and *travelers*, and *travelers* with *travels*. *Travelers* score *travel value* according to the *qualities* they assign to it.
Quality	An attribute defined by a *traveler* of a *travel experience*, *episode*, or/and an *interaction*. It scores *travel value*.
Situation	An event that shifts the *travel scenario* from *expected* to *real*. A *situation* can come from any of the *urban activities* or *travel scenario* components. It can involve any of *travel scenario* components.
Travel Value	A *value* of travel-related performances. It can be scored by *travelers,* on *interaction, travel episodes, travel experiences,* or *qualities.*
Technical System	The system that allows *travelers* to move, through *interactions,* from *technical systems* or *urban activities* to other *technical systems* or *urban activities.*
Travel Scenario	A combination of *travelers, technical systems, qualities, situations,* and *travel experience*. Two combinations of these are: what happens *for real* and what is *expected* by *travelers*
Urban Activity	The activity that *travelers* perform at the nodes of *travel experience.*
Travel Problem	The set of discrepancies between *expected* and *real travel scenarios* due to *situations.*
Consequence	The effects that a *travel problem* can have on all the *travel scenario* components.

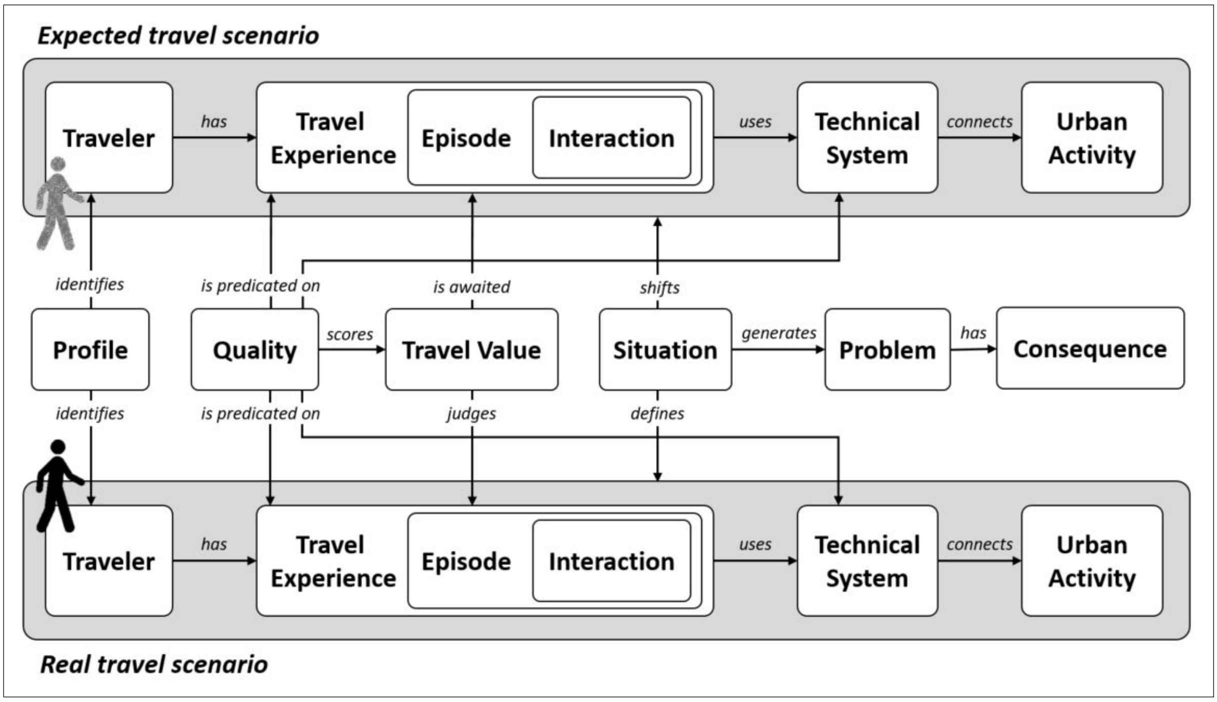


Figure 31. Traveler eXperience Conceptual Model diagram

The traveler perceives qualities from travel scenario components (including episodes and interaction).

These are predicates on his/her interaction with a technical system or other travelers, and his/her expectations on the travel scenario components. The nature of these qualities (positive or negative) affect his/her perception of how each of the values he/she expects are satisfied. For example, "dirty bus seats" is a predicate on a technical system and will negatively affect sensorial comfort.

II.6 Case study: TXCM on a demand-responsive transport service

A conceptual model is by nature a generic model that can be adapted to use. Therefore, the components that are used in studying a demand-responsive bus service (Figure 32) are restricted compared to those of TXCM. Moreover, some components are instantiated to fit the specifications of the service. For example, service staff are included within the *technical system* if the latter has been described as "the system that allows *travelers* to move, and a bus driver, for instance, contributes to that function. According to satisfaction surveys of the service's operator more than 90% of the users are satisfied. Among the issues experienced by the users, eleven problems were identified from the interview with the bus driver and observations:

1. Travelers who go past the stop but did not make the booking are prevented from boarding the bus, even if their destination is on the bus route.
2. The regular users of the service (time + space) make the same booking each time (they are not informed of the possibility to do so just once for multiple usages).
3. A user of a special category of heavy wheelchairs booked but could not use the service (the bus is not adapted).
4. A systematic questionnaire is used during the booking call. This is annoying for the regular users (who make up some 60% of all the users).
5. Travelers who are not informed that the service exists cannot readily perceive its physical presence (small bus panel, see Figure 33).
6. Sometimes nobody answers the booking call.
7. Sometimes the service cannot meet demand (full bus schedules).
8. Sometimes the bus is late, and the traveler has no means of knowing unless he/she calls the line.
9. Some road surfaces are uneven, and the shock absorbers of the bus are weak. For travelers suffering from joint problems this is problematic.
10. Travelers with strollers and seniors experience difficulties getting on the bus because of low sidewalks and the lack of low-floor technology aboard the bus.
11. The pass validator can be out of order.

The travel problem narratives are meant to point out the distress generated by the discrepancy between expectation and what happens for real (Table 11).

In problem 1, for instance, travelers who have not made the phone booking think that the bus is a regular one. They are therefore disappointed when they realize they cannot use the service, even if the bus has free seats and that it is heading to the same destination as they are. The disappointment here is twofold. First, they cannot use the bus. Second, although they are prepared to pay for the service, the bus driver does not allow them to board, following the instructions of the operator.

In the example in Figure 34, the traveler is an elderly woman who has a bad physical and cognitive condition. She saw the bus and she got on. But the bus driver asked her to get off, because she had not booked. The discrepancy between what she expected and how the scenario really happened is represented in these facts:

- She could not use the bus, she had to find another means of transport.
- She expected a total travel duration of 20 minutes and she spent 40.

- She expected to use a regular bus that needed no booking, which is a heavy cognitive load considering her impaired cognitive abilities.
- She expected to be informed of how the service worked before getting into such a situation.
- She expected the bus driver to let her on, even with no booking, but he was strict (he respects the limited insurance to registered users only).

Figure 32. The vehicle used in the DRT service

Figure 33. Barely visible bus stop

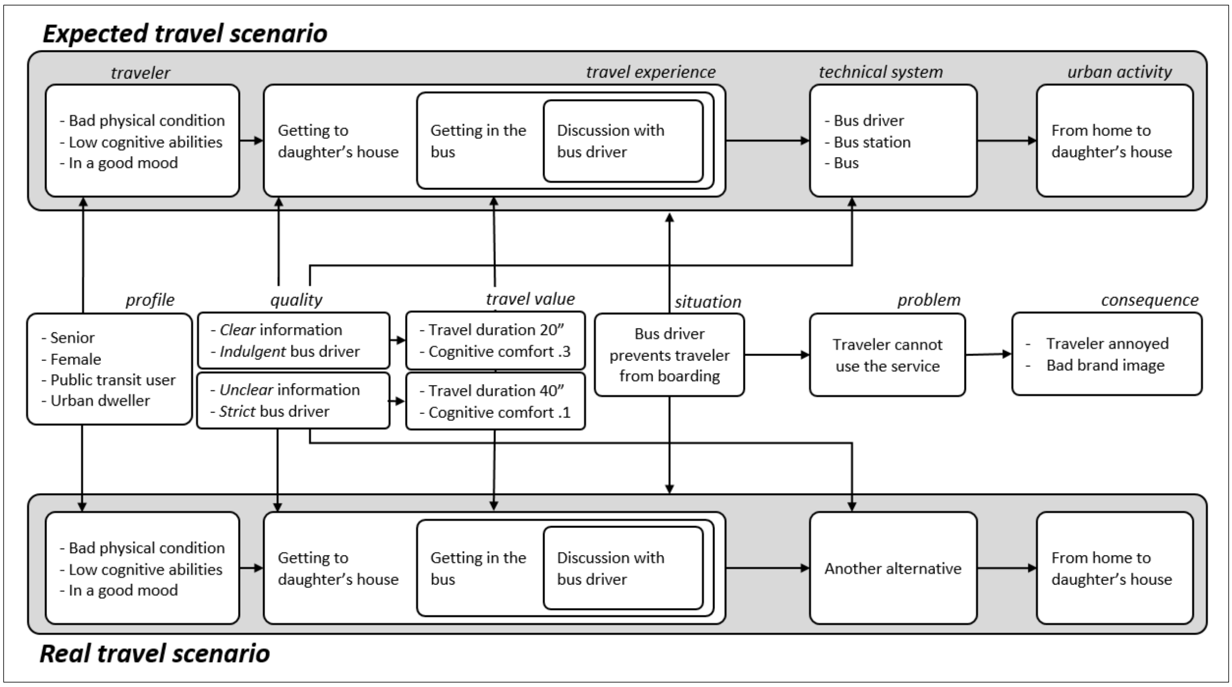


Figure 34. TXCM on the DRT service problem example

As a consequence of this, the elderly woman was annoyed, and the good mood she was in before experiencing this situation turned into a bad one, and her perception of the service operator was unfavorable.

Table 11. Travel problems through real vs. expected travel scenarios

	Real	*Pr.*	*Expected*
Interaction	Being stopped by the bus driver - Strict bus driver (service) -	**1**	- Board the bus (without booking) - Indulgent bus driver (service)
	Impossible to board the bus with the heavy wheelchair	**3**	Board the bus with the heavy wheelchair (after an accepted booking)
	Pass validation not completed	**11**	Validating the pass normally
Episode	Regular travelers making the same booking for the same itinerary each time	**2**	Regular travelers making one booking for their regular trips
	Regular travelers giving same information every time they call to make a booking	**4**	Regular travelers just giving itinerary
	Impossible to get the booking line (make the booking, use the service)	**6**	Get the booking line
	Bumpy trip (uncomfortable) - Backaches -	**9**	- Smooth trip (comfortable) - No discomfort
Experience	Pedestrians cannot identify the nature of – the sign panel Pedestrians cannot perceive the sign panel -	**5**	- Pedestrians know that the sign panel marks a transportation service - Pedestrians perceive the sign panel
	The trip demand meets no offer	**7**	Make the booking and use the service
	No information available about real bus - arrival time Bus not meeting its scheduled arrival time- interval	**8**	- Traveler informed of the real bus arrival time - Bus arriving within the scheduled arrival time interval

For all the eleven problems, the causes and consequences were induced according to what was observed and asserted by the bus driver (Table 12). Some consequences are more directly related to the problem than others.

Table 12. Causes and consequences of travel problems of the DRT service

Causes	*Pr.*	*Consequences*
[1ca1] Traveler does not make a booking **[1ca2]** Service's rules are too rigid **[1ca3]** Travelers not knowing about the service	**1**	**[1co1]** Travelers not using the service any longer **[1co2]** Travelers not arriving at destination (early) **[1co3]** Travelers annoyed (bad consequence for operator's image)
[2ca1] Travelers not informed of the possibility of booking once for multiple usage	**2**	**[2co1]** Regular travelers weary of answering the same questions every time they make a booking **[1co1]** Travelers not using the service any longer
[3ca1] Bus not adapted to some special category of heavy wheelchairs	**3**	**[3co1]** Users of some special wheelchairs are not informed of their exclusion
[4ca1] Booking information is not recorded so that they could recognize a regular user	**4**	**[2co1]** Regular travelers weary of answering the same questions every time they make a booking
[5ca1] Small bus sign panel **[5ca2]** Orientation of the sign panel does not help pedestrians see the bus stop **[5co2]** Car owners not respecting the bus stop area	**5**	**[5co1]** Low demand on the service **[5co2]** Car owners not respecting the bus stop area **[5co3]** Bus stops in the middle of the road
[6ca1] Lack of staff in the booking line service **[6ca2]** High call rate during some periods of the day	**6**	**[6co1]** First users thinking the service has stopped, and giving up **[6co2]** Regular travelers frustrated by the impossibility of making the trip they planned
[7ca1] Lack of buses **[7ca2]** High demand for some periods	**7**	**[6co2]** Regular travelers frustrated by the impossibility of making the trip they planned
[8ca1] Lack of communication between the service and the traveler **[8ca2]** Bus is late **[8ca3]** Booking line is defined as the booking line and not a hotline	**8**	**[8co1]** Traveler frustrated by uncertainty **[8co2]** Confused traveler
[9ca1] Weak shock absorbers **[9ca2]** Bumpy/rough road **[9ca3]** Fragile physical condition of senior travelers	**9**	**[9co1]** Travelers getting backache **[9co2]** Deterioration of the physical comfort aboard the bus **[9co3]** Senior travelers abandoning the service
[10ca1] Absence of low-floor technology aboard the bus **[10ca2]** Low sidewalk **[10ca3]** Weak physical condition of seniors **[10ca4]** Need of strollers to transport babies	**10**	**[10co1]** Physical discomfort **[10co2]** Risk of falls **[1co1]** Travelers no longer using the service
[11ca1] Pass validator technical issue	**11**	**[11co1]** Travelers thinking their pass is not valid for the service **[11co2]** Travelers trying multiple times and getting frustrated

For example, travelers no longer using the service is a consequence of the result "traveler annoyed". All the problems are interrelated, including their causes and consequences. For this reason, a basic causality network is created to sort out some properties of problems (Figure 35). [8ca1] for example, is the most trouble-making problem insofar as it generates multiple further problems (4 arrows out): if the service is not a common transport solution, and if there is no good communication with users and potential users, problems are expected to arise. Problems [1] and [10] are serious problems insofar as there are a lot of reasons why they can happen (6 for [1] and 5 for [10]). Problems [6] and [7] are closely related because they both lead to the impossibility of making the booking after calling the service.

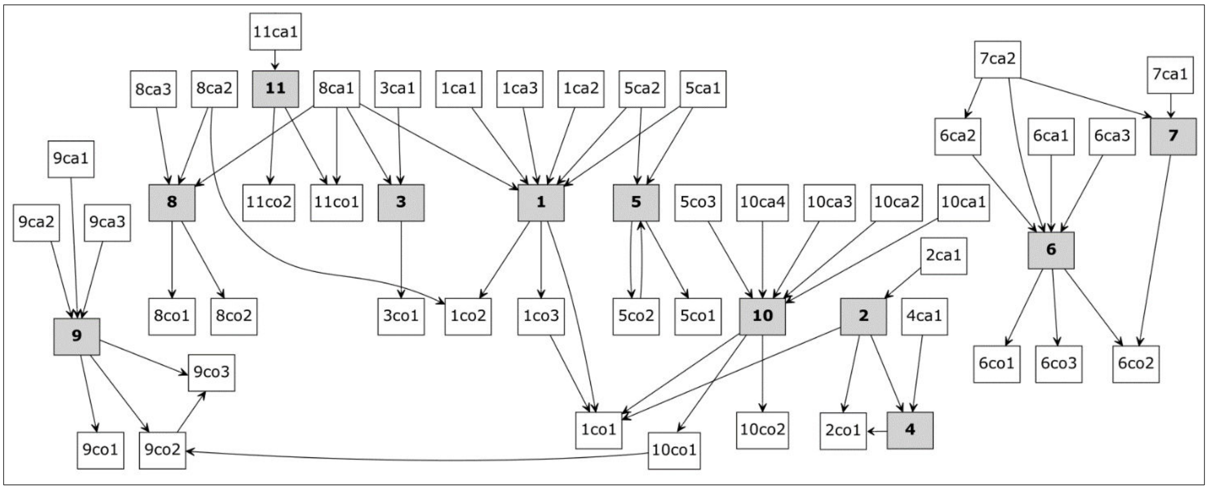


Figure 35. Problem causality network of the DRT service

II.7 Discussion

The Traveler eXperience Conceptual Model (TXCM) proposed in this chapter shows how a simple narrative from a traveler or an observation of a traveler's interaction with some physical artefact or service can be encoded with the objective of recording salient aspects of travel problems that encompass a door-to-door experience.

II.7.1 Travel problem projections on traveler experience

Let us take for example a traveler using the DRT service (of the case study) who wants to arrive on time to catch his/her infrequent train (1/hour). The bus arrives a few minutes late. Let us say that the problem is that the traveler missed the train. Described this way, we cannot talk about what happens in this traveler's mind, nor can we identify the technical problem. But if we take all the parameters including the bus driver, the bus schedule, the train schedule, the traveler's state, the consequences of missing the train, etc., then the problem's description becomes more insightful.

If we focus on what happens to the traveler's emotional state, and say that this is the traveler -centered problem, then we can identify the technical problem (related to the service) as a cause and what happens after missing the train as a consequence. Yet there is more to say about the traveler's emotional state. There are many emotional states to discuss. These might include being on the bus wondering if it will arrive on time for the train, knowing that the train has left, and the distress generated by thinking of what will happen next, or the reasons why this happened (annoyance about the service's lateness, regret for picking this service rather than another solution that would have got the traveler to the train station on time (e.g. a taxi).

Hence the focus we make on the problem will position the solution generation phase to find a way of solving one aspect or another. For example, if the problem is that the bus is not punctual, then the solution will be some way of making it arrive on time. If the problem is that the traveler is annoyed because he/she missed a train, then the solution will be a way to enable him/her to arrive on time (sending an Uber driver, for example). The first problem setting narrows the field of innovation to the bus only. It assumes that the service improvement is systematically related to the punctuality of the bus, and not on the traveler arriving on time. However, if we make both statements of the problem, we will gain more insight, and identify a causality relation between the two. We will be aware that the punctuality of the bus is only one possible way of enabling the traveler to arrive on time. One consequence of this is that the operator could enlarge its business model by creating cooperation with other urban mobility services (if it is not possible to systematically make the bus always arrive on time). Consequently, the more perspectives we have of traveler experience of the problem, the more readily we can improve the system.

II.7.2 Travel problems between causes and consequences

A *travel problem* covers not only what the traveler expresses when interviewed, or what is observed, but also the causes and consequences of the central identified problem: the consequences that a problem can generate are also problematic for the traveler. The example of the elderly woman illustrates this fact well. Extending the causes and consequences will bring out more insights into the deepest origins and the farthest consequences where, for each layer, a solution can be proposed.

The problem causality network allowed us to uncover the relationships between problems and opened the possibility of hierarchizing them. It can be further developed using graph theory measures such as betweenness and closeness centrality (Freeman, 1977). This will allow a more accurate and relevant problem hierarchy. Some causes can be combined to obtain a more insightful one. For example, the combined causes of problem 7 (high demand and lack of buses) emphasize the temporality of these two phenomena: addressing each separately (increasing the number of buses and/or diminishing the demand) does not consider the possibility of fluctuation of both, and that at some other times the buses ride empty. To specify the travel problems, it would be relevant to link the expected scenario to the traveler it concerns. In this way, even the number of travelers it concerns would be captured and so make the travel problem hierarchy more accurate.

Some of the identified problems can be a strategic design choice. For example, the lack of communication with potential users, if solved, can generate more demand that the service cannot handle. Therefore, it is important to have different stakeholders together to have a better understanding of travel problems.

II.7.3 Nature of travel problems

The solution generation phase is conditioned by the distinction between essential and accidental situations (Gorman, 2005): the predicates related to a component's nature (essential attributes) need a new design when those related to their accidental attributes can be solved by a change in how the UMS works. For example, if it is only one booking line agent who asks indiscreet questions (accidental), then correcting his/her behavior would solve the problem. Conversely, if it is the fact of asking travelers personal questions that is problematic, then the whole staff will be affected, and the process and databases will need a structural change.

II.7.4 Travel problem identification

Along the design process of an urban mobility system, the traveler's perspective should be considered; defining performance indicators and identifying the problems to be solved.

A problem can be identified just by studying technical systems and thinking of the negative affordances (Maier et al., 2009) it permits. This insight is obtained by making observations or by reviewing technical documents of UMS components, such as architectural plans or specification documents. Of course, deeper insights are obtained by asking the travelers about their experience with specific components that are identified as negative affordance holders.

Nonetheless, this way of performing a UMS diagnosis starts and ends with the system to be designed. The final loop does not enable us to assess whether the value expected by travelers is fulfilled, but only how well the solution fits the specifications it was made for in the first place. The traveler's point of view is included in the considerations of what is problematic with his/her experience with urban mobility systems. However, the designer loses travelers' perception of the qualities of the UMS, and how close the value it delivers is to the one expected by travelers. For example, a transportation operator uses indicators such as technical efficiency, intensity of use or service coverage to monitor the performance of its lines (Diana & Daraio, 2010). The traveler appears as a unit in ratios such as line length per inhabitant or persons per seat. The traveler's viewpoint is considered in measuring quality indicators like regularity of schedule, frequency, area coverage, modal preference, speed, walking time and transfers. These indicators are relevant to a holistic assessment of a service with diverse metrics. However, they do not provide answers on how far each traveler is satisfied with his/her experience using the service, and the reasons for his/her dissatisfaction with the service's qualities related to traveler experience dimensions.

II.8 Conclusion

The chapter starts from different perspectives on urban mobility systems to show how complex it is to consider such systems as objects of design. We then stress the relevance of the UX approach for modeling traveler experience of UMSs, insofar as the chapter illustrates possible interactions between travelers and artefacts during a door-to-door journey.

For that reason, UX was adopted for designing the conceptual model and adapted to match UMS complexity factors (multimodality, connection with other urban systems, supply-demand recursion, etc.). Observations uncovered the diversity of situations, technical system varieties, and contextualized micro-interactions. Workshops and interviews with travelers brought out problems of dichotomy between real and expected travel scenarios. Finally, case studies showed how travel problems can be identified from travelers' narratives, and how they affect the solution generation phase in the design process.

The conceptual model allows scaling from elementary interactions to travel episodes. This has the capacity to bring out the repercussion of the problems that arise at the interaction scale for the whole travel experience, including what happens to the urban activities the traveler expects to exercise. Yet the conceptual model, in its current form, does not enable us to extract qualitative information from the traveler experience. For example, the travel value vector (e.g. sensory comfort, travel speed, punctuality, price, infotainment, etc.) can be used as a metric to evaluate travel problems, by asking travelers to score each performance. Also, using a set of travel scenarios both expected and real lets us measure the performance of a UMS. On the other hand, if the focus is a traveler profile, the different scenarios can be a basis for measuring the traveler's satisfaction with a UMS or even at the scale of a city.

These traveler -centered performances can be compared to those a transport operator sets to monitor its UMSs as a stakeholder of traveler experience: the traveler can be considered as a stakeholder at the same level as a transport operator. Both expect value from the UMSs (Lindenau & Böhler-Baedeker, 2014). The comparison will tell us how far a transportation operator is considering the concerns of travelers regarding the performance of the UMSs it is responsible for.

Future research will take an extensively developed quantitative approach to evaluate travel problems using the travel value indicators, for example. Hierarchy will also be developed using the causality network to systematically identify the problems to be solved as a priority. Consequently, the solution generation phase will produce solutions for prioritized problems, and allow the solution to cover all the issues brought out to define the problem. This is a natural consequence, since the *problem* cannot be fully understood in isolation from consideration of the *solution* (Eastman et al., 2001).

Chapter III

Understanding urban travel problems: A grounded theory approach

Urban travelers experience problems when they use different products and services along a door-to-door journey. These problems are of different natures and might be perceived differently by travelers. Existing research has focused on travel problems for a specific traveler profile or transportation mode. However, neither archetypes of travel problems nor their possible causal relations were investigated. This chapter proposes a travel problem categorization including a causality scheme. The goal is to provide a tool that can be used to diagnose urban mobility systems' problems. Nine open-ended interviews with a maximum variation sample of interviewees were used to provide narratives on urban travel problems. Using a grounded theory methodology, the chapter proposes a taxonomy of travel problems and how each category can be a cause or a consequence of another category. It presents two case studies to show how the proposed tool can be used in decomposing a complex travel problem statement and enrich a simple one.

Key words: grounded theory, travel problems, taxonomy, causal scheme

A modified version of this chapter has been submitted to "Transportation Research Part A" Journal

III.1 Introduction

Urban mobility challenges lie in three interrelated dimensions: (1) the physical city and region, its infrastructures and technology, (2) policies and planning strategies and (3) how citizens live their everyday life moving in the city (Jensen & Lassen, 2011). These issues need multidisciplinary approaches to propose relevant and sustainable solutions (Pucci, 2016), placing people in the heart of their construction (Mitchell et al., 2016).

At the scale of urban dwellers, these challenges are experienced, inter alia, in the form of travel problems. Indeed, travelers use multiple products and services along with a door-to-door journey (Woodcock et al., 2014). During this journey, they experience difficulties, issues, challenges, or problems that need a relevant solution design. Indeed, in design practice, getting more about usage problems gives the designer the knowledge to design more relevant solutions for the users (Osterwalder et al., 2014, p.14). Research studying travel problems is sparse and uses multiple names to talk about the negative aspects of a traveler experience.

Indeed, *transit*-related research covers a bigger scope than traveler experience. It includes supply-demand balancing (Mcdermott, 1978) and policy related issues (Hook et al., 2014). The traveler is involved in representing the voice of the citizen in a wide range of transit-problems (Schachter & Liu, 2005) (Gaber & Gaber, 1999). *Commuter/passenger needs/issues* mostly describe problems related to a specific system. This could be a transport service (Sutton, 1987), an information system (Spyridakis et al., 1991), or an institutional small geographic area (Miller, 1986). *Transportation and transport*, in turn, cover different scales of problems or needs. These can be very precise such as seatbelt issues (Linden et al., 1996), or global such as accessibility and safety (Porter, 2010). On the other hand, they are either specific to a mode of transport (Gatersleben & Uzzell, 2003) (Katzev, 2003) or to a traveler profile (Knight et al., 2007) (Sammer et al., 2012) (Hjorthol, 2013).

Even though these studies involve travelers in defining their travel problems through surveys or focus groups, they lack abstraction in proposing archetypal categories of problems that might apply to all types of urban mobility systems, at different scales, and to all traveler profiles. Moreover, these studies are restrained by the preconceived views of the researchers on travel problems. Indeed, they are classified in pre-defined sets such as “cost, stress, time, and fatigue” (Talbot et al., 2016) or “cost, time, insecurity, discomfort, impact on communities” (Raymundo & Reis, 2017). Delbosc & Currie (2011b) brought out the causality between the traveler’s condition and travel problems. However, the proposed travel problems were considered independently, not taking into account how the condition of a traveler could have an impact on the experience itself and not considering possible causalities between the encountered problems. Morin (2014) has observed a dialogic pattern in defining complex problems and points out the importance of considering non-intuitive causation directions, where a problem can be the cause and/or the consequence of another one. Al Maghraoui et al. (2017) infer travel problem causes and consequences considering them as problems. However, the causation possibilities between travel problems still need a repository of potential travel problems on which the inference can be done.

Summarily, no existing study seems to propose an archetypal modeling of travel problems and how travelers experience these in combination. Design communities, however, propose archetypal models and definitions. For instance, Osterwalder et al. (2014, p.14) use the concept of *pain* which describes all that annoys the user before, during, and after trying to reach his/her goal using a product or service. By explicating the pains, solutions would naturally appear as *pain relievers*. However, such abstract concepts need the right tailoring to the context in which they are applied. For instance, Pronello & Camusso (2017) illustrates how the concept of “value proposition” applies on travelers’ needs for information.

This chapter addresses the following research question: *What are the problems travelers experience using urban mobility systems?*

Firstly, the grounded theory methodology is introduced and used in generating the taxonomy and its causality scheme. Second, the categories of travel problems and their inter-causation are exposed and discussed. Finally, a case study is used to illustrate how the taxonomy and its network can be used to diagnose travel problems of an urban mobility system.

III.2 Research method

The research methodology has been adopted from grounded theory literature (Charmaz, 2014). It starts from narratives and ends with a theory on the research question of interest. This research is intended to draw the perspective of travelers on travel problems with minimal literature bias. However, grounded theory is frequently performed by one researcher, which is the case for this research. Consequently, the modeler bias will still be there.

Four interviews, as an initial sample, have passed through a three-stage coding process (Figure 36) leading to an initial model as a set of categories. Saturation tests have then been operated on this model in order to add missing categories and enrich category definition.

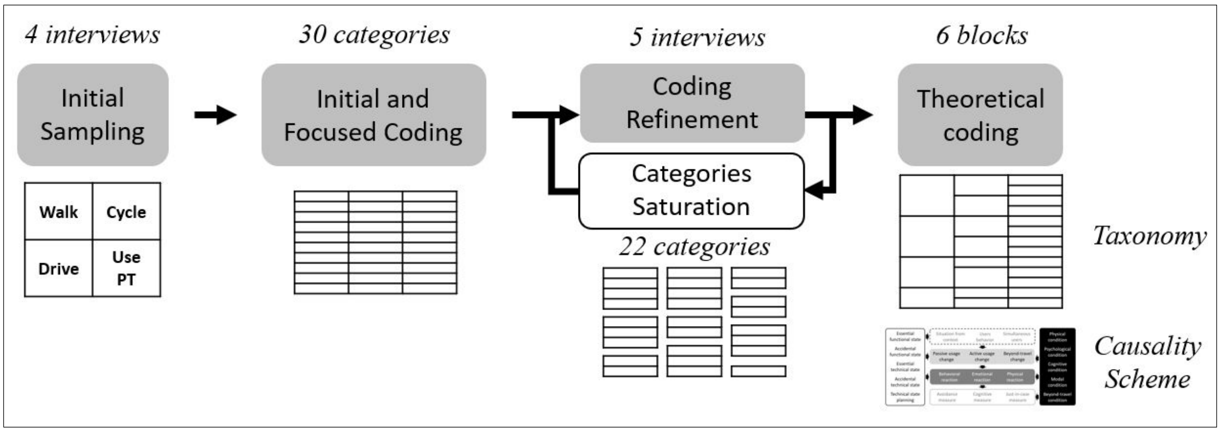


Figure 36. Research methodology stages

III.2.1 Initial sampling and interviewing

To cover most of the transportation modes with a minimal sample, the maximum variation sampling (Patton, 2005) has been chosen for four modes; walk, car, bike, and public transport. The four interviewees have been selected based on their modal choice for urban mobility to cover a large spectrum of travel problems in the dimension of the used technical systems: one exclusive cycler, one exclusive pedestrian, one exclusive public transport user, and one exclusive car/motorcycle driver. Three of them work as researchers at the Austrian Institute of Technology (at the same location) and one studies at the University of Vienna. Each of them spends less than 45 minutes to commute.

The questions were asked in an open-ended interview format. Some clarification questions were added to clarify some answers or to draw attention on unanswered aspects of the question. The interviewees were asked to freely talk about their travel experience. They were then asked to talk about their travel problems and relate their causes and consequences afterward. Finally, they were invited to think of what is problematic in the problems they identified and propose a definition of a "*travel problem*".

III.2.2 Initial and focused coding

The narratives of the interviews have been transcribed and coded interview by interview. The coding method was sentence by sentence and sometimes two or three sentences. The initial coding consisted of removing from the narratives the grammatical structure and mark down only the items that are linked to the question. For example, "*I am a scientist in the area of transportation, mathematician. I do like to cycle since we talk about mobility. That's my main transport for a long time now. I lived all over the world and used it wherever I was. Even when no one cycles there*". Is coded as *Mathematician, exclusive cycler since always, cosmopolitan.* However, causative connectors such as "*so*", "*because*", or "*that's why*" are recorded in the form of arrows that define causal links. The arrows are kept when categories are created. They consequently connect the categories and not only the instances.

The initial codes are abstracted into concepts that regroup these first codes as instances (focused coding). For example, "*mathematician*", "*urban sociologist*", "*student*" are instances of work nature concepts. Each of the categories that are identified from theoretical coding is allocated to a definition, following the logic of abstraction of codes.

III.2.3 Coding refinement

Thirty categories have been obtained from the focused coding (Appendix 1). These are refined according to the following criteria:

- A category that is embedded into another one is integrated into it. For example, "technical system capacity" is integrated into "essential technical state".
- Precisions are added in a category that is likely to be integrated into another one. For example, in "situation from travelers", "travelers" are assumed included in "context" to be included in the category "situation from context".
- A category that is too abstract and contains too many instances compared to the others, is split into two or more categories. For example, "altered usage" contains 16 instances. It is split into "passive usage change" and "active usage change".
- A name or a definition of a category is changed when it does not reflect the instances. For example, "Physical feeling" is changed into "Physical reaction" since it contains "sweat" and "get cold" as instances.
- Categories are organized in a way that facilitates theoretical coding. For example, categories that concern the state of the system are put together with a specific color (Appendix 2).

III.2.4 Categories saturation and theoretical coding

The model given by the initial sample is tested regarding its data and theoretical saturations (Saunders et al., 2018). Data (or code) saturation is assumed to be reached when no new category is created or a category is split (Hennink et al., 2017). On the other hand, theoretical saturation is assumed to be reached when no new properties are added to category definition (Morse, 1995).

To achieve the data saturation test, narratives from three other interviews (two from the greater Paris metropolitan area and one from Singapore) are used. The two Parisian interviewees are exclusive public transport users. The Singaporean one uses mostly public transport and car from time to time. The Viennese, Parisian, and Singaporean environments are assumed to have similar urban mobility problems. One by one, the codes from each interview are integrated into the Viennese theoretical model (Appendix 1). The instances that fit within the initial theoretical model are added. Whenever they do not fit, a new category is created. No new category was created while adding instances from the three interviews. Therefore, data saturation was assumed achieved by the fourth interview from the initial sampling.

To achieve the theoretical saturation test, a theoretical sampling is conducted (Coyne, 1997) to detail (1) categories lacking distinctive insights from the other categories; (2) categories containing few instances that do not reflect directly and clearly the definition. For example, some instances could fit within more than one category such as "no seated place available" that can fit in either "simultaneous use" or "number of users" in the taxonomy of Appendix 3. Two interviews are conducted to clarify some of the categories and generate more instances for some others. This led to displace some instances and modify some categories. Interviewees are researchers who have an expertise regarding urban mobility usage problems.

Theoretical coding is the last modeling phase. It is based on saturated categories after the theoretical sampling. In the travel problems model, categories are linked to each other forming both a taxonomy and a causality scheme. The organized categories are represented in the form of a diagram (Strauss and Corbin, 1998, p.153).

III.3 Results

From interview transcription to theoretical coding, the different stages of the grounded theory approach allowed proposing a taxonomy of travel problems in the usage of urban mobility systems. Moreover, it allowed linking different travel problem categories in a causality scheme. The answers given by different interviewees on how they define travel problems allowed proposing a travel problem definition.

III.3.1 Travel problems taxonomy

Travel problems, as perceived by travelers, are of different natures. They concern different facets of how a traveler experiences his/her usage of an urban mobility system. There are six kinds (blocks) of travel problems (Table 13).

1. The state of the system: How the system is designed, operated, and planned can be a problem for the traveler. This is in both essential and accidental forms of design and operation. For example, a bus can be scheduled to have a frequency of one per hour (essential functional state), if a traveler misses it he/she needs to wait for one hour. It may have a delay or may be canceled (accidental functional state) and delay all the day's schedule of its users. The population density in the area where it operates grows and the frequency remains the same (technical state planning). The bus may serve an intercity train station, where travelers carry big luggage, and yet may have no bag-racks (essential technical state). It is a hot summer day; the bus has an air conditioner, but it is out of order (accidental technical state).

2. Situations: What happens around the traveler, apart from how the system is designed and operated, can be a problem for the traveler? A situation can come from traveler's surroundings, the behavior of other travelers, or because of multiple travelers using the same system. Without an umbrella, if it starts raining, it is a problem (a situation from context). If a traveler wants to read a book during his journey and there is someone playing rap-music in his phone (traveler's behavior), it is a problem. A traveler who has back issues, not finding a seated place in a crowded bus (simultaneous travelers) is a problem.

3. Travel change: If the course of the travel or its consequences does not meet the expectations of the traveler, it is a problem. This shift from what is expected to what happens for real can take different forms. A traveler can miss his/her train to go to work (passive change) after a run to arrive at the station. He/she can then find an alternative if he/she does not want to wait for the next one (active change). He/she probably, therefore, arrives late at his/her morning important meeting (beyond-travel change).

4. Experience measure: What constraints the traveler depending on his/her prior travel experiences can be a problem. The measure can be taken either to avoid a situation, to protect oneself from a situation if it happens, or just to remain aware of what happens around. If a cycler has to spend 20 more minutes just to avoid a tram rail where he/she slipped once (avoidance measure), it could be a problem. If one has a big umbrella and needs to carry it all the time because it could rain anytime (just-in-case measure), it is a problem. An information system that shows the wrong information frequently needs double checking each time (cognitive measure) one wants to schedule his/her journey, which can be irritating.

5. Traveler reaction: How the traveler reacts to a state of the system, a situation, a travel change, or an experience measure, can be a problem. A reaction can be behavioral, emotional, or physical. If a traveler uses a line where nobody respects the queue, he/she will in turn not respect it (behavioral reaction). If a traveler has a headache and gets in a wagon full of teenagers making noise, he/she would be irritated (emotional reaction). If a traveler runs on a sunny day to get his train, he/she would sweat (physical reaction).

6. Condition: What conditions the travel and the traveler as a person. It is the ground on which a state of the system, a situation, a travel change, an experience measure, or a traveler reaction become problematic. A condition can be either psychological, physical, cognitive, related to the transport mode, or comes from before and after the travel. Someone who has been educated to be punctual (psychological condition) suffers a lot (embarrassed) if he/she arrives late at a meeting. A traveler who uses a wheelchair (physical condition) is more challenged than a regular person (not needing a wheel chair) when using public transport. Someone who does not have a driving license cannot use a car (modal condition). He/she is constrained to use public transport or a bike for example. Someone who does not have a shower at his/her workplace (beyond-travel condition) is more likely not to use a bike to come to work if he/she lives far away even though he/she likes to cycle.

Table 13. Travel problems taxonomy

Block	Category	Definition	Examples
State of the system	Essential functional state	State of the system that is essential to its intended functioning	1 bus per hour, limited zone coverage
	Accidental functional state	State of the system that is accidental to its intended functioning	Late train, wrong information
	Essential technical state	State of the system that is essential to its intended design	No bag-racks, no air conditioner
	Accidental technical state	Accidental state of the system regarding its nominal state	Bad smell, slow escalator
	Technical state planning	Essential state of the system does not evolve in design or functioning	No new lines, no bus frequency increase
Situation	Situation from context	Situation provoked by external factors to the system and travelers	Rain, no-car day, train drivers strike
	Travelers behavior	Situation provoked by the behavior of other travelers	Slow walk, stroller place not respected
	Simultaneous travelers	Situation provoked by travelers using simultaneously the system	Queue, no seated place available
Travel change	Active usage change	The decision-based action that traveler takes when a change happens in his/her expected travel	Buy coffee, find an alternative, squeeze in
	Passive usage change	Change a traveler undergoes when a change happens in his/her expected travel	Miss train, get pushed, slip
	Beyond-travel change	Change that is operated on a traveler's life before and after travel	Arrive late, miss flight, get sick
Experience measure	Avoidance measure	Measure a traveler takes to avoid a scenario that happened in the past	Avoid tram rail, abandon public transport
	Just-in-case measure	Measure a traveler takes to protect him/herself from a scenario that happened in the past	Carry an umbrella, consider buffer
	Cognitive measure	Additional attention a traveler makes preventing a scenario that happened in the past	Watch one's steps, double check schedules
Traveler reaction	Behavioral reaction	How the traveler reacts to a change in his/her expected travel	Say sorry, non-respect of queues
	Emotional reaction	How the traveler reacts emotionally to a change in his/her expected travel	Irritated, mood shift, ashamed
	Physical reaction	How the traveler reacts physically to a change in his/her expected travel	Sweat, get cold, allergic reaction
Condition	Psychological condition	How the psychological condition of traveler conditions his/her behavior before travel	Punctual, hate noise, superstitious
	Physical condition	How traveler is conditioned physically before travel	Weak immunity, reduced mobility
	Cognitive condition	How traveler is conditioned cognitively before travel	Ignoring alternatives, clumsy
	Modal condition	The obligation to use a specific mode or route instead of the desired one	No alternatives, no driving license
	Beyond-travel condition	What conditions traveler's life right before and after travel	No shower at work, have a meeting

It should be noted that all the aforementioned examples were linked with at least one problem from another category. The state of the system cannot be a problem on its own. The low frequency of a bus is not a problem if one does not wait for long. A situation is not a problem on its own either. A traveler using earphones would not even hear someone playing music in speakers. A travel change is not a problem on its own. A tourist would not be upset if he/she arrives one hour later than the beginning of the hotel check-in timeframe. An experience measure is not a problem per se. Avoiding the tram rail by taking a route that takes two minutes more does not make much of a difference for an itinerary of 50 minutes. A traveler reaction cannot constitute a problem alone. It is a reaction to some other problem. A traveler sweats as a reaction to hot weather or to the fact that he/she runs. A condition does not represent a problem if taken alone. A traveler who does not cycle or who lives next to his/her workplace would not mind not having a shower at work. As for "traveler reaction" kind of problems, all the problems are the consequence of some other ones. Vice versa, problems can be the cause of other problems.

III.3.2 Travel problems causality scheme

Interviewees expressed how they see the causal links between problems they declared. That is because they were formally asked to, but they also linked some of them before being asked. Figure 37 reports the links that were explicitly expressed by interviewees between instances of the categories. However, one can infer several other links that have not been identified as such. For instance, there is a causation between *situation* and *system*. This could be observed in the direct impact of a person having a faintness on the functional state of a train for example. Moreover, categories within the same block have causation links as well. For instance, an essential technical state (e.g. no air conditioner) can create an accidental technical state (e.g. bad smell during summer).

So on, one can expect that all travel problems categories can be the causes and consequences of each other.

Summarily, depending on his/her condition, a traveler experiences changes in his/her travel and reacts to it. These changes can be the result of some state of the system he/she uses or some situation that is external to the system. When repeated, the changes, the reactions, the situations, and the states of the system push the traveler to take measures in his/her next travel.

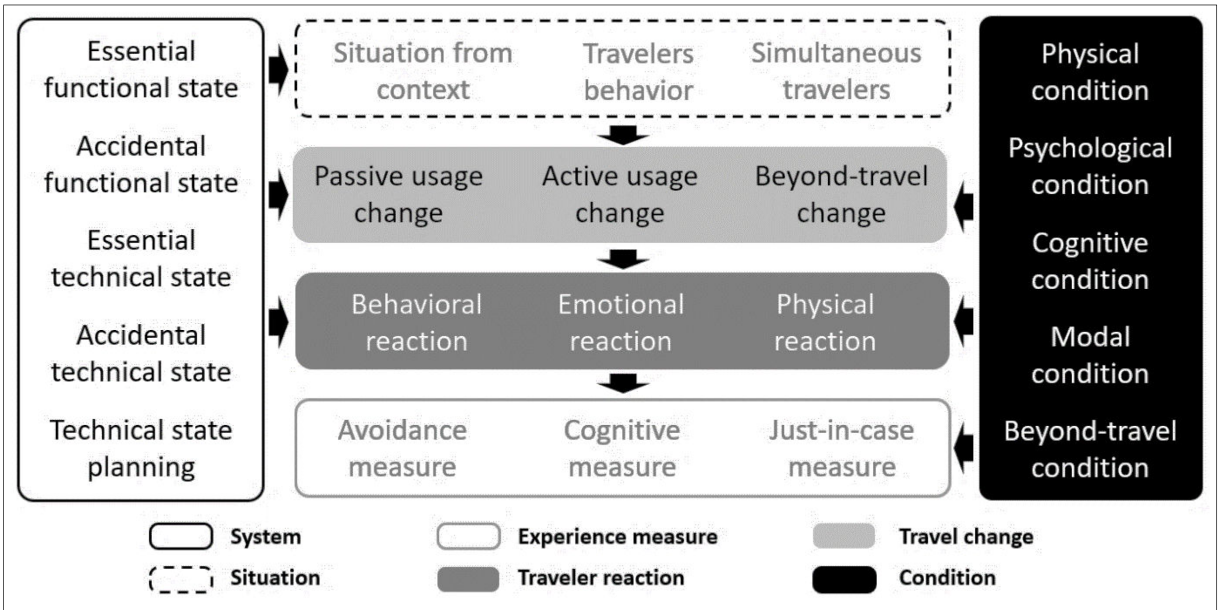


Figure 37. Travel problems causality scheme

III.3.3 Definitions of travel problems

At the end of the interviews, interviewees were asked to propose a definition of travel problems, based on the travel problems they declared. These are summarized versions of what they proposed:

1. (**No**) *information.* (**Un**)*familiar.* (**Wrong**) *mind settings* and *activities.*
2. What causes (**un**)*pleasant journey* for some reason.
3. (**Over**)*occupation of urban mobility systems.*
4. (**Un**)*wanted incidents* happening in the way.
5. What (**does not match**) with one's *idea of a perfect ride*.
6. When something in travel goes (**un**)*expectedly.* (**Un**)*satisfied traveler.*
7. What (**annoys**) a *traveler* in his/her *displacement*, but he/she still arrives at the destination.

There is one common core about these definitions. It is that all of them represent a negative predicate (**in bold**) of some referential state (*in italic*). For example, **wrong** *mind settings and activities* refer to some **right** version of mindset and activities. (**Un**)*pleasant*, (**un**)*expectedly*, (**un**)*satisfied*, and (**un**)*wanted*, all refer resp. to pleasant, expected, satisfied, and wanted versions of what goes wrong with the travel.

III.4 Enrichment of travel problems: illustrations

We propose a pragmatic use of the travel problem causality scheme and its taxonomy in diagnosing urban mobility systems. In order to cover most of travel problems categories, the scheme should be used by a multidisciplinary team. For example, psychologists and ergonomists can cover the "condition" block. Technicians and engineers can tell more about the "system" block.

To illustrate this use we refer to previous examples from (Al Maghraoui et al., 2017b). A list of eleven problems has been generated from an extended interview with the bus driver of an on-demand bus service. Two of these problems were expressed as follows:

P1: "Some road surfaces are uneven, and the shock absorbers of the bus are weak. For travelers suffering from joint problems, this is problematic"

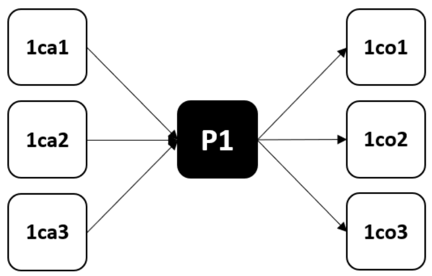
P2: "Sometimes nobody answers the booking call"

The first problem is a complex-framed problem and will be reformulated into an organized causal form. The second problem is a simple-framed problem and will be enriched into a richer causal form.

III.4.1 Reformulation of a problem

The causes and consequences of P1 that have been induced from observations and from the discussion with the bus driver, without support, are given in Table 14.

Table 14. Causes and consequences induced for problem P1

Causes of problem P1	Consequence of problem P1	Causal form of problem P1
1ca1: Weak shock absorbers **1ca2:** Bumpy/rough road **1ca3:** Fragile physical condition of senior travelers	**1co1:** Travelers getting backache **1co2:** Deterioration of the physical comfort aboard the bus **1co3:** Senior travelers abandoning the service	

The problem is expressed in a natural but complex way where it is difficult to identify a central problem and then induce its causes and consequences. What has been done in Table 14 is a decomposition of the problem with no explicit identification of what P1 is. 1ca1, 1ca2 and 1ca3 are already expressed in the problem statement. (1co1) is an assumption of "*problematic"* in P1. Only 1co2 and 1co3 have been induced as consequences of the complex composition of the problem. We then rearrange the structure of P1 into the causality scheme.

In Table 14, "P1" in the causal form, is not expressed per se, as long as it represents only the indication that there is some problem ("*this is problematic")*. Therefore, "P1" is replaced by the negative effect on comfort (1co2) as an interpretation of P1 (Figure 38). It is a passive usage change that travelers undergo because of the weal shock absorbers (1ca1) and the bumpy/rough road (1ca2) that represent accidental technical states of the system. Backache (1co1) is the physical reaction to the physical discomfort combined with 1ca3, the physical condition of travelers. Quitting the service (1co3) is an avoidance measure that travelers could take after this episode.

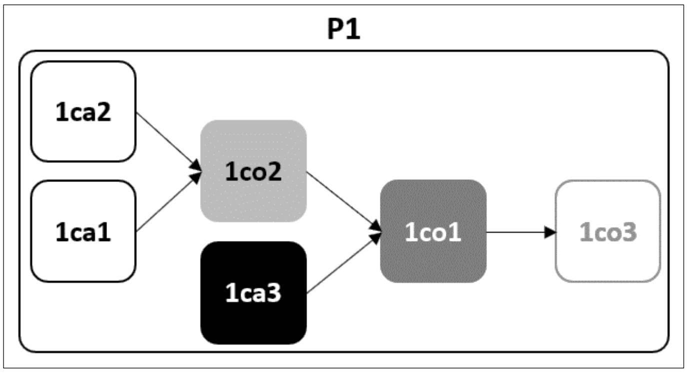


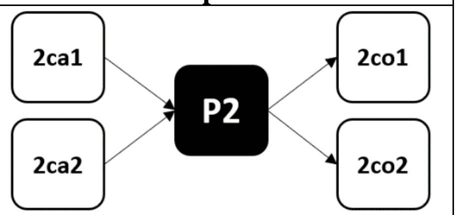
Figure 38. Reformulated causality network of problem P1

Problems like P1 are frequently encountered in interview or focus group outputs. They need, therefore, a reformulation in order to decompose their different problematic components and understand what the traveler, who expressed them in the first place, wanted to say. This helps the user of the scheme to reach the root causes that are more likely to efficiently prompt innovation. Ideally, this reformulation is to be conducted with the traveler who expressed the problem.

III.4.2 Enriching a problem

The causes and consequences of P2 that have been induced from observations and the discussion with the bus driver, without support, appear in Table 15.

Table 15. Causes and consequences induced for problem P2

Causes of problem P2	Consequence of problem P2	Causal form of problem P2
2ca1: Lack of staff in the booking line service **2ca2:** High call rate during some periods of the day	**2co1:** New users thinking the service has stopped, and giving up **2co2:** Regular travelers frustrated by the impossibility of making the trip as planned	

The problem is expressed in a simple way where there is a central problem "P2" and its causes (2ca1 & 2ca2) and consequences (2co1 & 2co2). Thanks to the structuring of P2 with the causality scheme, we can induce more problems (Figure 39).

P2 is an accidental functional state. It is caused by another accidental functional state (2ca1) and a situation involving simultaneous travelers (2ca2). As formulated, the consequences 2co1 and 2co2 are twofold. If giving up (2co1) is considered as a behavioral reaction, it has an implicit cause (2co1') which is a cognitive condition. Indeed, travelers give up because they are new users and do not know if the service is just temporarily saturated. If frustration (2co2) is considered as an emotional reaction, it has an implicit cause in the impossibility of making the trip as planned (2co2') which is a passive usage change. Indeed, travelers are frustrated because they could not make their trip as planned. 2co2' becomes then the direct consequence of P2.

The impossibility of making the trip as planned (2co2') points out a passive usage change but does not explain what changed exactly. In P2, when nobody answers the booking call, one needs to know what happens next. Does the traveler have to call again until he/she succeeds in booking a ride? The passive usage change would then be the extension of the booking duration. Does the traveler give up? The passive usage change would be the impossibility of using the service (2co2') and probably operating an active usage change by using the metro (2co21) for example. Moreover, the delay caused by this shift could also delay the activity of the traveler at the destination, beyond travel (2co23). The frustration (2co2) and the delay could lead the traveler to avoid using the service afterward (2co22). It the traveler is a punctual person (2ca3 as a physiological condition), his/her frustration is accentuated by the delay (2co23).

So on, many complex causations can be induced using only an accidental functional state to see how it impacts the travelers. The same logic could be applied in seeking deeply into the causes of the technical or functional problem where the traveler is less involved.

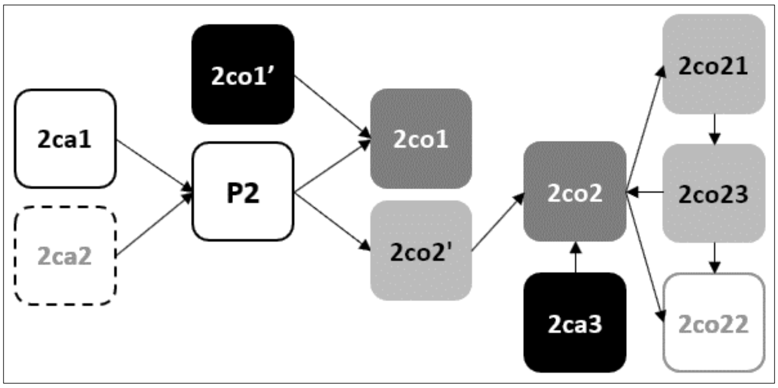


Figure 39. Reformulated and enriched causality network of problem P2

The categories of the causal scheme allowed, in these two examples, to clarify a problem that was expressed in a natural verbal way and to enrich a problem that encapsulated poor information concerning the traveler.

III.5 Discussion and conclusion

The chapter brings out the complexity of travel problems as travelers experience them in their door-to-door journey. So far, existing research have focused on travel problems for a specific traveler profile or mode of transport. However, neither archetypes of travel problems nor their possible causal relations were investigated. Indeed, in diagnosing urban mobility systems' travel problems, designers need support to complete the big picture of the traveler experience adding dimensions such as traveler condition or what happens outside of the journey time-frame. To fill this gap, we propose a travel problem taxonomy and its causality scheme that serve as a repository of travel problems archetypes.

This contribution has been made using a grounded theory methodology. It uses transcripts of 7 in-depth interviews of 1 hour each, in average, where a sample of travelers express their travel problems to end up with a taxonomy and a causality scheme of travel problems. Two use cases illustrated how basic travel problems verbatim can be enriched to bring out hidden facet of other problems they represent. The methodology of this research is purely qualitative and does not target any statistical representativeness of the sample it uses. It tried to get travel problems of different transport modes and travelers but does not exhaustively nor extendedly dig deep into all possible travel problems of all travelers and modes. Moreover, the model it proposes is exposed, by construction, to the modeler bias. Meaning that the final result of this study still needs proper validation and tests to make more robust the coding process.

Following the logic of Osterwalder et al. (2014, p.14), telling more about usage problems (pains) gives the designer more possibilities of solutions and more relevance to the user. Indeed, the complex form of a travel problem covers as many aspects of the traveler experience as possible. Therefore, if the solution is thought as a problem solver, it would cover as many dimensions as possible of the travel problems. Coming back to our second use case, solutions of the initial causes and consequences could be identified for each problem: (2ca1) possibilities to increase the size of the staff in the booking line service, (2ca2) peak-shave the demand on rush hours, (2co1) ask new users to wait few moments informing them of the call-line saturation, and (2co2) apology for the inconvenience. With the enriched version, more solutions can be considered; (2ca3) communicate the recognition of the importance of being on time, (2co21) offering regular travelers alternatives, (2co22) offering free rides to bring back the frustrated users, and (2co23) offering a discounted (or free) taxi ride to help the traveler arrive on time.

The different categories of travel problems that were identified in this study resonate in the literature in different contexts.

Most of the studies that relate travel problems, take a specific condition of travelers and identify the problems that are a direct source of this condition. For example, Musselwhite & Haddad (2008), Rosenbloom (2009) and Talbot et al. (2016) study how psychological and physical condition of seniors impacts their door-to-door mobility. Rosenbloom et al. (2004) and Wachs (2011) did the same for women, and Ullman & Schroeder (2014) and Karacaoglu et al. (2015) for disabled travelers. Harris & Tapsas (2006) and Sammer et al. (2012) investigated the travel problems as the combination of disadvantaged physical, psychological, cognitive, and modal conditions and essential/accidental states of the transportation system.

Depending on which scale one is positioned, the functional and technical state of a system changes. These works have a macroscopic vision of the concept of “state”; Sdoukopoulos et al. (2016) evaluate the performance of infrastructure and transport modes of Mediterranean countries. Olayinka (2016) studies travel characteristics in a poor country. Bocarejo S. & Oviedo H. (2012) investigate properties of a geographical area regarding accessibility. Other works have a microscopic vision of the state of an urban mobility system; Diana & Daraio (2010) consider for example headways, commercial speed, vehicle load factors or line capacities as state variables. Hüging et al. (2014) sets CO_2 emissions, noise, or maintenance costs as attributes to evaluate the state of a bus line.

What we called “beyond travel” problems are also the object of some studies. Likins (1986) studies the effect of a transportation system of the life of students in a campus. Gustafson (2014) mentions the negative effect of traveling on private and family lives. Fortney et al. (1995) study avoidance measures travelers take as a factor for low health aftercare.

Some studies consider the recursive causation between travel problems. For instance, Kim & Gallent (1998) investigate the causation between financial condition of travelers and essential functional state of bus service (e.g. crowd, delays). Punpuing & Ross (2001) map the many relations between essential functional states (e.g. traffic, road travel speed) traveler behavior (e.g. commuting time) and traveler measures (e.g. route change, mode change).

With no explicit causation, some studies have a large coverage of travel problems. Edwards & Smith (2008) and Zavitsas et al. (2010), for instance, identify at the same time, beyond travel condition (e.g. population growth), technical state planning (infrastructure flexibility), travel situations (congestion, pollution peak), travel changes (accidents), essential states (e.g. intermodal facilities) and traveler measures (modal shift).

The main challenge with using a set of travel problem archetypes is that one has to choose a direction to investigate. Indeed, the exhaustivity of problems cannot be fully obtained given the time and effort this might take to a designer. This direction will depend on one’s design intent. If it is to bring more customization of the mobility solution, then the direction would be to investigate the traveler different conditions. If it is to know how travel problems impact travelers, then the direction would be to investigate the changes, the reactions, and the measures. If the design intent is to upgrade the technical solution, then the direction would be the “system” and “situation” dimensions.

Chapter IV

Stimulating usage problem generation: An urban mobility case study

Designers improve urban mobility solutions by investigating archetypal usage problems in existing mobility systems. User-centered design methods help accomplish this task, but lack effectiveness when not supported by appropriate tools. Here we posit that the use of a traveler -centered stimulus improves the effectiveness of travel problem generation. To test this hypothesis, an experiment is conducted with two control groups as a baseline for non-stimulated problem generation and two experimental groups that are provided with a traveler -centered stimulus. The two sets of groups are composed of one group of urban mobility experts and one group of non-experts. Results show that stimulated groups generate novel ideas with a greater variety covering most of the traveler experience dimensions than non-stimulated groups.

Keywords: User centered design, user participation, design problem(s), case study, stimulation

A modified version of this chapter is under revision in "Design Studies" Journal

IV.1 Introduction

Framing problems in design practice can be a hard task if designers are not familiar with the problem they are dealing with (Dorst, 2011). This is why designers systematically take time to first accumulate and order the knowledge they need to assimilate the problem at hand (Lawson, 2005: p 34). A large domain of knowledge in most design methodologies (Tomiyama et al., 2009) concerns the users of the system to be designed and their archetypal usage patterns (Yannou et al., 2016).

The wider this knowledge, the more successful the user-centered innovation is likely to be, as the system designed will be made to meet users' wants and needs rather than manufacturer-centric goals (von Hippel, 2005). Involving users in the design process is consequently vital to any user-centered design endeavor (Abras et al., 2004).

User-centered design practice involves users in different ways and forms (Hanington, 2003). Most user-centered methods involve users in more than just usability-testing (Vredenburg et al., 2002) and also include diagnosing existing systems, where users are asked to express the problems they experience using these systems, typically in the form of interviews or focus groups (Céret et al., 2013). However, diagnosing an existing system remains a technically-centered process that *uses* the knowledge of the users as an input to improve technical solutions or solve technical problems (Gasson, 2003).

Human-centered design aims to meet users' goals and interests (Boy & Narkevicius, 2014). Designers then become facilitators, setting the design framework where users can co-create with them (Sanders & Stappers, 2008). This human-systems integration process designing social-technical systems rather than purely technical ones involves the natural design ability that all users have (Boy & Narkevicius, 2014; Norman et al., 2016; Cross, 1999). However, for this participatory design practice to be successful, appropriate tools should be used in order to catalyze user voice (Sanders, 2002). In ideation sessions, for instance, users are supported with stimuli to unlock broader exploration of different areas of their knowledge network (Santanen et al., 2004).

This chapter is a part of a research project dealing with human-centered innovation in the context of urban mobility. Urban mobility has recently gained increased attention from design communities, as it poses challenges when it comes to designing mobility systems as a simple set of products and services (Wartzack et al., 2017), and from manufacturers and transport operators as they seek to shift towards a more traveler -centered vision of urban mobility systems design (OECD, 2014).

People travel from A to B within a geographical area using multiple transportation means and services, and these systems are produced and operated by different providers (Mitchell et al., 2016), which leads to travelers experiencing multiple problems when using a combination of these systems in a door-to-door travel experience. Consequently, the process, models, knowledge, and expertise used in design need to take into account the complexity of urban mobility systems (Sussman et al., 2005).

Regarding problem identification (Morgan, 1997: p 13), focus groups bring out the global view that users have concerning a system that they use collectively, such as an urban mobility system (Grosvenor, 2000). However, transportation design research rarely considers travel problems identification as an design knowledge output (Coughlin, 2001; Kerschner & Aizenberg, 2004; Cunningham et al., 2000). Even when travelers are asked to express the problems they encounter, they are not supported to open up and tell more about their traveler experience. Without a traveler -centered stimulus, they end up expressing a handful of problems that cover a narrow range of dimensions of the traveler experience.

The research question we address in this chapter is: *What is the effect of a traveler -centered stimulus on the effectiveness travel problems generation?*

To answer this question, an experiment is conducted with four different groups: two control groups are used as a baseline for a non-stimulated focus group, and two experimental groups are provided with a model adapted from TXCM—a Traveler eXperience Conceptual Model (Al Maghraoui et al., 2017b). Working out from four main sources of problems (technical, personal, contextual, and activity-related), eleven categories are developed as archetypal perceived travel problems.

Section 2 examines the transportation research using user-centered methods to identify usage problems of urban mobility systems. It then reviews ideation effectiveness metrics to set a basis for evaluating travel problem generation. Section 3 discusses testing such a design tool in the form of an experiment. The traveler -centered design tool is then presented as the stimulus that focus group participants use for travel problem generation. The experimental setup shows how different ideation metrics are evaluated from the four focus groups. Section 4 analyses the results to uncover how each of the selected ideation effectiveness metrics is affected by the use of the traveler -centered design tool. This analysis then goes on to discuss the merits of involving users in developing design tools and how this practice can be improved for usage problem identification (sections 5 and 6).

IV.2 Background and related research

The knowledge that designers obtain from users can be acquired through the whole design process (Buur & Matthews, 2008). The ideas that designers get from users through design methods are not only about the solution but can encompass every single basic element of thought contributing to advancing design knowledge (Jonson, 2005). Good ideas need appropriate ideation components for users to produce the targeted knowledge (Hernandez et al., 2010).

Reviewing of the transportation research dealing with the identification of travel problems highlights how considering the point of view of travelers is crucial to diagnosing urban mobility systems. Reviewing selected metrics for assessing problems ideation sets a basis for evaluating travel problems as ideas.

IV.2.1 Identification of travel problems

Using user-centered methods in transport systems research helps emerge insightful problems that travelers may experience during their use of urban mobility systems.

In diagnosing public transportation systems for users with cognitive disabilities, Fischer & Sullivan Jr. (2002) involved university researchers, assistive technology specialists, transportation planners, and technology developers. Traveler input came from answers to surveys and feedback from interviews with an assistive care community group. Sammer et al. (2012) led a more in-depth analysis of the specific needs and experiences of impaired-mobility travelers. In addition to surveys, they used face-to-face interviews to collect information about trips and personal attitudes to social and transport issues with their impairments, and thus set up a typology of problems based on respondents' answers.

Katzev (2003) approached transportation problems from the perspective of urban communities. In demonstrating how car-sharing could be a good solution for environmental and social issues, he studied car-sharing and car-owning communities through the lens of their mobility behavior. The main metrics for trip behavior were miles and frequencies. No substantial qualitative material about this behavior was gathered other than the reasons people had for joining car-sharing communities. A deeper behavior analysis was conducted by Sopjani et al.(2016) who canvassed new users of an electric carpooling system for their views and thoughts on how their habits have changed. This allowed them to create user profiles including variables such as lifestyle, perceived newness, and awareness.

Splitting service quality into different attributes, the trip into different stages, and users into different profiles, Woodcock et al.(2013) and Ettema et al. (2016) led productive investigations on user satisfaction with intermodal trips. Differentiation of service quality attributes allowed them to evaluate overall satisfaction regarding each travel stage and to set each quality attribute. However, they did not elicit the problems that contribute to travelers' dissatisfaction nor the causality between different travel stages (e.g. the effect of a bus delay on satisfaction with waiting time at the next transport mode).

The same limitations remerge when designing user-oriented information for transportation systems (S Hörold et al., 2013). When the trip is modelled as a set of tasks and the information is designed on that basis, its loses fluidity through the whole journey, especially when travelers are not familiar with using the online smartphone platforms (Beul-Leusmann et al., 2013). Kremer et al. (2017) proposed a holistic view of user experience journeys in a bike-sharing system to tackle this lack of through-trip fluidity.

They consider approaches such as emotional dynamics and interaction steps, but the process of defining usage problems still keep the travel stages separate.

Read et al. (2017) used a large set of human factors methods for transport analysis and design. Interviews helped uncover the decision-making process of travelers while crossing the railway system, and user scenarios unfolded the course of the crossing episode. However, in improving the crossing experience, the study limited the problems definition to "unplanned events that critically affect objectives". Consequently, not all of the essential problems related to the traveler's physical or psychological condition or to the design of the railway system's components were considered. Moreover, even when users actively participate as stakeholders in the format of focus groups, they only serve as a means for concept idea evaluation, and are not actually involved in the problems definition.

Transportation research is increasingly using focus groups as a design method to improve transportation solutions (Coughlin, 2001;Kerschner & Aizenberg, 2004; Cunningham et al., 2000; Santana et al., 2018). The common denominator to this scholarship is their pre-defined focus on traveler problem-solving. Indeed, they set the problem first, and then ask participants questions about their experience regarding the problem at stake.

In summary, urban mobility research does not usually integrate enough contextual complexity in identifying travel problems. Moreover, most often, it considers travel problems as fragmented travel episodes, ignoring their links to other episodes. Furthermore, user-centered methods have been used in cases but as a means to answer predefined research questions that under-involve users. Given the lack of traveler experience-relevant dimensions for setting travel problems, a solution to assist travel problems ideation needs metrics to be evaluated.

IV.2.2 Effectiveness of travel problems ideation

The conclusions of an ideation experiment can diverge when the measures of quality of ideas are changed (Reinig et al., 2007). It is therefore important to carefully set the metrics that would reflect the effectiveness to be measured and the insights it brings besides quantity.

For an idea to be considered as a piece of design knowledge, it needs to accomplish its function. It should allow the designer to attain his design goal (Reich, 1995). The evaluation can concern either the ideation process or the ideation outcomes. Shah (2003) demonstrates the difficulties involved in measuring the effectiveness of cognitive ideation processes, and therefore proposes novelty, variety, quality, and quantity as basic metrics defining ideation outcome effectiveness. It is the designer's job to pick the right meaning for each metric depending on the nature of ideas to be evaluated, the design goal, and whether ideas are to be evaluated separately or in groups. One of the rare examples in the scholarship dealing with problems as ideation outcomes uses quantity, creative quality, and time spent in divergent thought on problem-finding as metrics (Basadur et al., 1982). However, in this example, the scope of problem-finding effectiveness is tailored to training for industrials in problem-solving creativity.

If ideas are design concepts, *quality* can be defined as the technical feasibility of an idea and how well it meets the design specifications (Shah et al., 2000). Dean et al. (2006) went a step further and defined workability, relevance, and specificity as sub-metrics for quality. These metrics remain relevant only for design concept generation, but in Shah's definition, the quality of an idea is a distance between the idea and some reference, regardless of the idea's nature. If the design goal is to identify usage problems, ideas should be grounded in users' real-world practice as a pragmatic piece of knowledge (Creswell, 2009).

Both *novelty* and *variety* need a basis of comparison in order to be measured (Verhaegen et al., 2013). Novelty sets the originality of an idea among other ideas or a group of ideas compared to another group of ideas (Peeters et al., 2010). Variety needs a tree-structured concept space as reference for how function is satisfied (Shah, 2003) but only works for design concept generation. Disregarding the nature of ideas, the tree structure stands for the genealogy of idea abstraction, which can be applied to every kind of idea. What is important is that there is an abstract structure of ideas. If the ideas of two groups of participants are to be compared in terms of novelty and variety, they need a concept space that is embedded in the reality of the problems. The genealogy of the problem space should reflect the diversity of usage reality and not just physical and working principles as for technical solution ideas.

Quantity is a generic metric that can be applied to any kind of ideas by counting. However, when the design tool to be evaluated uses examples, it becomes vital to consider design fixation (Jansson & Smith, 1991) in setting quantity metrics. As quantity sub-metrics for design fixation concerns, Atilola et al. (2016) set quantity of non-redundant ideas, number of repeated example features, and percentage of example features used. If travel problems are related to each other, then no redundant problem will be identified as long as each problem is a cause or consequence of a previous one. Moreover, ideation flow would be sustained by the emergence of new problems that would themselves be used in generating other ones.

The scholarship considering usage problems as ideas fails to consider the effectiveness of framing usage problems as an ideation process and problems as ideation outcomes. Therefore, to answer the research question of this chapter, an experiment is set up with metrics tailored to measure the effect of using a stimulus on the effectiveness of problem framing.

IV.3 Research method

Identifying usage problems in urban mobility systems starts with an exploratory problem identification study, for which small-sized focus groups are a suitable ideation format (Morgan, 1997, p 13; Tang & Davis, 1995). The participants must be made to interact while responding to the facilitator's questions, because urban mobility problems are mostly experienced collectively. This study is therefore a small-scale design experiment that needs to be rigorously set (Cash et al., 2012).

Based on the problem framing (as ideation) effectiveness metrics in section 1.2, this chapter evaluates a stimulus (a design tool) for emerging the travel problems (as ideation outcomes) generated in traveler focus groups. Quality of the outcomes is assumed as taken for granted, as the travelers themselves generate the ideas. In comparison with no stimulus, quantity (*H1*) and variety (*H2*) are hypothesized to improve, given the fact that the stimulus takes into account the complexity and travel stages in urban mobility. Novelty (*H3*) is assumed to be positive (Figure 40. .

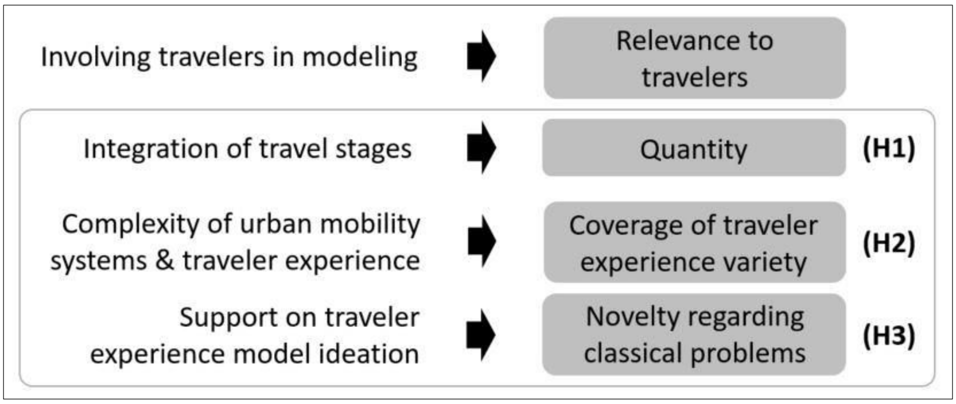


Figure 40. Expected effects of the traveler-centered stimulus on travel problem generation

First, the treatment (the stimulus) is set (Nemeth, 2004, p.299). Then, the experimental procedure, variables, data collection, and analysis are presented.

IV.3.1 Pilot test

The stimulus went through several iterations before being used in the experiment as the treatment. A conceptual model of traveler experience built upon travelers' observations, interviews, and the urban mobility literature (Al Maghraoui et al., 2017) generated a travel problems taxonomy. Subjective dimensions and travel-problem sources were identified from lead user interviews (Von Hippel, 1986) and generated a travel-problem sources network. Finally, eleven problematic sources were extracted to form the so-called "stimulus" used in the experiment (Table 1 and Appendix 5). A pilot experiment was conducted to test the format of the stimulus and define a logic for coding problems (Figure 2). The stimulus took the form of a taxonomy presented with instances for each of its categories. The taxonomy was composed of four main "sources of problems" related to state of the technical system, personal state and reactions, contextual elements, and activity-related constraints. The codes were used to label the problems generated.

This preliminary experiment consisted of two groups of three participants. Both groups were asked to identify usage problems with a major urban train line that all participants frequently use. One group was provided with the stimulus (Table 16) after 15 min of no-stimulus problem generation. The second group did the same exercise without any support. The outputs of this workshop allowed to formalize the logic with which problems were classified in the thirteen categories and subcategories for *variety* calculation. Moreover, we were able to refine some aspects of the experiment protocol using observations during the workshop, feedback from participants, and the problems generated (Table 2).

Table 16. Pilot test stimulus for potential sources of travel problems

Sources	Categories	Sub-categories	Code	Instances
Technical	Physical	Essential	TPE	Few seats in the bus, shaky railroad, no shelter at the bus stop, non-adjustable car seat, hilly city
		Accidental	TPA	Frozen and slippery ground, broken/cold seats, wagon overheated, door blocked
	Functional	Essential	TFE	20-min gap between two trains
		Accidental	TFA	Train late/cancelled, screen shows wrong information, train terminates before destination, portico out of order
Personal	State	Physical	PSP	Sick, with huge luggage, tired, in a wheelchair, pregnant, blind, deaf
		Emotional	PSE	Stressed, angry, surprised, disgusted
		Cognitive	PSC	Lost, confused, unable to read
	(Re)action		PA	Wait, find alternative, inform colleagues, get slowed down, slip/fall, hit pedestrians, sweat
Contextual	Weather		CW	Rain, cold, wind, sun, hot
	Behavior of fellow travelers or the system's agents		CUB	Smoking, not respecting the queue, brusque movement in a shared lane, drivers shouting, disagreeable agent
	Simultaneous use		CSU	Crowds, queues, no parking places left, congestion, cycling with pedestrians
Activity-related	Condition		AC	Arrival time obligations (meeting), need to arrive in good condition, no parking spaces, no showers
	Effect		AE	Arrive late, miss flight, stressed at work, delay/cancel tasks

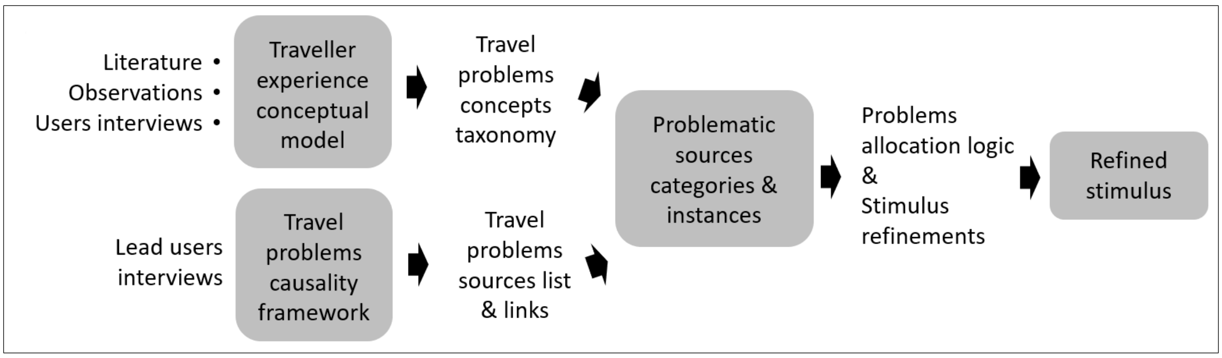


Figure 41. Stimulus construction phases

Table 17. Refinements of the experimental protocol learned from the pilot experiment

Pilot experiment issue	Proposed modification
The limit between *accidental* and *essential* problems is not clear	Define accidental problems as problems that are not connected to the design of the system
The group with stimulus has less time because of the explanation phase	Propose a coffee break for the two other groups with a discussion topic far divorced from the transport problems
Several problem categories were not or only poorly covered by both groups	Highlight these categories as consequences or causes of the problems from other categories
Abstract categories confuse participants	Remove the taxonomy and leave only a list of eleven categories (some were merged)
Scholarly vocabulary confuses participants	Use regular language for labelling categories
Examples alter the preciseness and originality of the generated problems	Explain the categories textually and give examples that are not related to the system to be diagnosed verbally
Written examples given to participants with the stimulus caused fixation	Replace written examples with a simple description and give verbal examples
Both groups failed to identify *emotion, body, mind, do,* and *arrival* problems	Emphasize them as consequences of the commonly-identified categories
Participants with stimulus did not use the connections between categories	Replace the connections by an arrow that goes from categories commonly identified to the non-identified ones
Participants with stimulus continued generating problems until the end of the session whereas the other groups stop earlier	Use the evolution of problem generation as a dependent variable to evaluate impact of the stimulus on ideation dynamics (as in Tyl et al. (2014)
Participants said more than they wrote	Give the instruction: if someone wants to speak, they need to write down his/her idea as a problem
Some problems had a complex formulation that places them in more than one category	Set the problems labelling logic

The final stimulus consists of eleven categories of travel problems. They are presented to participants as potential archetypal sources of travel problems to stimulate their memory of using the urban mobility system under study. Each category is explained by a name and a description (Appendix 6). Category blocks are presented as two sets. 'Design', 'operation', 'system problem', 'operation problem', 'weather', and 'people' represent the "objective" categories recognized by the pilot experiment participants from both groups, while 'do', 'body', 'mind', 'emotion', and 'arrival' represent the "subjective" categories where no problem was identified by either group (Table 3). There is a causality that operates between the two sets, which participants are invited to think through.

Because some problems were formulated in a complex way, they fit into more than one category. For example, "Last week we waited inside the train for more than 30 min" is labelled both "Do" and "Op problem" as the participants expressed what they did in the train that had an operational problem.

Other kinds of problem labels were not clearly identifiable, especially operation problems. For example, "the headways are not well planned. Sometimes two trains arrive within 4min when other times there a 20 min gap is, even at the same point of the day" is an operational problem insofar as it talks about a train that is behind or ahead of its schedule. On the other hand, it is an observation of a fault in the global train line system's operations. As the problem is formulated explicitly as "not well planned" and the delay issue is labelled both "operation" and "Op problem", there is no room for interpretation on labelling. If a problem is not explicitly formulated, it is not labelled.

Less identifiable labels are found in problems formulated with the word "problem" without further explanation. For example, "problems with suspicious luggage" can be classified in almost all the categories. Indeed, it depends the meaning projected for the word "problem": if we are talking about the fear felt by a traveler when he or she sees unattended luggage, it would be labelled "emotion", whereas if we are talking about the delays it causes in train-line schedules, it would be labelled "op problem". To prevent generating this kind of problem, participants are told not to use the word "problem" or any other generic word that could be given any kind of meaning in the scope of travel problems identification.

Table 18. Traveler experience stimulus: traveler -centered sources of travel problems

Category		Source of problems
Objective	**Design**	For me, the system is not well designed
	Operation	For me, the system is not well operated
	System problem	Problems occur accidentally with the system
	Operation problem	Problems occur accidentally with the system's operation
	Weather	The weather can cause me problems with my trip
	People	- The behaviour of the people around me can be a problem for me - Problems emerge when many people use the system at the same time
Subjective	**Do**	- When there is a problem with my trip, I react or do something about it - What I do with my trip can cause me problems with it
	Body	- My body feels troubled when there is a problem with my trip - I can be physically challenged in my trip
	Mind	- My mind feels troubled when there is a problem with my trip - My mind can prove a source of the problem for my trip
	Emotion	- My emotions feel troubled when there is a problem with my trip - My emotions can prove a source of the problem for my trip
	Arrival	- What I do when I arrive is affected by problems with my trip - My destination facilities & activities I do can cause problems in my trip

Adverbs of time concerning the system's design or operation, such as "sometimes", "always", or "often", systematically label the problem as "system problem" or "operation problem".

IV.3.2 Experiment design

The aim of this study is to test a stimulus that reflects the objective and subjective sources of traveler - perspective travel problems, and that has an observable impact in terms of effectiveness of travel problems generation (as ideation outputs). The stimulus is hypothesized as the *treatment* that would increase the *quantity,* the *variety*, and the *novelty* of travel problems due to the fact that it considers the traveler's perspective when built into the ensuing model.

IV.3.2.1 Experimental procedure

The experiment consists of four teams, each made up of three participants. It takes place in two phases (15 and 30 min) following an introductory brief (Figure 3). All the teams are given the same initial input:

- A verbal brief setting the boundaries of the system to be evaluated.
- A verbal brief on how problems should be written down.

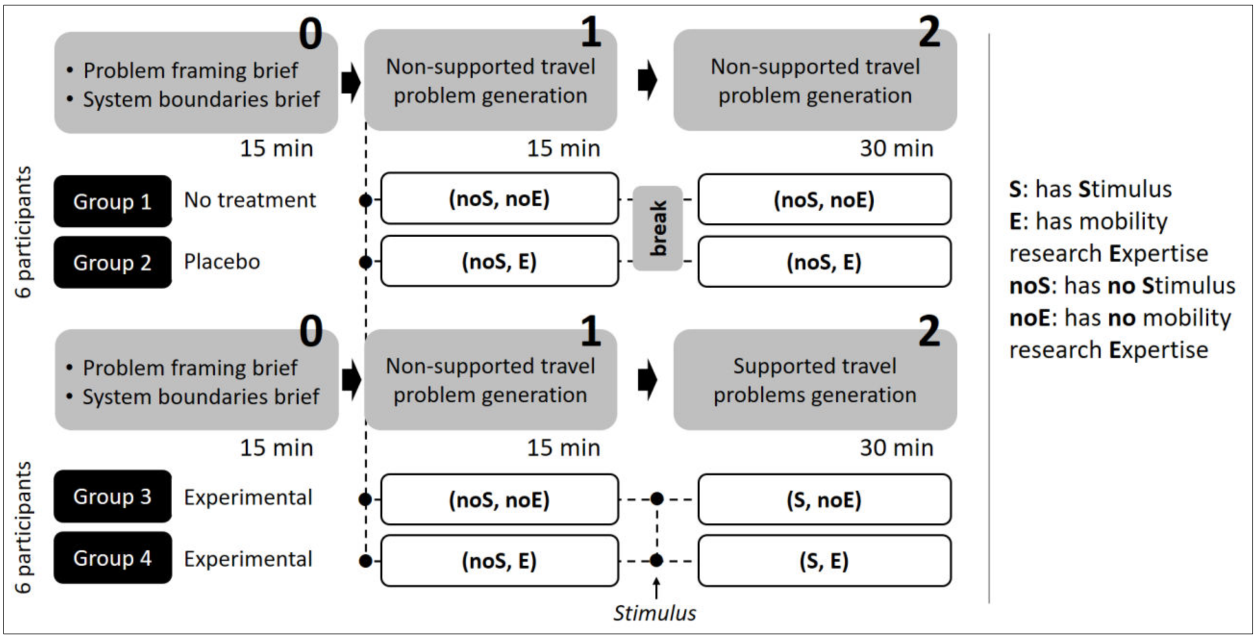


Figure 42. Experimental procedure

The brief is presented by a researcher who acts as facilitator and timekeeper (Figure 4). Each group has one participant who is responsible for recording the problems generated by his/her group as well as participating in the problem generation exercise.

The system of study is a rapid transit bus line connecting a public transport hub to a business area where all the participants commute to work every day. They all take the same route from the hub to their work location. The boundaries are made clear to the participants, and include their transition from the hub to the bus station, and through to their arrival at the office.

Figure 43. Setting of the experiment

The brief states how problems should be framed to facilitate allocations to categories for data analysis. The sole restriction was to avoid using generic words such as "problem" or "issue". The intent is to get as many details as possible on participants' experience with using the system of study. However, participants are not given written examples, as a measure to avoid fixation on how the example is framed and what dimension of the traveler experience it concerns. They are only given a few verbal examples unrelated to the system of study, and only if asked for. Moreover, to allow a record of all the problems discussed, participants are asked to write down what they want to say before voicing their points.

Questions are only allowed in the beginning, and not during the course of the activity, to avoid possible between-group variation in assimilation of the brief.

All groups use the same material. Each group is given the same set of pens and post-its, a table, and a computer open on an Excel spreadsheet that records a time label.

When Group 1 (G1, no treatment) and Group 2 (G2, placebo) are invited to have a coffee break and a discussion outside of the experiment scope, the two experimental groups are given additional input 15 minutes after the beginning of the problems generation session, i.e.:

- A verbal brief on how to use the stimulus.
- Two sheets of paper containing Table 3 and Figure 3.

During both experimental phases, a second researcher observed the synchronicity between what participants said and what they recorded. The objective was to ensure that most of the problems were reported.

IV.3.2.2 Independent variables

The focus of the experiment is set on the stimulus and its effect on travel problem framing outputs. Therefore, the main independent variable is use of the stimulus. However, as “urban mobility research expertise" is assumed to co-contribute to the effectiveness of travel problem framing outputs, we also set a placebo baseline (Adair et al., 1990). One example of expertise is agent-based transport simulation. The knowledge covered by this expertise is very likely to increase expert participants’ consideration of varied travel problems objective problem categories.

Therefore, two variables to observe the experiment’s output variations are:

- The use of the (task-related) stimulus: S and noS
- The urban mobility expertise of the (subject-related) participants: E and noE

IV.3.2.3 Groups

Twelve participants with a mean age of 29 years (7male, 5 female) were volunteers selected from the research institute the authors work in. All of them are working with both academic and industrial structures. They were personally invited two weeks before the workshop was held, and were all familiar with problems concerning this bus line and route.

Considering the independent variables (S, noS) and (E, noE), we used four focus groups composed of participants (Table 19) where the task was problem identification (Morgan, 1997, p.13). Moreover, the usage of public transportation systems needs to be discussed collectively in order to emerge problems that are commonly experienced by users (Grosvenor, 2000).

Groups 1 and 2 are control groups for *Stimulus* as a treatment (Solomon, 1949). Groups 1 and 3 are control groups for *urban mobility Expertise* as a placebo treatment (Adair et al., 1990).

Group sizes range between three and five participants per group, with no significant variability on the idea generation outputs (Baltes et al., 2002). Therefore, as it was hard to get users of the same system traveling the same route every morning and working at the same place all together on the experiment day, the minimal focus group size was adopted.

Table 19. Composition of the four focus groups related to dependent variables

Participants	have **no** urban mobility **E**xpertise	have urban mobility **E**xpertise	
use **no****S**timulus	**G1:** noS, noE	**G2:** noS, E	**noS=G1+G2**
use **S**timulus	**G3:** S, noE	**G4:** S, E	**S=G3+G4**
	noE=G1+G3	**E= G2+G4**	

For analysis of the results, travel problems generated by G1 and G2 are aggregated into the noS group, G3 and G4 into the S group, G1 and G3 into the noE group, and G2 and G4 into the E group.

IV.3.2.4 Controlled variables

Controlled variables are variables that are assumed to influence the experiment outputs but are outside the scope of this research. We elected to neutralize their effect (Nemeth, 2004, P.300). This experiment was exposed to two kinds of controlled variables: variables related to participants as subjects and as users of the system of study, and variables related to problem framing (task-related) (Table 20).

Table 20. Summary of the experimental setup

Dimensions	**Experiment values**	
Hypotheses	• *The use of the stimulus increases quantity of travel problems (H1)* • *The use of the stimulus increases variety of travel problems (H2)* • *The use of the stimulus increases novelty of travel problems (H3)*	
Variables	**Independent**	**Dependent**
	noS: has no Stimulus *S*: has Stimulus *E*: has mobility research Expertise (placebo) *noE*: has no mobility research Expertise	Q_1: Quantity of travel problems– 1^{st} phase Q_2: Quantity of travel problems– 2^{nd} phase Q_3: Rate of growth in travel problems V_1: Coverage of travel problem categories– 1^{st} phase V_2: Coverage of travel problem categories– 2^{nd} phase V_3: Growth in variety of travel problems N_1: Novelty –1^{st} phase N_2: Novelty –2^{nd} phase N_3: Novelty growth
	Controlled	
	Participants - Design-discipline background -> no participant has this kind of profile - Trip route -> all participants do the same origin-destination trip using the same bus *Task* - The material used -> pens, post-its and a PC for all groups - Initial instruction -> same for all groups - Some ideas are discussed and not recorded -> Anyone who wants to speak needs to write the idea down first - Interaction with the facilitator influences assimilation of the initial brief -> Questions are only asked at the beginning of the session - Example fixation -> Give examples verbally, not on the stimulus sheet (for experimental groups), and only examples that are unrelated to the system under study	
Case study	A rapid transit bus line (91.06C) connecting a public transport hub to a business area	
Data	Collection	- Problems with timed recordings (in excel spreadsheets) - Observing participants behavior
	Coding	- Coding the collected problems (allocation to categories)
	Timed counting	- Counting the problems through time
	Analysis	- Comparison of quantity, novelty, and variety of problems generated between groups and sets of groups - Qualitative assessment of the experiment

The stimulus is partly based on user experience (UX) literature, so if some of the participants have a background in design disciplines, then they may generate travel problems with more variety than a regular participant. This case is prevented by only choosing participants with no background in design.

Travel problems vary depending on the interval [origin, destination] travelled by a bus line user and the time he/she picks the bus, and typically involve traffic variation and in-station passenger flows. To control this variable, all participants do the same origin-destination route using the same bus-line at the same times in a day as in regular use.

The material that is used to support travel problem generation, apart from a stimulus, could influence ideation effectiveness. All groups are therefore given the same material: pens, post-its, and a PC. The ideation instructions are also the same. All groups are given the same instructions at the same time for the first ideation phase. Groups 3 and 4 are also given the same instructions for the second phase.

Observation in the pilot experiment found that participants verbalize some ideas that they forget to record. To control this variable, participants were instructed to write down every idea that comes into their mind before sharing it with the group. This is a strategy to reduce the gap between spoken and written ideas.

Moreover, any interaction with the session facilitator could influence how a participant assimilates the first collective instruction that should be communicated the same way to all participants. To avoid this, participants were instructed to ask their questions before the ideation phase, so that every participant can benefit from the facilitator's answer.

Finally, for all groups, and S groups in particular, example fixation was controlled by providing all participants with verbal examples that are not directly related to the system under study.

IV.3.2.5 Dependent variables

To test the three parts of the experiment's hypothesis, dependent variables were selected for each part, as follows.

The use of the stimulus increases the quantity of travel problems (H1).

- Quantity of travel problems in the 1st phase (Q_1): the number of problems generated in the first phase of the experiment.
- Quantity of travel problems in the 2nd phase (Q_2): the number of problems generated in the second phase of the experiment. All ideas are counted as recorded on the excel tables.
- Rate of growth in quantity of travel problems (Q_3): $\frac{Q_2 - 2Q_1}{2Q_1}$, the growth ratio of travel problems between the two experiment phases (knowing that the second phase lasts twice as long as the first phase).

The use of the stimulus increases the variety of travel problems (H2).

Allocation to problem categories was performed by two independent researchers with a high enough inter-research Pearson's correlation rate (r=0.82) to fulfil the experiment conditions (Clark-Carter, 1997). Each problem was assigned from one to four labels out of the eleven pre-defined categories. Final category allocations were approved by the two researchers (Appendix 7).

- Coverage of travel problem categories in the 1st phase (V_1): percent coverage of travel problems among the predefined categories in the first phase of the experiment.
- Coverage of travel problem categories in the n the 2nd phase (V_2): percent coverage of travel problems among the predefined categories in the second phase of the experiment.
- Growth in travel problem variety (V_3): $V_2 - V_1$,: the growth in variety of travel problems between the two phases of the experiment.

The use of the stimulus increases the novelty of travel problems (H3).

Novelty only applies in categories that contain at least one problem for the group that it concerns. Novelty N_{ijk}in phase i of the experiment, in group j, proportionally to the total number of problems dispatched through the eleven categories (T_{ij}), is equal to *1* if the problem is unique to its category *k* (Equation 1(a)), equal to *0* if the problem is repeated four times or more in its category *k* (Equation 1(b)). Otherwise it is calculated as in Equation 1(c) (inspired from (Peeters et al., 2010) and (Linsey et al., 2011));

$$N_{ijk} = \begin{cases} (a) & 1 \quad , \quad n_{ijk} \leq \frac{T_{ij}}{11} \\ (b) & 0 \quad , \quad n_{ijk} \geq \frac{4T_{ij}}{11} \\ (c) & 2 \times \left(0.5 - \left(\frac{1}{10} \times \frac{n_{ijk} - \frac{T_{ij}}{11}}{\frac{T_{ij}}{11}}\right)\right), \quad \frac{T_{ij}}{11} < n_{ijk} < \frac{4T_{ij}}{11} \end{cases} ; \forall i \in \{1,2\}; \forall j \in [1,4]; \forall k \in [1,11] \quad (1)$$

n_{ijk} is the number of problems in phase i, in group j, per category k. T_{ij} is the total number of problems generated in phase i, by group j, through all eleven categories.

For example, $N_{248} = 1$ in phase *2*, in Group *4*, for the eighth category “body”. Indeed, $n_{248} = 1$, which is less than ($\frac{26}{11}$) as maximal value to score a novelty of *1*.

In phase *2*, in Group *1*, for the fourth category “operation”, $N_{214} = 2 \times \left(0.5 - \left(\frac{1}{10} \times \frac{8 - \frac{26}{11}}{\frac{26}{11}}\right)\right) = 0.523$

- Novelty in the 1st phase (N_1)
- Novelty in the 2nd phase (N_2)
- Novelty growth (N_3): $N_2 - N_1$, the growth in novelty of travel problems between the two phases of the experiment.

IV.4 Results

The results of the experiment consider the sum of the two experimental groups (G3 and G4) as a single experimental group (S group). The sum of the placebo group (G2) and the no treatment group (G1) is analyzed to gauge the influence of mobility expertise on the results (NoS group).

First, quantity is examined by counting the problems generated between groups and over the two phases of the experiment. Then, variety is studied for each group, calculating the coverage of problems in each of the pre-defined categories. Finally, novelty is calculated for each group.

IV.4.1 Effect on the quantity of travel problems

Table 21 presents the number of travel problems generated throughout the experiment (with 5-min intervals), and between phase 1 and phase 2 of the experiment for the four groups and per set of two groups. The groups together scored a total of 111 problems during the 50 minutes of the experiment.

The stimulus is designed to help participants dig deeper into their memory to generate more problems than the situations they would spontaneously remember. Therefore, it was hypothesized that the quantity of problems generated would be more for the S groups compared to noS group and would increase from the first phase to the second phase. However, there was no increase in quantity of travel problems from phase 1 to phase 2 nor from noS to S in phase 2. Indeed, the noS groups together generated 10 more problems than the S groups together, and scored better on quantity growth rate: -5% for NoS compared to -25% for S.

During the initial phase, S and noS groups generated a comparable amount of travel problems (resp. 20 and 21), while E and noE scored a relatively different amount of problems (resp. 18 and 23). This difference was created between G1 and G2 (resp. 13 and 8). Indeed, G2 was late at typing down the problems generated and spent most of the first phase discussing and taking notes on post-its.

Three out of four groups experienced a decrease in problem quantity, which would be explained by cognitive inertia in ideation (Briggs & Reinig, 2010). However, G2 showed a different growth rate compared to the other groups. Indeed, at the beginning of the second experiment phase, the group voiced its ambition to score the highest among all the groups, which was noticeable in the 25–40 min interval of the experiment. So, if we exclude the atypical group (G2) from E-group analysis, it could be said that the non-expert group G3 profited more from the stimulus by generating two more problems than the expert group G4 (resp. 16 and 14).

Table 21. Travel problem quantities as recorded

Time-frame (min)	G1	G2	G3	G4
0–5	3	0	2	2
5–10	5	2	4	4
10–15	5	6	4	4
Break				
20–25	1	0	1	1
25–30	1	5	3	4
30–35	5	6	2	3
35–40	3	6	4	2
40–45	4	3	2	2
45–50	2	4	4	2
Quantity / phase	**G1**	**G2**	**G3**	**G4**
1st phase (Q_1)	13	8	10	10
2nd phase(Q_2)	16	24	16	14
Growth rate (Q_3)	-38%	50%	-20%	-30%
Quantity / phase	**noS**		**S**	
1st phase(Q_1)	21		20	
2nd phase (Q_2)	40		30	
Growth rate (Q_3)	-5%		-25%	
Quantity / phase	**noE**		**E**	
1st phase (Q_1)	23		18	
2nd phase(Q_2)	32		38	
Growth rate (Q_3)	-30%		6%	

All participants were asked to generate as many problems as they could with as much detail as possible. Variety and novelty were chosen to assess this second aspect of the problems generated.

IV.4.2 Effect on the variety of travel problems

Table 23 presents the distribution of the generated travel problems through the eleven predefined categories, per group (1,2,3, and 4) and per set of groups (noS, S, E, and noE). The Kruskal and Wallis test on phase 1 confirmed that G1, G2, G3, and G4 showed identical distributions in terms of coverage of travel problem categories ($\chi^2_{.95}$=7.815, p=.559). Table 7 highlights representative examples of travel problems within each of the predefined categories.

The stimulus is designed to help participants uncover new aspects of their urban mobility experience. This includes their introspective experience and what happens with their activities before departure and after arrival. It was therefore hypothesized that the variety of problems generated would be more for group S compared to noS and would increase from the first phase to the second one. Variety was found to decrease for group S in the second phase (from 100% to 91%). This was due to problems generated by G3, in the first phase, that were rather expected in the second phase. However, taken separately, variety increased for G4 while decreasing for G3 (resp. +10% and -18%). Indeed, all the categories that were not covered in the first phase for both groups were covered in the second phase (emotion, arrival, and weather for G4; body for G3). Conversely, other categories were not covered in the second phase (system problem for G4; weather, arrival and system problem for G3). In the second phase, novelty was higher in group S than in group noS (resp. 91% and 82%).

Similarly to quantity, expert groups scored more variety than non-expert groups (+18% for E and -9% for noE), as both expert groups scored 100% novelty in the first phase.

Table 24 presents the distribution of the problems generated through the two sets of the eleven pre-defined categories. Group S clearly focused more on the Objective set of categories in the second phase than group noS did (46% for S and 15% for noS). On the other hand, this set of categories increased more for group S than group noS (resp. +17% and +6%). Moreover, the non-expert group (G3) used the stimulus more than the expert group (G4) (resp. +34% and -3%). For instance, Figure 5 shows the difference in evolution of travel problems in objective and subjective sets of categories for G1 and G3.

The categories that were not covered by the noS groups through the two phases together (i.e. scoring a total of three or less) were body, mind, emotion, and arrival. The only different category was "do" where G2 scored 6 problems at the second phase, as seen in the second-phase subjective categories score (22% compared to 4% for G1).

Table 22. Examples of travel problems in the eleven pre-defined categories

Category	Example from groups	Gr
Design	Signage problem: lack of visibility	**G1**
Operation	Low frequency after 19:00h	**G2**
Sys problem	Sometimes the display is blank	**G2**
Op problem	Buses cancelled at the end of the day without warning	**G1**
People	Many people waiting for the bus -> full bus	**G4**
Weather	Bus windows are not tinted, which amplifies the effect of the heat from the sun	**G2**
Do	Often people run from the train station to catch the bus, or from the bus to the train station, and that may cause panic for some users	**G2**
Body	Body aches and dizziness from fatigue or having to stand on the way	**G3**
Mind	The logic of opening the doors is not clear (the back doors are not always open)	**G3**
Emotion	When the bus is full, attitudes of a few people can be disturbing (sometimes people do not even say sorry when they push you ...)	**G3**
Arrival	If we have a lot of stuff, then the bus is not at all a good choice (bringing my lunch to work)	**G4**

Table 23. Variety in travel problems generated

Phase 1	G1	G2	G3	G4	noS	S	noE	E	All
People	5	3	3	2	8	5	8	5	13
Weather	1	0	1	0	1	1	2	0	2
Design	4	1	3	2	5	5	7	3	10
Operation	5	5	1	3	10	4	6	8	14
Sys problem	1	0	1	2	1	3	2	2	4
Op problem	2	2	6	1	4	7	8	3	11
Do	0	0	1	2	0	3	1	2	3
Body	2	0	0	1	2	1	2	1	3
Mind	0	0	1	3	0	4	1	3	4
Emotion	0	1	1	0	1	1	1	1	2
Arrival	0	0	1	0	0	1	1	0	1
Total	20	12	19	16	32	35	39	28	67
Variety (V_1)	64%	45%	91%	73%	73%	100%	100%	82%	100%
Phase 2	**G1**	**G2**	**G3**	**G4**	**noS**	**S**	**noE**	**E**	**All**
People	4	4	4	4	8	8	8	8	16
Weather	2	5	0	2	7	2	2	7	9
Design	4	9	4	5	13	9	8	14	22
Operation	8	6	3	3	14	6	11	9	20
Sys problem	1	3	0	0	4	0	1	3	4
Op problem	6	5	4	3	11	7	10	8	18
Do	0	6	5	3	6	8	5	9	14
Body	0	1	3	1	1	4	3	2	5

Mind	1	2	4	1	3	5	5	3	8
Emotion	0	0	6	2	0	8	6	2	8
Arrival	0	0	0	2	0	2	0	2	2
Total	26	41	33	26	67	59	59	67	126
Variety (V_2)	64%	82%	73%	91%	82%	91%	91%	100%	100%
V growth (V_3)	0%	+36%	-18%	+10%	+9%	-9%	-9%	+18%	na

Table 24. Category coverage of travel problems generated

Phase 1	G1	G2	G3	G4	noS	S	noE	E
Objective	90%	92%	79%	62%	91%	71%	85%	75%
Subjective	10%	8%	21%	38%	9%	29%	15%	25%
Phase 2	**G1**	**G2**	**G3**	**G4**	**noS**	**S**	**noE**	**E**
Objective set	96%	78%	45%	65%	85%	54%	68%	73%
Subjective set	4%	22%	55%	35%	15%	46%	32%	27%
Subjective set growth	-6%	+14%	+34%	-3%	+6%	+17%	+17%	+2%

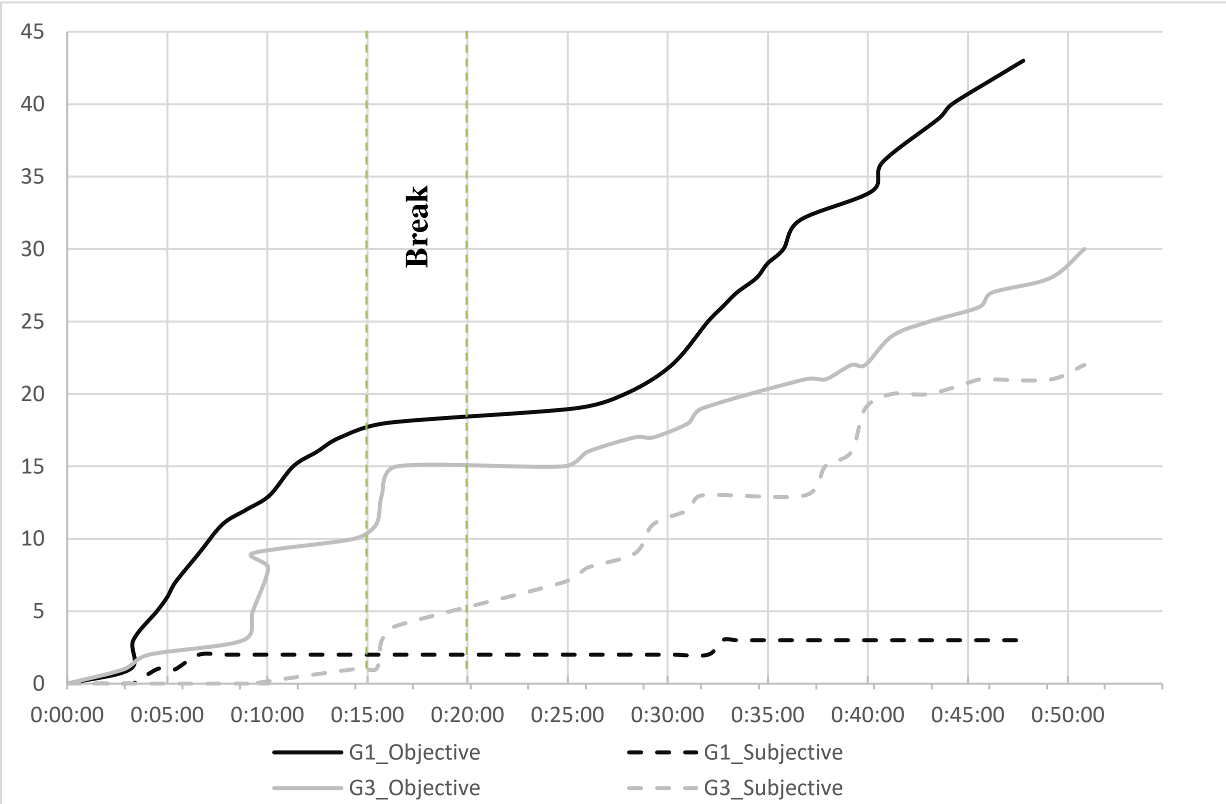


Figure 44. Comparison of the evolution of travel problems in the different sets for G1 & G3

IV.4.3 Effect on the novelty of travel problems

Table 25 presents the novelty of travel problems in each of the pre-defined categories, per group (1,2,3, and 4) and per set of groups (noS, S, E, and noE).

The model underlying the stimulus assumes that each of the traveler experience aspects (translated into travel problem categories) are important for describing a traveler experience problem. This is why it was hypothesized that the stimulus would increase travel problem category novelty by showing participants new aspects of their traveler experience. Indeed, average novelty in the second phase was higher in teh S group than the noS group (resp. 94.8% and 91.8%). However, average novelty remained constant for the S group yet increased by 5% in the noS group. Once again, this was related to G2 that scored an increase of 17%, which is higher than all the other groups together, although it had the lowest novelty score in the first phase (75.3%). Group E and noE scored very similar on average novelty (resp. 94.5% and 94%) and growth in average novelty (resp. +2.6% and +1.6%).

The lowest novelty scores—scoring under 75%—, as highlighted in grey, were found mainly in the objective set of categories in both the first and the second phases of the experiment. Moreover, in the second phase, only G1 and G2 (noS groups) scored low on novelty. Group E scored low on novelty in the design category and group noS score low on novelty in the operation category. Figure 6 shows how the problems are distributed through the eleven pre-defined categories comparing S to noS groups (SD(S)=3.01, SD(noS)=5.03).

Table 25. Travel problem categories novelty per group

Phase 1	G1 (%)	G2 (%)	G3 (%)	G4 (%)	noS (%)	S (%)	noE (%)	E (%)
People	65	65	85.3	92.5	65	88.6	74.9	80.7
Weather	100	na	100	na	100	100	100	na
Design	76	100	85.3	92.5	85.6	88.6	80.5	96.4
Operation	65	28.3	100	78.8	51.3	94.9	86.2	57.1
Sys problem	100	na	100	92.5	100	100	100	100
Op problem	98	83.3	50.5	100	92.5	76.0	74.9	96.4
Do	na	na	100	92.5	na	100	100	100
Body	98	na	na	100	100	100	100	100
Mind	na	na	100	78.8	na	94.9	100	96.4
Emotion	na	100	100	na	100	100	100	100
Arrival	na	na	100	na	na	100	100	na
Novelty (N_1)	86	75.3	92.1	90.9	86.8	94.8	92.4	91.9
Phase 2	**G1 (%)**	**G2 (%)**	**G3 (%)**	**G4 (%)**	**noS (%)**	**S (%)**	**noE (%)**	**E (%)**
People	86.2	98.5	93.3	86.2	93.7	90.2	90.2	93.7
Weather	100	93.2	na	100	97	100	100	97
Design	86.2	71.7	93.3	77.7	77.3	86.4	90.2	74
Operation	52.3	87.8	100	94.6	74	97.6	79	90.4
Sys problem	100	100	na	na	100	na	100	100
Op problem	69.2	93.2	93.3	94.6	83.9	93.9	82.7	93.7
Do	na	87.8	86.7	94.6	100	90.2	100	90.4
Body	na	100	100	100	100	100	100	100
Mind	100	100	93.3	100	100	100	100	100
Emotion	na	na	80	100	na	90.2	97.6	100
Arrival	na	na	na	100	na	100	na	100
Novelty (N_2)	84.8	92.5	92.5	94.8	91.8	94.8	94	94.5
N growth (N_3)	-1.2	+17.1	-0.4	+3.8	+5	0	+1.6	+2.6

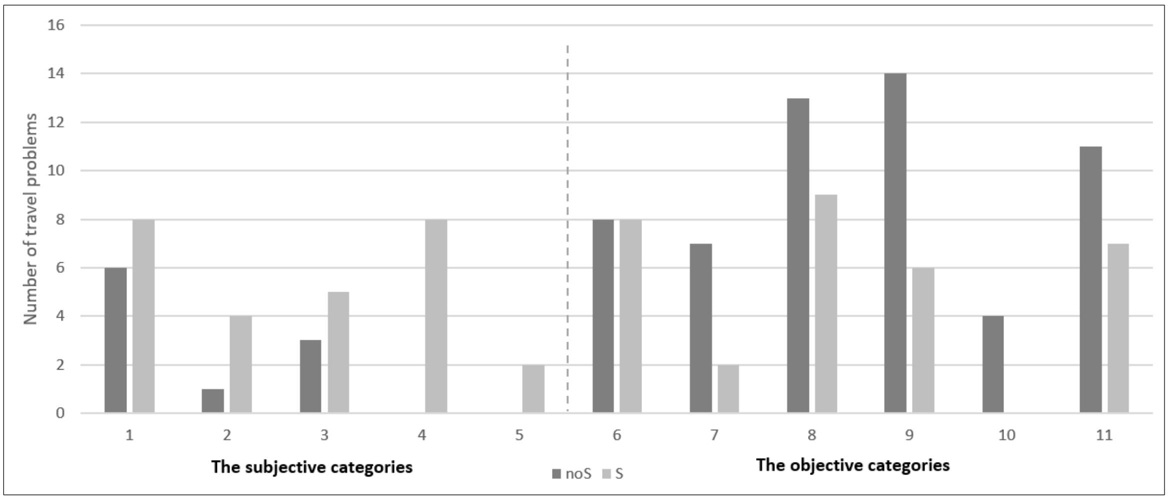


Figure 45. Travel problems distribution through the eleven pre-defined categories

IV.4.4 Qualitative insights

Both the researcher who observed the groups during the experiment and the facilitator reported some insightful comments.

The first uncontrolled variable that influenced the course of the experiment was a technical problem that G4 and G1 experienced using the excel spreadsheet. Indeed, the time recording cells displayed the same time in some of the recorded problems in the first phase of the experiment. This momentarily interrupted the groups concerned, but the issue was quickly fixed. The problems that were not recorded at their genuine time have been distributed uniformly through the appropriate period of experiment time. G3 modified its fifth problem, which altered the G3 timeline but was fixed by roughly re-establishing the initial timeline.

The second important uncontrolled variable that influenced the experiment's outputs is a difference between the written reporting and the verbal expression of problems by participants. In the controlled variables, the fact that participants tend to say more than what they write was controlled. However, the difference between how they formulate the problems verbally and how they type them in the excel table was not controlled. Indeed, the category allocation depends solely on what is written down, and is neutralized—as far as practicable—from any interpretation. Therefore, if a participant verbally expresses a problem by talking in the first-person form, the problem would probably include a Cat2-categories label. For example, in G3, one of the comments was "I almost fell to the ground". This was reported as "catastrophic driving", which would add a "do" label to the problem if written down. Moreover, the control assumed over spoken vs. written problems was not enough. Indeed, it was noted that some participants talk about a problem that is more of a personal perception, but do not type it down, showing a kind of auto-censorship. For instance, "I don't see fire extinguishers when I get into the bus" was recorded by the observer-researcher but could not be found in the excel tables. Making an audio recording of the complete workshop for each group would help avoid missing any of these unrecorded problems. However, it would also require identifying, from group conversations, what is considered a problem and what is not, whereas this is precisely the role of participants in the workshop.

G2 was observed to not be recording problems on the PC but rather on post-its. This explains the low number of problems in the first ten minutes (2 compared to 6 and 8 for other groups). Moreover, the times that are displayed in the time recording cells are different from the actual point in time the problems were verbally expressed by participants. Indeed, the delay includes the time for expression, the formulation proposed to the person responsible for typing it, and the time for typing it (that sometimes took more than a minute).

We observed a degree of snowballing between series of generated problems. This was sometimes expressed verbally by participants (e.g. "this joins that problem"). For instance, four of the first seven problems from G1 were related to crowding. The problems are expressed in general terms in the beginning and then expanded into other aspects of the traveler experience.

The competitive spirit of participants varied from one group to the other and was observed strongly in G2 which was the only group that kept asking how much time they had left. G4 was observed discussing a lot without recording, which affected their quantity score (G4 posted the lowest).

By the end of the second phase of the experiment, more silent moments were observed in all the groups.

IV.5 Discussion

The hypotheses of the experiment are evaluated against the different dependent and independent variables. The value of the stimulus is discussed for different stakeholders who are involved in its usage in the urban mobility systems design process.

IV.5.1 Evaluation of the hypotheses

Table 26 presents a roll-up of the dependent and independent variables that served to evaluate the experiment's hypotheses. Q_1, V_1, and N_1 are used to calculate Q_3, V_3, and N_3., respectively.

Table 26. Roll-up of values for the hypotheses variables from the mobility expertise perspective

Variables		noE		E	
		noS	S	noS	S
Quantity (H1)	Q_2	29	26	32	24
	Q_3	-38%	-20%	50%	-30%
Variety (H2)	V_2	64%	73%	82%	91%
	V_3	0%	-18%	36%	10%
Novelty (H3)	N_2	84.8%	92.5%	92.5%	94.8%
	N_3	-1.2%	-0.4%	17.1%	3.8%

When no urban mobility expert is involved (noE groups), invalidation is found in V_3 where the S group unexpectedly scored a high variety score in the first phase of the experiment. Validation is only found in V_2 and N_2. Q_2, Q_3, and N_3 are discussable. In Q_2, the difference between noS and S is only 3 problems, which represents a difference of 5.4% (29 (noE, noS) +26 (noE, S)). Moreover, the stimulus appeared to mitigate the deceleration in quantity for group S (Q_3: -20% for S compared to -38% for noS). Finally, there was no difference in decrease in novelty between the S and noS groups (N_3: -0.4% for S compared to -1.2% for noS). Nevertheless, novelty still decreased even with the stimulus, which invalidates the hypothesis on N_3 in H3. This means that providing a stimulus to non-expert travelers enhances their travel problems generation effectiveness in terms of variety and novelty but not necessarily quantity.

On the other hand, in E groups, the atypical results of G2 (noS, E) invalidated H1 on both Q_2 and Q_3. Group E scored 8 more problems than group S (14.3% of (32+24)) and an 80% difference in Q_3. Nevertheless, the (S, E) group scored better in V_2 and N_2 and its variety and novelty increased when provided with the stimulus, so we cannot conclusively confirm that the stimulus hinders expert participants in generating more problems.

Table 27 shows that, even excluding the atypical behavior of G2 (noS, E) on H1, it nevertheless scored better than G1 (noS, noE) in all the other variables. This confirms the assumption of a positive influence of urban mobility expertise on ideation effectiveness.

Regarding the combination of stimulus plus urban mobility expertise, there was no noticeable difference in problem quantity in Q_2. However, the quantity growth was slightly higher in the noE group, which could mean that expertise hinders the stimulus effect on quantity. Expert participants also scored better in variety and novelty compared to non-expert participants, which means that expert travelers profit more than non-experts from the stimulus in terms of problem variety and problem novelty. This could be explained by the fact that expert travelers become more aware of the subjective categories when given the stimulus than the non-expert travelers.

Table 27. Roll-up of values for the hypotheses variables from the stimulus use perspective

Variables		noS		S	
		noE	E	noE	E
Quantity (H1)	Q_2	29	32	26	24
	Q_3	-38%	50%	-20%	-30%
Variety (H2)	V_2	64%	82%	73%	91%
	V_3	0%	36%	-18%	10%
Novelty (H3)	N_2	84.8%	92.5%	92.5%	94.8%
	N_3	-1.2%	17.1%	-0.4%	3.8%

According to the results in Table 28, H1 is invalidated. H2 and H3 are validated regarding V_2 and N_2that are better with use of the stimulus than without. H2 is invalidated regarding $V_3$when the stimulus is introduced. As N_3 remained constant through the experiment, H3 cannot be totally validated.

Table 28. Roll-up of values for the hypotheses variables comparing expertise and stimulus effects

Variables		noS	S
Quantity (H1)	Q_2	40	30
	Q_3	-5%	-25%
Variety (H2)	V_2	82%	91%
	V_3	+9%	-9%
Novelty (H3)	N_2	91.8%	94.8%
	N_3	+5%	0%

IV.5.2 The value of the stimulus

Several stakeholders involved in diagnosing urban mobility systems could benefit from using a traveler -centered stimulus for emerging travel problems.

The first stakeholders to profit from the stimulus are the participants. The stimulus helps them remember sequences of their experience to tease out problems that do not intuitively come to mind as such. Indeed, they gain self-awareness of how their past mobility experience happened. A travel problem is not only related to what they watch as observers, but it is also about how they feel and how problems can have knock-on effects on what happens at the destination. The other categories together constitute a wider picture of an urban mobility experience. Moreover, by using the stimulus, participants produce a more balanced picture of their mobility experience as they led, giving similar attention to each of its aspects.

The second stakeholder to profit from the stimulus is the designer. Indeed, better-quality problem generation outcomes should translate into more relevant solutions (Yannou, 2015). The problems that are generated using the stimulus cover most of the aspects of traveler experience using verbatim from the users themselves expressing their subjective concerns. The translation that participants tend to operate on their personal perception to produce more objective and system-oriented problems is neutralized. Indeed, participants are invited to freely and openly express their thoughts and feelings, which liberates them from self-censorship. The effect on solution generation is that the problems are framed including subjective variables that might be correlated to participants' profiles. Solutions would thus be more personalized according to the specificity of each respondent's profile. For example, G4 provided this problem in the second phase: "*we feel less safe/comfortable when there are a lot of people around in the bus*". This feeling might be shared by everyone. By reviewing who the respondent is, the designer can know which user profile this problem fits, and design the solution accordingly (e.g. personalizing a proposed itinerary depending on comfort-feeling preferences). Moreover, the feeling is expressed regarding a situation that happens around the traveler, which concurrently links into a problem of unsafety and discomfort but also its cause, which is the crowd on the bus. The solution would, in this case, include both the capacity to increase the feeling of safety and comfort if the crowd happens and, at the same time, its capacity to reduce that crowd. This causality value can be further enhanced by proposing an ideation session that pushes participants to identify the links between problems they have and think of new consequences and causes as new problems to be reported.

The insights that a designer gains from travel problems can be exploited by a transportation operator when the data are quantitatively significant. Indeed, tailored surveys can be designed in response to outputs from focus groups conducted with specific samples of travelers. Having more detailed preferences matching with travelers' profiles would allow operators to add more human-centric performance indicators. The diagnosis of the mobility system they operate would then show them flaws that directly impact traveler satisfaction and connect these flaws to their original technical problems.

The two metrics that represent variety and novelty are meant to fill the gap left in ideation outputs evaluation by quantity alone. Indeed, Briggs & Reinig (2010) show that value in idea-quantity is insufficient to establish gains in idea-quality. Therefore, in asking travelers to state the problems they experience using some urban mobility solution, a support is needed so that they can generate problems that most reflect their experience. Classical design tools that are not tailored to the nature of the system to be diagnosed fail to produce problems that cover relevant dimensions of the user experience related to the system of study. For instance, Kremer et al.(2017), even with a user-centered approach, still lacks travel stages integration and considers a segmented evaluation of the experience without taking into account the destination as part of the experience nor the causality between subjective and technical problems.

For these reasons, this experiment highlights that it is vital to involve users (of the system to be diagnosed) in the design of stimuli for problem identification, not just design concepts generation.

The groups that did not receive the stimulus represented the classical way participants in focus groups are asked to generate problems. Results showed that these groups score less in variety of problems and novelty than groups that receive a traveler -centered stimulus.

The results of this experiment would be more reliable if the experiment was repeated several times over. This would allow to test whether G2 would confirm its (atypical) behavior —especially for Q_3. Moreover, it would consolidate the conclusions made on novelty and variety. It is, however, difficult to recruit participants who are using a system on the same route and find a time-slot where everyone is available for the experiment.

IV.6 Conclusion and perspectives

The chapter evaluates the effects of a traveler -centered stimulus on the effectiveness of travel problem generation. So far, user-centered methods have served to uncover different aspects of problems that users experience when interacting with products and services. However, they are used in isolated -off as a means to answer predefined research questions that under-involve users. Consequently, they miss unspoken usage problems that users and designers do not think of alone. In urban mobility, given the lack of traveler experience-relevant dimensions for setting travel problems, a proposed solution to tackle this issue needs metrics to measure travel problem generation effectiveness.

This study shows that using a traveler -experience based stimulus in travel problem generation helps participants generate problems covering the traveler experience dimensions. The stimulus is a textual description of two broad categories of problems, which are: (a) Objective problems related to Design, Operation, Weather, People; (b) Subjective problems broken down into Do, Body, Mind, Emotion and Arrival classes.

Participants tend to intuitively generate objective problems that are related to the system of study and to its usage-environment surroundings. The stimulus improves their ability to remember and frame more subjective problems related to what they do and how they react to their surroundings. Moreover, while increasing the *variety* and *novelty* of problems, using a stimulus for problem generation also decreases the number of problems generated. Mobility expertise, in turn, has a positive influence on problem generation effectiveness. On the other hand, expert participants benefit more from the stimulus than the non-experts in terms of variety and novelty, since they better exploit the subjective categories.

Subjective traveler experience dimensions give an additional lever to travel problem generation in aligning travel solutions with traveler concerns. It gives solutions a better potential to satisfy traveler expectations on the quality of their experience using actual urban mobility systems. For instance, if a traveler expresses his/her dissatisfaction with dispassionate announcements of delays, then a solution would propose to add apologies to the announcement or advise the announcer to adopt a more compassionate tone. In addition, subjective problems, being causes and consequences of technical objective problems, emerge causality between the technical performance of urban mobility systems and its impact on traveler satisfaction.

The metrics that were used to evaluate such stimulus do not consider travel problem causality links. Since participants do use a snowballing logic in generating problems, it would be relevant to add a metric that refines *novelty* in considering *causality*. This would reflect the dynamics of problem generation and help participants become aware of how they move from one problem to another and consciously orient their problem generation process (Santanen et al., 2004). Moreover, to expand the relevance of the experimental hypothesis to usage problem framing with different systems beyond urban mobility, the stimulus needs to be adapted by design to each system of study.

This research intends to help designers stimulate users to express more of their usage problems. It can also help decision-makers to link the technical performances of the systems they manage to the satisfaction of the final users. Furthermore, this article considers the limits of design practice when it comes to designing large-scale complex systems such as urban mobility systems. Indeed, traveler experience involves more diverse issues than a user experience with a simple artefact in a private environment. Here we also encompass the social interactions between users and considers the importance of what comes after the usage time-frame, which therefore broadens the boundaries of the system of study to all the elements that users effectively consider as usage problems.

Causality should systematically be considered in further research into helping participants generate usage problems and how these can be exploited in conducting combined user satisfaction–system diagnosis surveys.

Chapter V

Traveler specific attributes in transport modeling and simulation: The case of a new shared autonomous vehicle service

Modeling transport systems is usually based on variables that are projected on time and space. For instance, simulation and optimization models rarely go beyond cost, time and space as determinants when analyzing travelers' choice regarding their transport mode. This chapter shows how the knowledge of traveler experience helps to determine relevant variables that subtend travelers' willingness-to-use a mobility service. We exemplify the approach for a shared autonomous vehicle service. An online survey was carried to collect data on travelers of the greater Paris region and their position regarding autonomous vehicles. On the one hand, the chapter identifies profiles of travelers that are more likely to accept autonomous vehicle technology. On the other hand, it identifies subjective criteria of travelers behind their willingness-to-use a shared autonomous vehicle service depending on their current mode of transport. The chapter shows how traveler specific attributes are relevant to studying a mobility system and how these can enhance the accuracy of agent-based models and the traveler preference dimension in optimization models.

Keywords: Traveler specific attributes, modal shift estimation, acceptance, willingness-to-use

A modified version of this chapter has been submitted to the Euro Working Group on Transportation 2019

V.1 Introduction

In designing urban mobility systems, transport operators and industrial actors are challenged by issues of sampling, scaling, setting performance indicators, gathering and analyzing qualitative data, involving stakeholders, and setting the boundaries of the system to be designed (Al Maghraoui et al., 2017a). One of the reasons why these challenges are persisting is that, at the scale of a city, urban mobility systems are anchored in the urban life of travelers which is evolving with technology.

Travelers are invited to participate in the design of urban mobility systems because they have valuable knowledge of their experience as users of these systems (Webb et al., 2018). Transport operators and industrials collect this knowledge using different methods. Satisfaction and stated preference (SP) surveys are one way of doing so (Bradley & Kroes, 1992). Surveys are designed to measure the level of satisfaction and preferences of travelers regarding a mobility system. However, they often miss most of what travelers have to say about their mobility experience and choices because they come with preconceived ideas of what utility and preferences are (Jiao et al., 2012), especially for a service that does not exist yet; Autonomous Vehicles (AVs).

This technology has a big potential of disrupting the behavior of travelers and their preferences regarding the transport mode choices that will be offered to them (Le Vine et al., 2015). Moreover, the high heterogeneity of travelers suggests that the use of simplistic models would not allow sufficient discrimination of potential AVs use (Krueger et al., 2016).

In recent years, the variables behind travel choice has been shifting from pure economic and spatio-temporal components towards a more complex set of parameters including quality of life and social dimensions of urban activities (Jones, 2014). In investigating public opinion on AVs, in addition to cost, Bansal et al. (2016) and Howard & Dai (2014) identified safety as being one of the most important factors for choosing or not choosing to use an AV. Analyzing online forums discussions, Fraedrich & Lenz (2014) added comfort and flexibility as perceived positive feature of AVs that could push people to use them.

Haboucha et al. (2017) considered some traveler specific attributes such as environmental concern or joy of driving which they called “attitudinal variables” along with socio-demographic attributes such as gender and age in estimating AVs adoption in the future. However, this study only concerned a population of drivers and the list of attitudinal variables was based on literature with no feedback from the participating drivers.

In transport models, the most frequently used variables are either spatial or temporal, and sometimes economic (Cascetta, 2009) (Ortuzar & Willumsen, 2011). In the specific case of AVs, agent based and optimization models for instance use variables of the same nature but rarely include traveler specific attributes.

For agent-based models, in (Auld et al., 2017) the value of travel time in AVs is attributed uniformly to the agents without considering to which real travelers they correspond. In (Azevedo et al., 2016) and (Martinez & Viegas, 2017), preferences of agents for AVs and destination choice are based on available traveler data of existing modes without considering what could change in travelers’ opinion due to vehicle automation. In (Boesch et al., 2016), the demand is estimated to be “highly detailed” but this was only spatial and temporal with no particular attention to traveler diversity. Even in “microscopic travel demand” modeling, Heilig et al. (2017) represent travelers for a scenario with AVs with no private cars, using data of traveler preferences for today’s transport situation. Hörl (2017) uses only time, distance, and cost in scoring trip possibilities including AVs, assuming that these are the main explicative variables that underlie transport mode choice.

In optimization models, travelers are often considered having uniform preferences and behavior. Besides the optimization objectives are either temporal, spatial, or economic. For instance, considering shared AVs as a user-centric service, Alonso-Mora et al. (2017) developed a dynamic assignment model that has for sole traveler-centric variable the location of travelers. Travelers are often modeled as a demand that is randomly generated through time and space (Levin et al., 2016). The objective of optimization models is often operation-centered like minimizing the number of stops an AV performs (Pimenta et al., 2017) and sometimes utility-based, aiming to maximize a global utility for both passenger (e.g. waiting time) and AV (e.g. occupation rate) (Kümmel et al., 2017) for instance.

In definitive, few studies use traveler specific attributes in modeling and simulating transport systems with AVs. Moreover, when it comes to estimating modal shift towards AVs, most studies using SP surveys either come with attributes derived from studies on existing transport modes or do not give travelers the possibility to express themselves.

This chapter addresses the following research question: *How can traveler specific attributes improve transport modeling and simulation?*

In section 2, the chapter presents the method used in conducting an online SP survey on AVs. This includes the setting of traveler specific attributes and the questionnaire. In section 3, the results of the survey are illustrated, showing the influence of traveler specific attributes on participants' answers on AVs acceptance and their willingness-to-use a Shared Autonomous Vehicle Service (SAVS). In section 3, the results are used to enhance the accuracy of an agent-based simulation and the traveler preference dimension in an optimization model of a SAVS.

V.2 Material and method

To answer the research question of this chapter, an optimization model and an agent-based simulation are used to illustrate the effect of considering traveler specific attributes in addition to classical generic variables. These are detailed in section 3. We use the results of a survey we conducted on AVs acceptance and SAVS willingness-to-use of travelers of the greater Paris region (Figure 46).

To set the survey, we start by setting the relevant traveler specific attributes for AVs in order to personalize the questionnaire to each travel mode and get the rationale behind participants' answers. A model for SAVS is set to simulate how the service would look like depending on travelers' current specific attributes. The results are analyzed using regression trees and participants' answers.

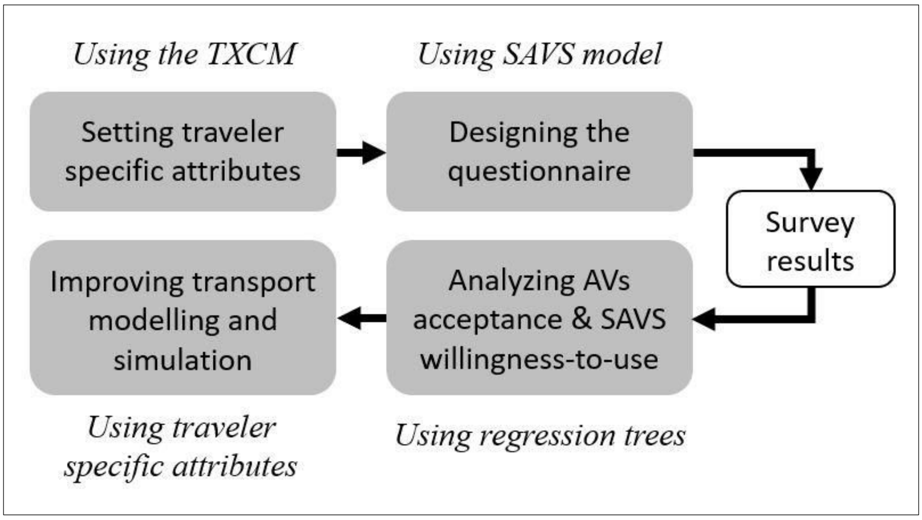


Figure 46. Research methodology

An online survey was conducted with 457 of the inhabitants of the greater Paris region to estimate their potential modal-shift from their current mode of transport to a Shared Autonomous Vehicle Service (SAVS). Most of the survey participants were active (231) or students (199). These two categories constitute together 88% of the population aged between 15 and 64 of the greater Paris region according to the study of the French National Institute of Statistics and Economic Studies on the region's population of 2015 (INSEE, 2018) (see Figure 48 for more details).

In the first part of the questionnaire, participants are asked to fill in traveler specific attributes about their typical daily journey. Afterwards, they were asked if they would one day -a priori- use an autonomous vehicle instead of their current mode of transport. In the second part of the questionnaire, based on the information of the participants on their typical daily journey, a model-based proposition of a similar journey with the SAVS is simulated and presented to them next to their current journey information. Using this comparison, participants are asked if they would or not -a posteriori- replace their current mode of transport by the SAVS and provide the reasons behind their choice.

Participants were informed the survey would take 6 minutes and would involve questions related to their preferences regarding a new mode of transport offering new travel possibilities. Participants were not offered compensation for responding but were told that their involvement would help advance the science of transport. The survey was constructed on Lime Survey, allowing participants to take it online via computer or mobile device and adapt the questions and the simulation to their answers of the first part of the questionnaire.

V.2.1 Setting the traveler specific attributes

In the questionnaire, there are three sets of traveler specific attributes that were created using a traveler experience model (TXCM) (Al Maghraoui et al., 2017b). Indeed, the TXCM points out that the metrics over which a mobility system is evaluated should be instantiated regarding the properties of this system and how different travelers experience these. In the case of AVs, the modal shift needs to define the current used mode and its properties. For example, what changes clearly for car drivers is that they do not need to drive anymore when using a SAVS. Therefore, the feature of being able to do another activity during the travel time is differentiating. For a public transport (PT) user this feature would be the fact that they will have a comfortable seated place if they use a SAVS. The list of these attributes is generated this way for each one of the transport modes.

The first set of traveler specific attributes is socio-demographics: age, gender, socio-professional category and income. These were chosen to match with the attributes of the global transport surveys. Indeed, in agent-based simulation, there is a need for population synthesis that must match with the actual population.

The second set is related to participants' evaluation of their current mode of transport and how the SAVS would change their appreciation of these. Participants are asked to put two different scores in front of each of them. The first one is an evaluation of their current mode of transport and the second one is an importance rate behind their choice to shift or not to SAVS. The score attributes are: travel monthly cost, travel total time, parking time (for car and bike users), walking time (for car and PT users), waiting time (for PT users), safety, security, comfort, infrastructure, and freedom during travel.

The third set is a singleton that represents participant's willingness-to-pay for extra 20% of the cost of the monthly SAVS subscription to have non-shared private rides. It is the optimization model that uses this attribute because it deals with rides that are shared and other ones that are not.

V.2.2 The first part of the questionnaire

The first part of the questionnaire was organized into three blocks:

1. *Socio-demographics:* age, gender, socio-professional category, and income.
2. *Typical daily one-way journey:* origin-destination regions, mode of transport, monthly cost, travel-related times (depending on mode: waiting, parking, total…).
3. *Evaluation of the current journey* (on a 5-point Likert scale): Safety, security, comfort, freedom during travel.

At the end of these blocks, participants are asked if they would rather or not (Yes/No) use an autonomous vehicle replacing their current mode of transport.

V.2.3 The SAVS model

Information from participant's typical daily one-way journey was used to simulate an alternative travel using the SAVS for the same participants' travel attributes. The cost was estimated from the prices of Lyft USD 300/30 rides subscription plan (Lyft, 2018). It was assumed that the unlimited extra rides cost was covered by the driver's cost savings. Hence the monthly fares for unlimited rides; €150 in Paris, €220 in Suburbs, and €300 in Paris + in Suburbs + between Paris and Suburbs.

The total travel times were calculated using the total travel time *(x)* entered by the participant (Table 29). It depends on the transport mode of the participant. The SAVS has the behavior of a car concerning the speed and duration, but without parking nor walking times. For public transport (PT), the values are based on the data of the French global transport survey of 2010 in the greater Paris main travel patterns (Paris-Paris, Paris-Suburbs, Suburb-suburb). For example, in Suburb-Suburb trips, the average total travel time is 51.1 min for PT and 20.56 min for the car (hence the ratio 0.4). For the bike, the values are based on ratios of the mean speed of the car (V-Traffic, 2014, p: 6) (Le Monde, 2014) and bike (Wesawit, 2013). For example, in Paris-Paris trips, the average speed is 13 km/h for bike and 15.3 km/h for the car (hence the ratio 0.85). For a walk, it was assumed that the SAVS, as for a car, is eight times faster in average whatever the travel pattern.

The SAVS has a waiting time between 0 and 10 min. For each mode, it has a comparative description of all the travel attributes. For a car user, for example, it is explained that there is no parking time and that the user has no need to keep eyes on the road (Table 30).

Table 29. SAVS alternative calculation of total travel time

Total travel time	PT	Car	Bike	Walk
Paris-Paris	$x \times 0.79$	$x - (t_p + t_w)$ $t_p: parking\ time$ $t_w: walking\ time$	$x \times 0.85$	$x \times 0.125$
Paris-Suburbs	$x \times 0.8$		$x \times 0.34$	
Suburb-Suburb	$x \times 0.4$		$x \times 0.25$	

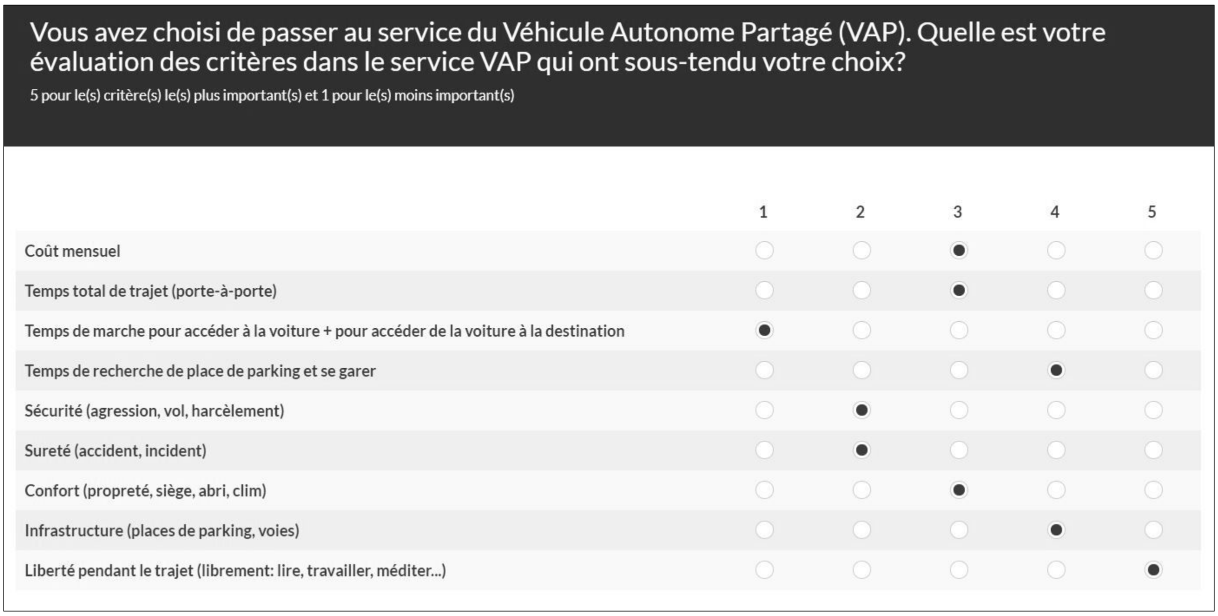
x: total travel time, in minutes.

Table 30. Example of a car user alternative trip with SAVS

Criteria	Your trip by car	Your trip by SAVS	Explanations
Monthly cost	€350	€150 Paris €220 Suburbs €300 Paris + Suburbs	Unlimited trips based on a monthly subscription
Total travel time	50 min	40 min	Like a car but without the time it takes to get to the car, find a place to park and then get to your destination after parking. It's like a taxi
Parking time	5 min	0 min	No need for parking
Walking time	5 min	0 min	There is no walk to do
Waiting time	0 min	0 min – 10 min	You are waiting at your location. This time varies during the day without exceeding 10 min
Safety	4/5	The vehicle is equipped with an image processor that captures abnormal behavior in the vehicle and asks for help	
Security	3/5	The vehicle would drive better than a human	
Comfort	5/5	Like in a taxi	
Infrastructure	3/5	No need to park, or gas stations	
Freedom during travel	1/5	You can freely read, work, meditate without hands on the wheel or eyes on the road, but not smoke or speak loudly on the phone	

V.2.4 The second part of the questionnaire

When the alternative SAVS travel is exposed to the participant, he/she asked if he/she rather of not (Yes/No) uses the SAVS in the future as a replacement of his/her current mode of transport as a final answer. Depending on his/her answer, he/she is asked to indicate a score (5-point Likert scale) to tell how important each of the criteria behind his/her decision is (Figure 47). The list of the criteria is generated depending on the mode as for block 2 of the first part of the questionnaire.



Vous avez choisi de passer au service du Véhicule Autonome Partagé (VAP). Quelle est votre évaluation des critères dans le service VAP qui ont sous-tendu votre choix?

5 pour le(s) critère(s) le(s) plus important(s) et 1 pour le(s) moins important(s)

	1	2	3	4	5
Coût mensuel	○	○	●	○	○
Temps total de trajet (porte-à-porte)	○	○	●	○	○
Temps de marche pour accéder à la voiture + pour accéder de la voiture à la destination	●	○	○	○	○
Temps de recherche de place de parking et se garer	○	○	○	●	○
Sécurité (agression, vol, harcèlement)	○	●	○	○	○
Sureté (accident, incident)	○	●	○	○	○
Confort (propreté, siège, abri, clim)	○	○	●	○	○
Infrastructure (places de parking, voies)	○	○	○	●	○
Liberté pendant le trajet (librement: lire, travailler, méditer...)	○	○	○	○	●

Figure 47. A Screenshot of the criteria scoring page of the questionnaire

An additional field is proposed to participants to add another criterion that they estimate being important for their choice and to put a score on it if they wish. If the participant answers Yes, he/she is asked if he/she would pay extra 20% to have a private ride, as a VIP rider. If he/she answered no, he/she is asked in what occasion he/she would use the SAVS.

V.3 AVs acceptance and SAVS willingness-to-use

Introducing traveler specific attributes in analyzing technology acceptance of AVs and willingness-to-use of a SAVS allowed to identify profiles of potential users and a rationale behind choosing or refusing to shift towards a service involving AVs.

According to the results obtained from the first part of the questionnaire, we obtain the distributions of the participants through age, gender, socio-professional category (Cat), income, mode of transport (mode), and origin-destination regions (trip) (Figure 48). Except for income (380 answers), all other categories have been filled (457 answers). More than half of the participants were young people under 24. Most of them were men. The socio-professional category distribution of active + students (94%) matches quite well with the greater Paris region (88%) of the population aging between 15 and 64 (INSEE, 2018). The modal split of PT + Car (83%) matches less (58%) (OMNIL, 2012). The incomes were fairly distributed with a higher proportion (35%) of the [€1000, €2000] segment. The trips outside Paris city are 87% of the total number of the whole region trips, while the real proportion is 70% (OMNIL, 2012).

The results represent the relation between traveler specific attributes of participants and their position regarding AVs and a SAVS. On the one hand, the answers of participants to the question if they would one day -a priori- use an autonomous vehicle instead of their current mode of transport are assumed to reflect the autonomous vehicle technology acceptance. It can be analyzed using socio-demographic and travel-related attributes.

On the other hand, their answers to the question they would (Y/N) -a posteriori- replace their current mode of transport by the SAVS are assumed to represent their willingness-to-use the SAVS in the future. It can be analyzed using the scores participants filled for the reasons (criteria) of their choice.

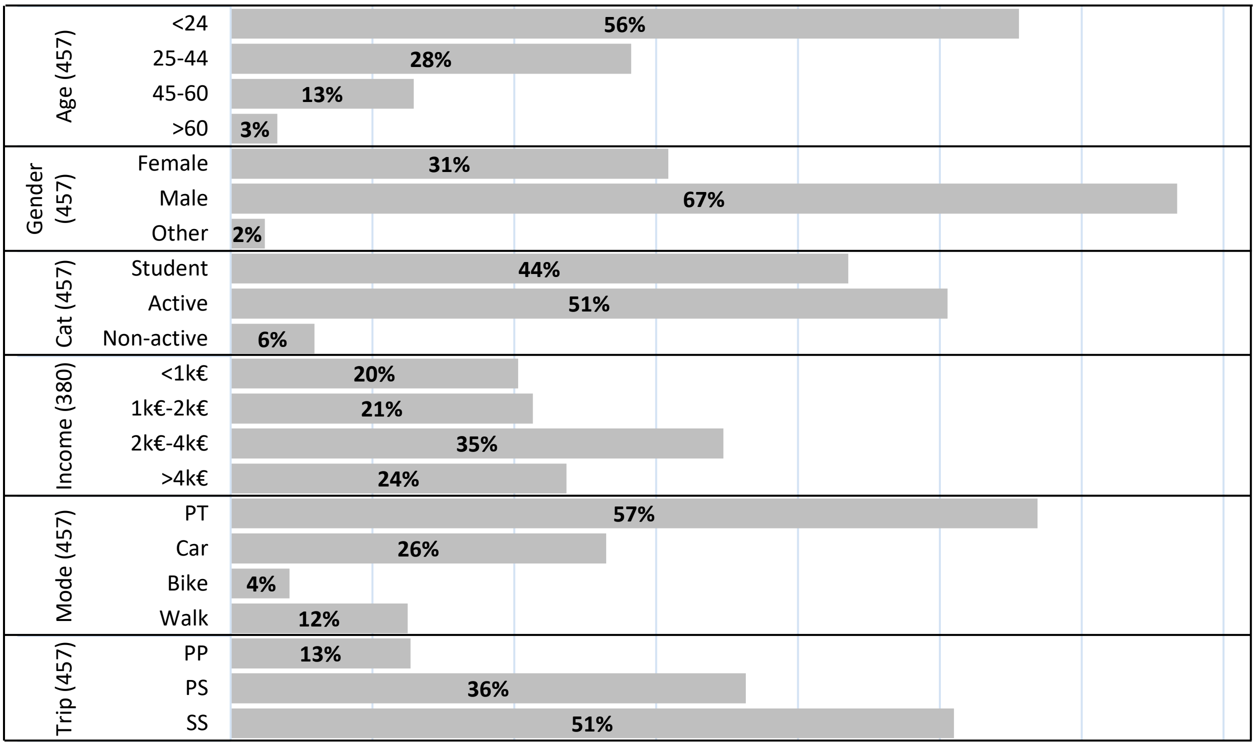


Figure 48. Distribution of the surveyed population

V.3.1 Prior acceptance of an autonomous vehicle technology

When the results of the answers of the first part of the questionnaire were analyzed, it was found that 67% of participants would accept to use an autonomous vehicle (AV) as a replacement of their current mode of transport (Figure 49). Car users had the largest potential to change mode, followed by public transport users; 60% conversion rate for car users and 58% for PT users. Travelers biking or walking did not score that high: 20% together.

Figure 50 shows the distributions of answers (Yes/No) through age, gender, socio-professional category, income, transport mode, and origin-destination regions. These represent the projection of the AV technology acceptance of participants. It appears that there are some differences between the categories of each segmentation, especially in mode and age. In the transport mode, for example, it is clear that biking and walking have lower rates of acceptance than PT and car. Moreover, seniors are more likely not to accept AVs than young adults. However, participants in each category are not equally represented. Therefore, it is relevant to build a regression tree to see which categories mostly influence AV acceptance.

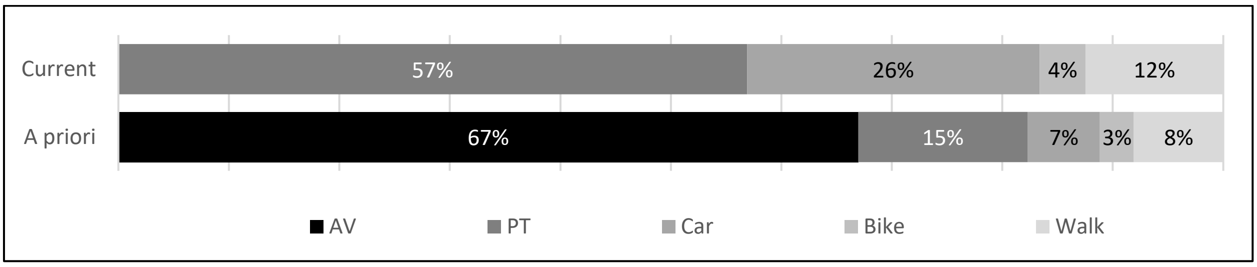


Figure 49. Acceptance rates of an AV technology

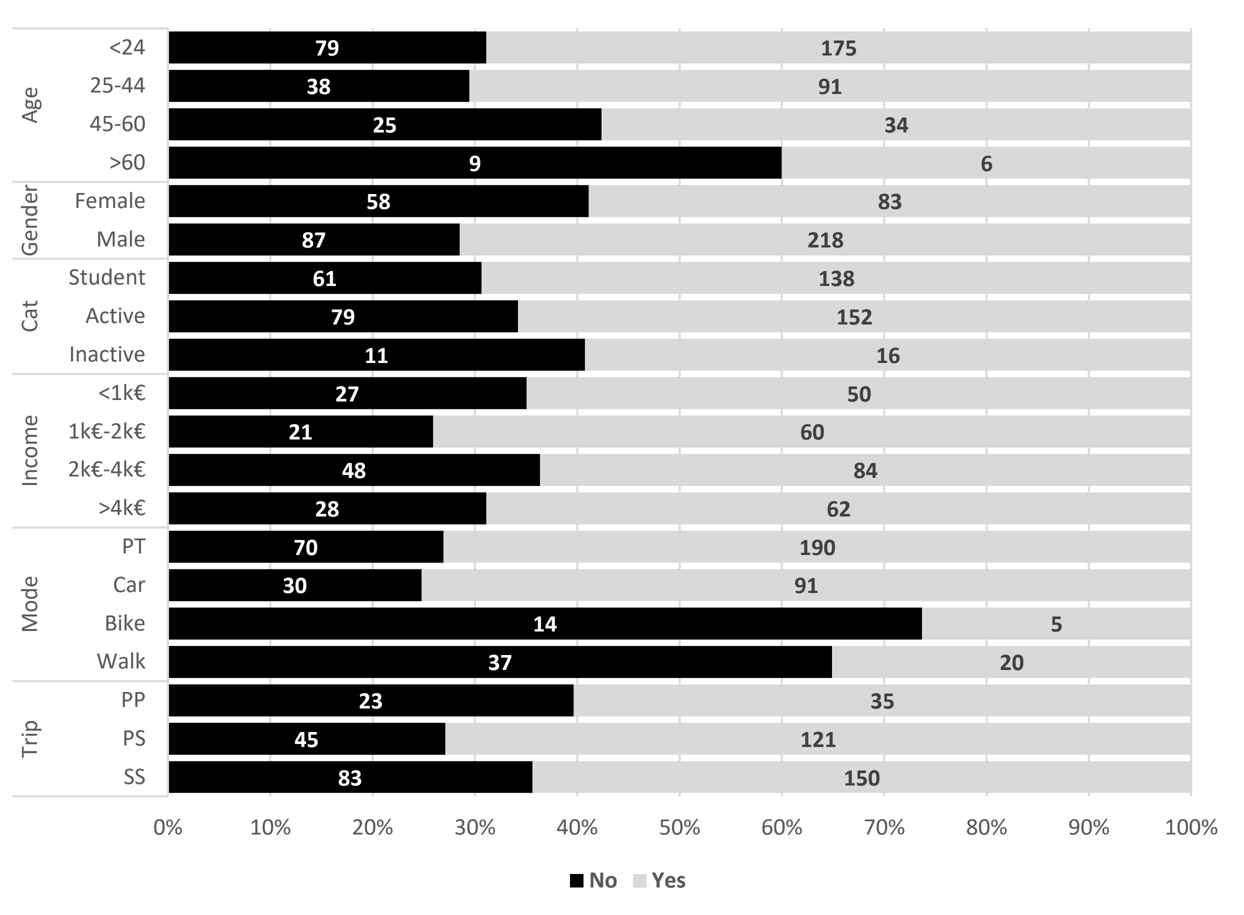


Figure 50. Distributions of answers a priori

V.3.1.1 Analyzing AV acceptance using a regression tree

To visualize the hierarchy of factors influencing participants' choice of accepting or not accepting the autonomous vehicle technology to replace their current model of transport, we use a regression tree (Venables & Ripley, 2002).

Figure 51 shows that the four main influencing factors on AV acceptance are the mode of transport, the gender, and the socio-demographic category in line with the origin-destination geographic area. Indeed, among the 67% of all participants who said yes, 86% are PT or car users. Those who have a probability of .72 to say yes, meaning that among PT and car users 72% said yes as in Figure 50.

Following the same logic, we highlight four profiles of participants that score higher than .7 of AV acceptance probability. They represent together 56% of all participants who answered Yes. They are all PT or car users.

1. Male participants who are students or inactive (.88 probability).
2. Male participants who are active and earn more than €2000/month (.80 probability).
3. Male participants who are active, earn less than €2000/month and own a car (.74 probability).
4. Female participants who commute between suburbs (.73 probability).

Participants who bike or walk are more likely not to accept AVs with a probability of .59. According to participants' extra comments (Appendix 10), the main reasons are that the short distance commute does worth it or that it is healthier to walk or cycle.

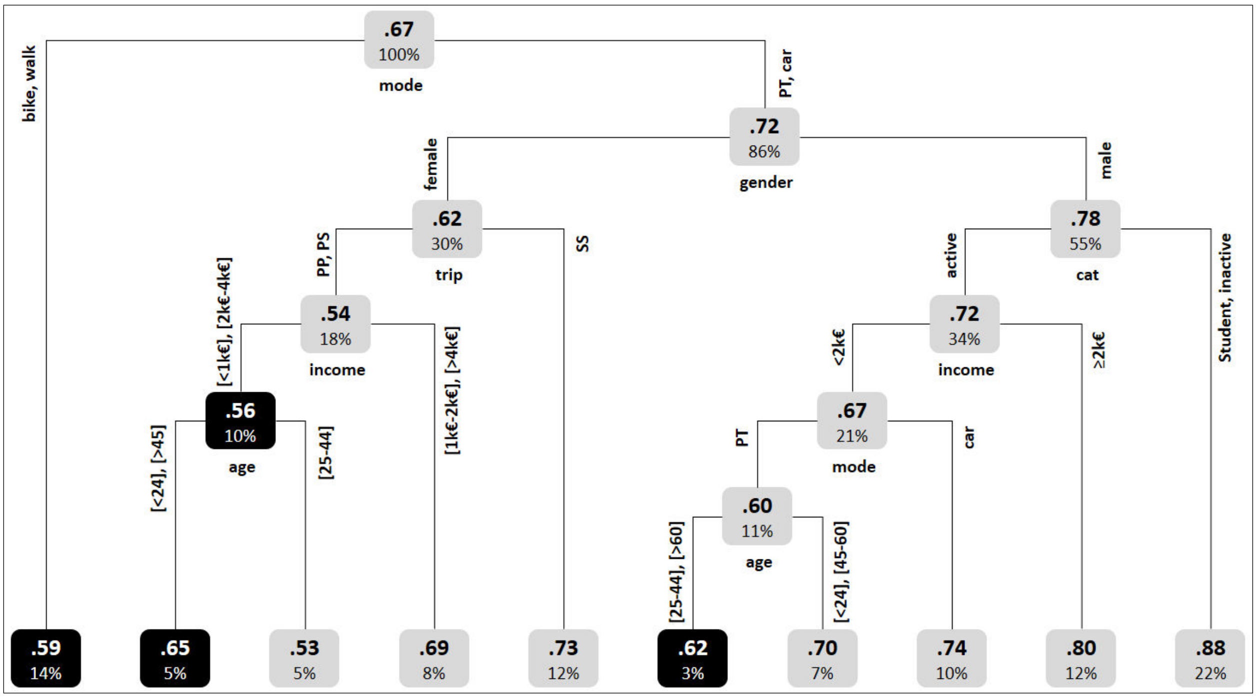


Figure 51. AV acceptance regression tree

V.3.2 Willingness-to-use a shared autonomous vehicle service a posteriori

In the second part of the questionnaire, respondents were informed how the SAVS would look like regarding their current typical journey (see Appendix 8 for the distribution on answers a posteriori). It was found that 30% of participants would use the SAVS as a replacement of their current mode of transport (Figure 52). Car users had the largest potential to change mode, followed by public transport users; 27% conversion rate for car users and 17% for PT users. Travelers biking or walking did not state they would be ready to change their mode (8% together).

Compared to the acceptance of AVs, the percentage of PT and car users who state their willingness-to-use a service as SAVS decreased by resp. 41% and 33%, where biking and walking only decreased by 12% each.

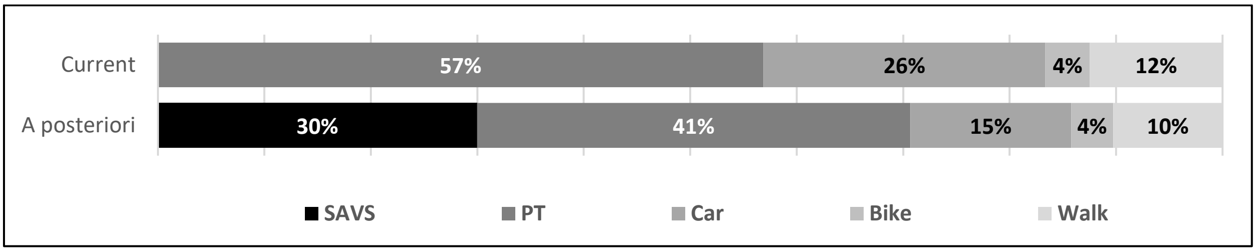


Figure 52. Rates of willingness-to-use a shared autonomous vehicle service

V.3.2.1 Analyzing the willingness-to-use the SAVS based on a regression tree

The reasons behind participants' choice on their willingness-to-use the SAVS were gathered by the transport mode and by the positive/negative response (Yes/No). Figure 53 shows the distribution of the average scores of respondents on their willingness-to-use the SAVS whatever the mode. It is noticeable that the cost is the first criterion accounting for a negative answer. On the other hand, comfort, freedom, safety, and total travel time underlie a positive answer.

As the scores of criteria accounting for positive answers were close, we used a regression tree to visualize the hierarchy of criteria. Figure 54 shows that the main four influencing criteria on SAVS willingness-to-use are comfort, travel time, and freedom. Comfort is quite discriminating given the fact that people who score 5 for it have a probability of .8 to say yes to the SAVS. Travel time and freedom are less significantly discriminating given their lower probabilities.

For negative answers, an additional regression tree was generated with normalized answers in order to have most important criteria with a score of 5 and the least important with a score of 1. Figure 55 shows that the most influencing criteria on SAVS unwillingness-to-use are cost, security, and the mode of transport. Indeed, the most reluctant participants give higher importance to cost (≥3.8 average) with a probability of .97, participants without a car -with a small transport budget- with a probability of .84, and participants giving less importance to cost (>2.8 average) but higher importance to security (≥4.7 average) with a probability of .78.

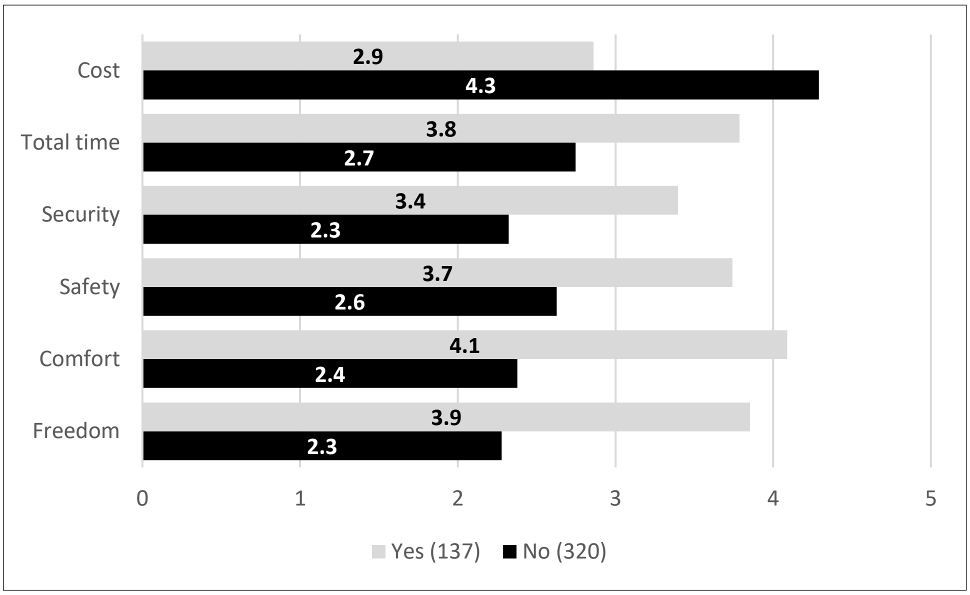


Figure 53. Willingness-to-use criteria average scores

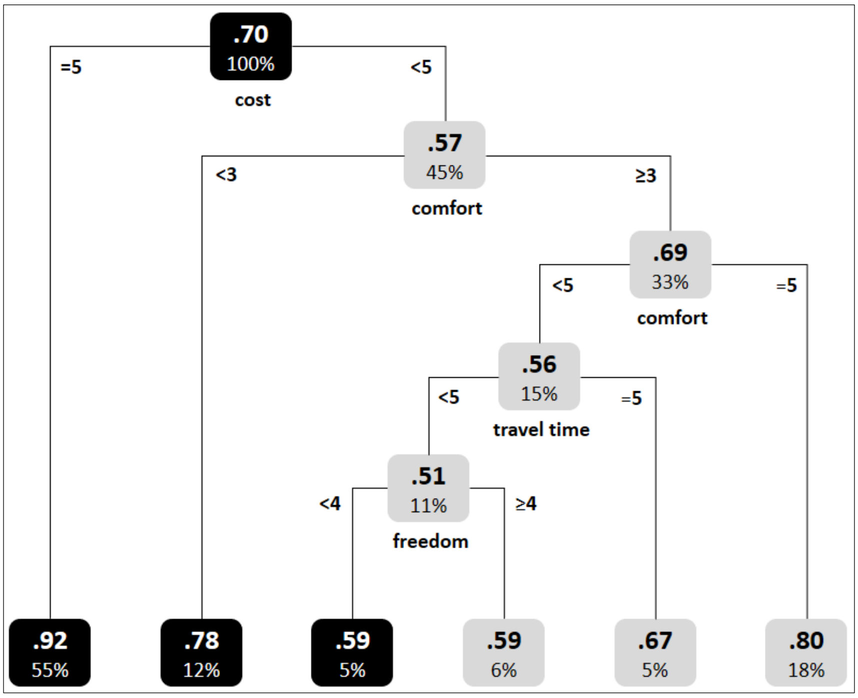


Figure 54. Willingness-to-use a SAVS regression tree

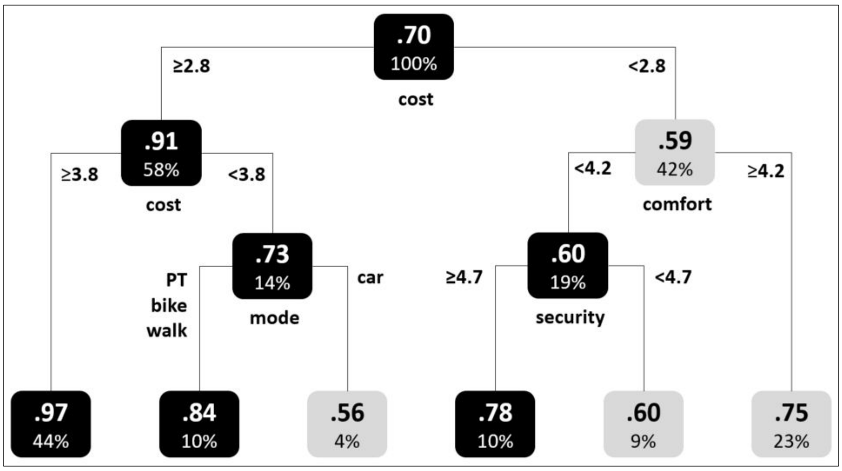
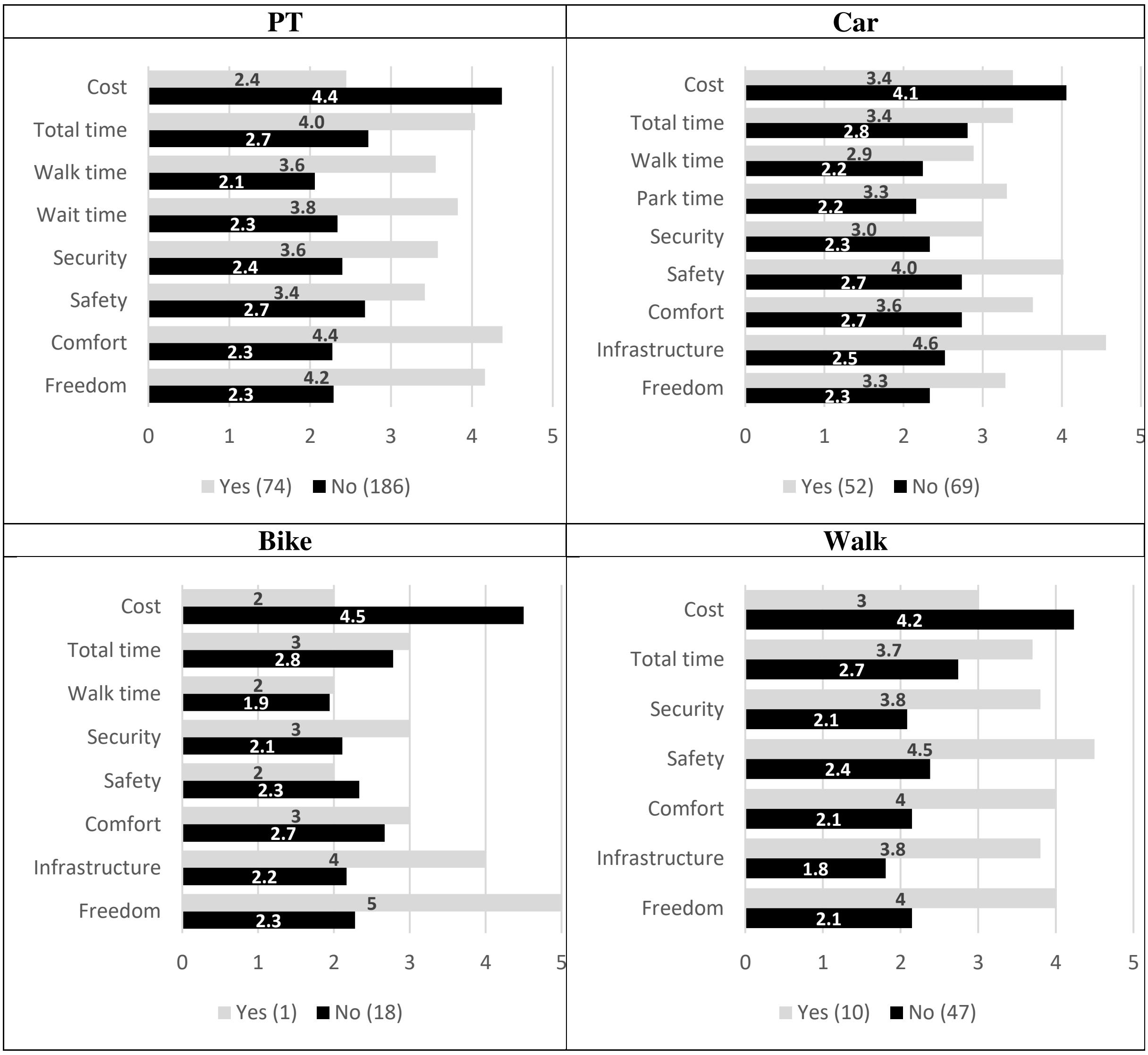


Figure 55. Unwillingness-to-use a SAVS regression tree

Table 31. Average scores of willingness-to-use criteria per mode of transport



In fact, there are specific criteria for each transport mode (Table 31). For instance, the most important criterion for car users willing to use the SAVS is infrastructure, scoring 4.6. For car users, the benefit of the SAVS regarding infrastructure was that they would not need to worry about parking spots or service stations anymore. Criteria were described adapting to specificities of each mode (Appendix 9). For PT users, the criteria influencing a positive answer were comfort and freedom, scoring resp. 4.4 and 4.2. Participants who walk said Yes for safety reasons. There was only one participant with a positive answer as a bike user scoring 5 for freedom as the most important criterion.

V.3.2.2 Analyzing the willingness-to-use the SAVS based on participants' feedback

Participants had the possibility to fill an additional field for another criterion underlying their willingness-to-use or not the SAVS (Appendix 10). Criteria for a negative answer were 3 times more numerous than for a positive one, matching the (30%, 70%) distribution of (Yes/No) a posteriori.

Participants added 101 responses on an additional criterion for not willing to use the SAVS. Car users privileged the freedom-of-use they have with owning a private car (13 out of 30) over the freedom within the vehicle an AV can provide. This is one of the formulated reasons: "*The real point is on the availability sure and immediate (in - of 5 or 10 min) which is the true freedom of the personal vehicle or the exclusive autonomous vehicle (not shared)*". 9 answers praised the pleasure of driving a car and 8 still do not trust the capabilities of AVs on being reliable and safe. 17 out of 48 PT users estimate that PT beats the SAVS on environmental aspects (energy consumption and pollution). 8 believe that SAVS would still have traffic jam problems like cars do, and 8 question its reliability. 6 out of 13 bike users believe that cycling is more environment friendly than AVs, and 4 of them prefer cycling for health reasons. Out the 10 responses on walking, 7 estimate their journey too short to be done with an AV.

The 27 responses proposing new criteria for willingness-to-use the SAVS, mostly from car and PT users, were too diverse and sparse except for environmental concern. Indeed, 8 answers praised the benefit of SAVS in being environment friendly among PT and car users. The other answers pointed out the features that are absent in the current transport mode of participants. For example, PT users appreciate the temporal availability of the SAVS and the possibility to have their luggage taken care of. Car users estimate the sharing mode of the service would decrease their impact on the environment and spare them the difficulties related to driving (stress, fatigue).

The presence of environment in both positive and negative criteria can be explained by the fact that the energy system of the SAVS was not mentioned in the questionnaire. Therefore, each participant responded according to the assumption he/she made about it.

V.4 Using traveler specific attributes in transport modeling and simulation

The traveler specific attributes are firstly used to enhance the accuracy of demand in an agent-based simulation showing a significant difference in simulation results when introducing the technology acceptance in relation with age and gender. Secondly, the preference of participants regarding sharing the ride with others is used to improve the overall traveler-centered performance of the SAVS operation.

V.4.1 Agent-based simulation accuracy enhancement

In this section we present the results of a simulation operated by Reza Vosooghi, a PhD Candidate with whom the survey was designed. The section is co-authored with him. The detailed version of the results is in (Vosooghi et al., 2019).

Agent-based simulation is used in estimating operational characteristics and planning (e.g. fleet specification and size) for future urban mobility solutions. Agent-based transport simulation needs a synthetic population that is based on socio-demographic data of individuals and households. These are extracted from public microdata and regional transport surveys (INSEE, 2018). An open source generator has been developed to this purpose (Kamel & Vosooghi, 2018). The socio-demographic data is then linked to activity-chains that are operated in the region, using existing transport systems to which SAVS has been added. The existing recent studies using agent-based simulation for AVs do not consider the influence of traveler specific attributes variation on decision making of agents regarding the use of AVs. One of the consequences of this is that the travel patterns generated by the simulation do not reflect the variety of travelers the synthetic population of agents represents.

To tackle this gap, age and gender were considered in setting the trip scoring function of agents in their decision to use (or not) the SAVS. The classical scoring function considers all the travelers having the same utility per mode of transport. The change that has been operated is that the constant utility of mode has been multiplied by an AV acceptance (or service trust) factor. For the SAVS as a mode of transport, this factor is a linear combination of age and gender factors. On the one hand, the results of the survey showed rates of AVs acceptance of 71.5% for male and 58,9% for female (Figure 50). The gender difference has been rounded to 20% and the gender factor has been set to 1.1 for male travelers and 0.9 to female ones. On the other hand, using the same logic, for both travelers younger than 45 years and older than 60 constant values are considered respectively, and for middle-age travelers this factor changes linearly.

Table 32 shows the changes on SAVS service demand after introducing AVs acceptance. As mentioned before, women and elder people are less likely to use the SAVS. As a result, *inactive travelers* used less SAVS in all scenarios compared to those when AVs acceptance are neglected. In the contrary, *students* used this mode more significantly. No significant change is observed in the active population however.

Table 32. AVs acceptance impact on SAVS user rate among each socio-professional category

Fleet number / Profiles	1000	2000	3000	4000	5000	6000	7000	8000	9000	10 000
Active	-2%	1%	4%	0%	2%	2%	4%	3%	1%	3%
Students	12%	36%	39%	35%	24%	26%	25%	13%	15%	12%
Inactive	-7%	-17%	-13%	-4%	-17%	-22%	-7%	-14%	-6%	-8%

Travelers with different socio-professional categories have consequently dissimilar daily trip patterns. Therefore, by introducing this variation, SAVS is used in a different temporal pattern. The hourly SAVS in-service rates of all scenarios shown in Figure 56 prove this variation. We can observe two peaks related to peak hours. As illustrated by shades of grey, peak areas corresponding to the case of neglecting AVs acceptance has higher values especially for the fleet size of between 2k and 7k vehicles. As mentioned above, SAVS use for *students* and *inactive travelers* have significantly changed in those scenarios and especially in the case of 3k fleet size. These traveler profiles have a different hourly trip patterns compared to active travelers, particularly concerning their secondary activities.

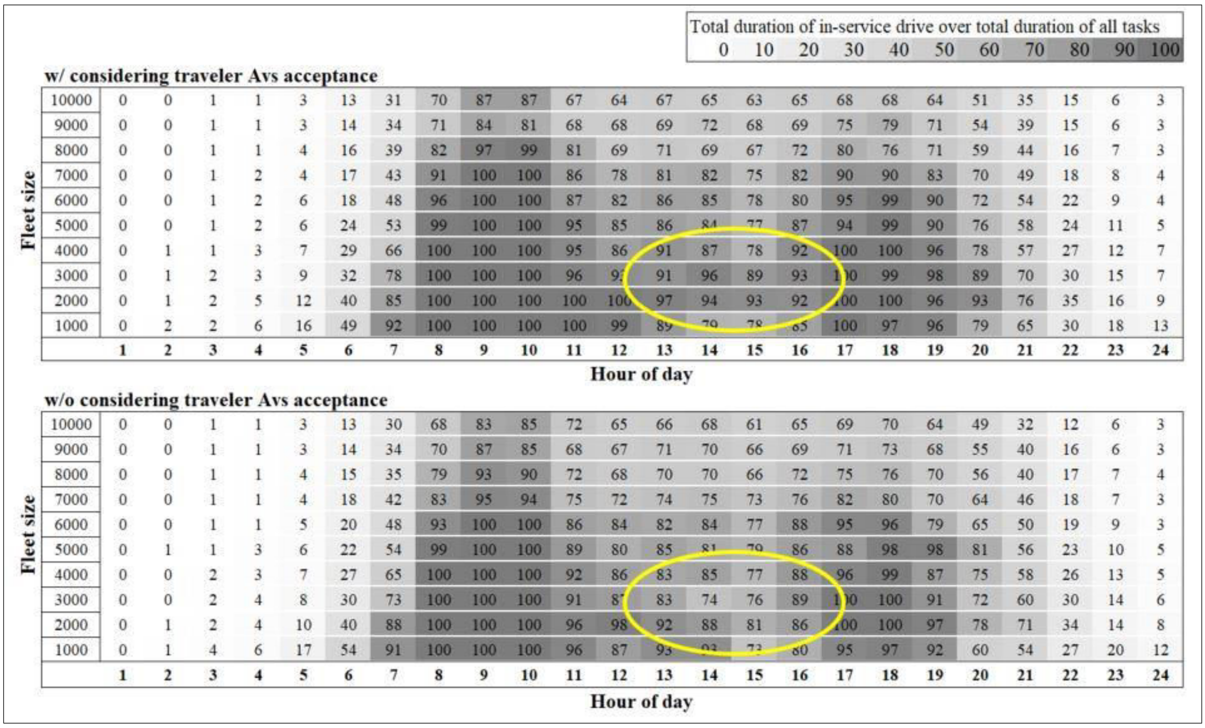


Figure 56. Hourly SAVS in-service rate with and without considering traveler AVs acceptance

These results showed that by introducing the influence of age and gender on AVs acceptance, we could simulate more accurate SAVS demand and in-service rate.

V.4.2 Introducing traveler satisfaction in shared mobility optimization models

In this section we present the outputs of the optimization model operated by Abood Mourad, a PhD Candidate with whom the survey was designed. The section is co-authored with him. More details of the optimization model are illustrated in (Mourad et al., 2018).

We introduce traveler profiles into an optimization model that is used to operate the SAVS. In order to match travelers in ride-share trips, the model uses the concept of meeting points. Thus, riders can be picked up at their origin locations or at a pickup meeting point, and dropped off at their destination locations or at a drop-off meeting point. These meeting points are usually located at feasible walking distances from traveler origin and destination locations. The main advantage of using meeting points is that they can lead to shorter detours compared to the case where travelers are only picked up/dropped off at their origin and destination locations (Stiglic et al., 2015) (Figure 57).

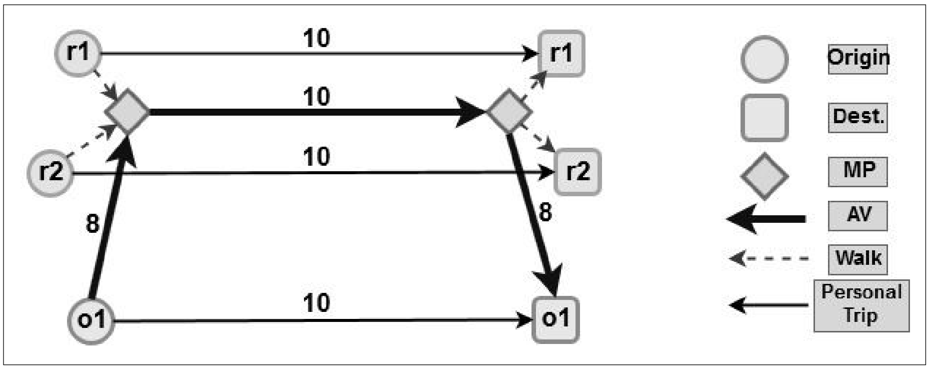


Figure 57- Ride-sharing with Meeting Points - Distance Savings

We start by defining the set of feasible matches (shared rides) between different travelers (phase-1). A feasible match respects the time constraints (time windows) of its participants, the capacity of the vehicle, and achieves a distance saving. The distance saving is obtained by comparing the distance of the shared trip with the sum of distances of individual trips (i.e. when no sharing is done and every traveler travels alone from his/her origin to his/her destination location) (see the example in Figure 57). Then, a matching optimization problem selects the best matches among the ones generated in phase-1 such that the number of matched travelers and the corresponding distance savings are maximized.

In the original model (Mourad et al., 2018), all traveler demands are assumed to be homogeneous, i.e. no traveler profiles are considered. Now, we introduce the concept of "VIP" travelers into the model and we analyze its impact on the operator revenues as well as the quality of the service provided. VIP travelers are those who are willing to pay extra 20% of their travel expenses in order to have a private on-demand AV (no sharing with others). The survey showed that 40% of participants who are willing to use the SAVS, are ready to pay extra 20% of the shared trips price.

In order to test the proposed model, taxicab trips from New York City are used to generate traveler trips (TLC, 2017). These trips correspond to short trips around city center with an average travel time of 9.04 mins. AVs are assumed to be homogeneous with a capacity of 4 places and 24 km/h speed. The maximum walking distance that travelers could accept to reach a meeting point is set to be 500 m. The AV transport cost per km is set to be 0.2 €/km based on (Cortright, 2017). In addition, the travel cost per km for non-VIP travelers is considered to be 0.2 €/km and for VIP travelers 0.24 €/km (20% more than the normal fee, reference to our survey) (Table 33). The 0.2 €/km fee is calculated using the same average monthly subscription price (220€) as presented to the surveys' participants. The average daily kilometrage is assumed at 36 km.

When tested over different instances of more than 3000 travelers, the results indicate that the service operator general benefit might decrease by up to 4% when 40% of the travelers are assumed to be inscribed to the VIP service. Although VIP travelers pay extra charges for the service, the operator will also have some additional cost. These additional costs are related to AV cost per kilometer. More precisely, an AV that was able to serve 2 or 3 travelers in the original case, might have to serve only a VIP traveler in the second case which might increase the system-wide AV-miles and thus increase the operational cost for the operator.

However, introducing traveler profiles into the system has the potential to enhance the quality of the service provided. First, for VIPs, they will have a more comfortable and relatively shorter travel times, as they will be transported directly from their origins to their destinations. In addition, for the non-VIP travelers, the results indicate that their average detour time will decrease by 11% (0.326 min) and that their average waiting time (at meeting points) will decrease by 5.5% (0.204 min).

Table 33. Instance Characteristics and Parameters

Trip pattern: short trips around city center	Parameters
Average number of travelers	3042
Average trip distance for traveler	3.64 km
Average trip time for traveler	9.04 mins
Max walking distance to meeting point	0.5 km
Walking speed	4 ft/s
Vehicle speed	24 km/h
AV capacity	4
AV cost per km	0.2 €/km
Traveler fee per km	0.2 €/km
VIP traveler fee per km	0.24 €/km

Summarily, by considering traveler profiles the SAVS operator invests 4% of its profit to increase overall traveler satisfaction. Indeed, the private ride preference of VIP riders is satisfied and generate a positive effect on the non-VIP riders who have shorter rides and less waiting time.

V.5 Conclusion

This chapter starts by relating the lack of consideration of traveler specific attributes in modelling and simulating transport systems. In the case of forecasting either traveler would adopt AVs in the future or not, it suggests a set of traveler specific attributes as explanatory assets to know who are travelers that are the most likely to use AVs. Introducing traveler specific attributes in analyzing technology acceptance of AVs and willingness-to-use of a SAVS allowed to identify profiles of potential users and a rationale behind choosing or refusing to shift towards a service involving AVs.

Moreover, an optimization model and an agent-based simulation have been proven to benefit from introducing these traveler specific attributes among their generic ones. Indeed, the accuracy of the demand on SAVS in the agent-based simulation has been improved and the temporal in-service rate has been altered, reflecting the heterogeneity of travelers. The optimization model considered traveler preference for riding privately the SAVS and showed that the overall satisfaction of traveler increases by doing so.

The outputs of the survey that has been used in this chapter produced different contributions. The first one is that it allowed to identify who are the travelers most accepting the AV technology regarding their socio-demographics. The second one is that it allowed to hierarchize the reasons for willing (or not) to use the SAVS for each mode of transport. The third one is that it identified the percentage of travelers who accept to pay extra for private rides among those willing-to-use the SAVS. The fourth contribution is that it allowed to identify additional reasons behind travelers' willingness (or not) to use the SAVS.

Besides, the survey confirms similar studies that have been conducted during the last five years on AVs acceptance and willingness-to-use. All of them consider high income as a positive influential factor as it represents the capacity to use a service that would be costly (Zmud et al., 2016) (Bansal et al., 2016) (Haboucha et al., 2017). Exceptionally, Kyriakidis et al. (2015) alone found out that higher income societies are more concerned by the technology and relate it to their awareness of its non-maturity. Male and young participants are always the most likely to accept AVs as a replacement mobility solution

(Haboucha et al., 2017) (Hohenberger et al., 2016) (Bansal et al., 2016) (Kyriakidis et al., 2015) (Payre, 2015) (Schoettle & Sivak, 2014) (Power J.D., 2012). The influence of the mode is not widely considered in these studies. However, PT users are often the closest to AVs acceptance (Zmud et al., 2016) (Krueger et al., 2016) (Haboucha et al., 2017).

Cost is widely recognized as the most important barrier participants consider in their willingness-to-use AVs in all their forms (shared or non-shared) (Howard & Dai, 2014) (Bansal et al., 2016) (Caldwell, 2014) (Krueger et al., 2016) (Fraedrich & Lenz, 2014). Comfort and security are given less importance as most of the surveys sample car drivers only. Time saving was considered also a positive factor by Accenture (2011) and KPMG (2013). Criteria that participants added were also present in literature. Participants who enjoy driving (Kyriakidis et al., 2015) , who are concerned by environmental friendliness (Howard & Dai, 2014) and safety (Bansal et al., 2016) are more likely not to use AVs. Safety is also believed to improve in AVs and therefore is a positive influential factor, like in (Fraedrich & Lenz, 2014).

The use of traveler specific attributes in the two transport model examples that have been shown in this chapter, relates an important observation. Indeed, transport operators and industrials attribute more importance to technical-centered variables in evaluating or forecasting transport systems. This way, they neglect the human-centered indicators that concern the satisfaction and the specificity of travelers. This chapter prove that they would win more by combining both traveler (specific) and technical (generic) variables, especially for transport systems that are not existing yet.

General discussion

In section I.3.6, we state that our main research question is; *"How can traveler experience be modeled to feed travel problems diagnosis?"*. We answered it by designing a traveler experience model (object of the Chapter II) from which we derived two other research questions that made the object of Chapters III and IV; "*What are the problems travelers experience using urban mobility systems?"* and *"What is the effect of a traveler -centered stimulus on travel problem generation effectiveness?"*.

The last chapter proposed an answer to the research question that is a trial to bridge design and transportation research; *"How can specific traveler attributes improve transport modeling and simulation of autonomous vehicles?"*. We presented each chapter with its own discussion. Now we present the general discussion of the thesis, integrating the chapters together.

Summary of the results

In this thesis, we have used an action research methodology with a design research purpose. Combining different methods, the objective was to improve the outputs of travel problem diagnosis and the performance of transport modeling and simulation regarding traveler-centered variables.

We started with a literature review bridging human-centered design and transportation. We then identified some challenges facing the practice of designing urban mobility systems related to their complexity. This helped us formulate our main research questions and set a research action protocol.

In the literature, we identified some limitations for modeling the traveler experience. Combining observations, interviews, and workshops, we set a conceptual model of the traveler experience that takes into account most of the complexity factors of urban mobility. The model included the concept of travel scenarios and defined a travel problem as being the difference between *real* and *expected* travel scenarios. This first version of the model was experimented on a case study of an on-demand bus service in Paris suburban area. We showed that travel problems are more than what travelers say and a more complete framework is needed to identify most of the problems travelers could express. This way the second research question was formulated aiming at identifying travel problems as perceived by travelers.

We have not found any papers modeling archetypes of travel problems that can be used by a designer to capture what travelers can say about their travel problems. We built a grounded theory of travel problems in the form of a taxonomy and a causal scheme. The grounded theory methodology used interviews from 6 urban mobility experts as lead-users to inform us about their travel problems. The taxonomy serves as a reference framework that represents the big picture of travel problems and the causal scheme to link all the identifiable problems and generate more. Together with the traveler experience conceptual model this contribution served to design a stimulus that is meant to help travelers, in a focus group, express better their problems. This was tested for cycling, walking, driving, and using public transport experiences in Paris, Singapore and Vienna.

We proposed an experiment in order to evaluate the impact of the stimulus on a travel problem generation session. We used quantity, variety and novelty of generated travel problems as the metrics to evaluate the impact of the stimulus. Two control groups were used as a baseline for non-stimulated problem generation and two experimental groups were provided with the stimulus. All groups participants were regular users of the same bus shuttle. Results showed that stimulated groups generate novel ideas with a greater variety covering most of the traveler experience dimensions than non-stimulated groups.

Coming back to our last research question, we conducted a survey. We used its results to add variations in travelers' profiles in transportation modeling and simulation. On the one hand, we identified profiles of travelers that are more likely to accept autonomous vehicle technology. On the other hand, we identified subjective criteria of travelers behind their willingness to use a shared autonomous vehicle service depending on their current mode of transport. We then showed the relevance of subjective travel attributes with regards to studying a mobility system and how these attributes can enhance the accuracy of agent-based models and the traveler preference dimension in optimization models.

After reviewing the results, we now translate these into both theoretical and practical contributions.

Contributions

This thesis contributed to both design and transportation research communities. On the one hand, it brought a solution to improve the problem diagnosis phase of the design process. On the other hand, it proved the value of having human-centered attributes in transportation modeling and simulation. Indeed, it brought elements of context and complexity from transportation research to design practice, and human-centered design qualities to transportation models (Figure 58). There are two types of contribution of this thesis; theoretical and practical.

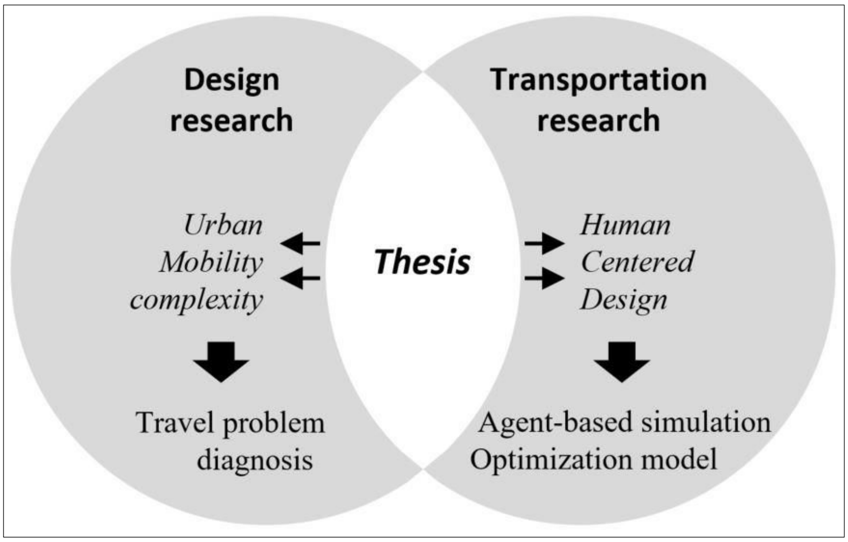


Figure 58. The position of the thesis in design and transportation research communities

Theoretical contribution

Combining the visions of design and transportation research, this thesis has two main theoretical contributions that reflect the constructivist side of its approach.

Extending the user experience (UX) framework

The user experience framework only covers segmented episodes of the traveler experience (Ortíz Nicolás & Aurisicchio, 2011), even in its developed forms (Kremer et al., 2017). Indeed, it does include most of the human-centered approaches such as contextualizing the user interaction with the system, involving the users in identifying the pains, etc. but fails at systematically including complexity factors of urban mobility. The traveler uses urban mobility systems through time and space. Each episode that happens in some place or moment systematically affects all the other episodes, even beyond the travel timeframe.

The traveler experience conceptual model (TXCM) includes all these factors and proposes a way to measure a travel problem. The TXCM presents a traveler experience as a *process* that happens in time and space when a traveler moves from one *urban activity* to another using different *technical systems*. It can happen through different *travel scenarios*. When a *situation* happens, it *shifts* a travel scenario from what the traveler *expects* to what happens *for real*. This may generate one or several *travel problems* if this difference is perceived as negative. The TXCM uses a problem narrative as an input and projects it through all the concepts.

Building a reference framework of travel problems

In transportation research, travel problems are dealt with on a case-by-case basis. Even though they detail the context of urban mobility in their definition, they are either specific to some traveler profile (Hjorthol, 2013), or to some transport mode (Katzev, 2003). In design research, travel problems are considered as usage pains (Osterwalder, Pigneur, Bernarda, & Smith, 2014, p.14). Although these consider different human-centered dimensions, they need the right tailoring to the complexity of urban mobility.

The travel problem taxonomy and causal scheme we proposed combines both urban mobility complexity and human-centered dimensions of the traveler experience. Using interview transcripts of lead users, the model breaks down twenty-two travel problem categories, organized in six blocks.

This can be expressed as: Depending on his/her [1. condition], a traveler experiences [2. changes] in his/her travel and [3. reacts] to it. These changes can be the result of some [4. state of the system] he/she uses or some [5. situation] that is external to the system. When repeated, the changes, the reactions, the situations, and the states of the system push the traveler to take [6. measures] with regards to his/her next trip.

Practical contribution

To fulfil our pragmatic knowledge claim, we proposed a practical use of the theoretical contributions to support travel problem diagnosis and to improve the accuracy of transportation modeling and simulation regarding traveler profiles. The first ready-to-use contribution is a stimulus that can be handed to travelers, in a focus group, to help them think of varied and rich problems. The second one is more of an add-on that is plugged in transportation models to allow them to consider travel subjective attributes, improving consequently their accuracy.

The two contributions target two different populations; engineering or innovation designers and transportation researchers or engineers.

A stimulus for travel problem generation (TPGS)

When travelers are asked to talk about their problems about urban mobility, they usually point out the technical problems around them (Read et al., 2017) or the behavior of other travelers (Fischer & Sullivan Jr., 2002). However, they know a lot more than this. They indeed need a support to dig deeper in their memory to tell how they feel and why they feel bad when a problem occurs.

To capture the knowledge of travelers about their travel problems, we designed a stimulus that uncovers aspects of the traveler-experience they do not think of intuitively. After testing it with two groups of 6 PhD students, we used it with 6 transport experts and 6 non-experts groups of travelers. Results showed that the stimulus allowed both of them generate varied and novel travel problems than the groups that generate problems without any support. As a consequence, the stimulated groups help designers think of urban mobility solutions that cover most of their travel problems.

An add-on to transportation modeling and simulation

The outputs of most transportation models and simulations do not reflect the subjective dimensions of the trip they represent. Rather, they target variables that are directly projected on time, space, and cost (Cascetta, 2009) (Ortuzar & Willumsen, 2011). They miss accuracy regarding variables that represent the travelers. In the case of future transportation systems such as Automated Vehicles, the preferences of travelers are unknown. Therefore, they need to be predicted using stated preference surveys for example.

To fill this gap, we introduced traveler specific attributes which are socio-demographics, evaluation scoring and private ride preference. We propose two ways of introducing these in transportation models. By using the results of a stated preference survey, we have identified profiles of travelers who are most likely to adopt an autonomous vehicle service (SAVS) in the future.

The first use of these profiles was in an agent-based simulation. In the scoring function, we added a preference factor related to age and gender reflecting their influence on the willingness-to-use the SAVS. The results of the simulation showed that the SAVS is used more outside peak hours than when no traveler preference variation is considered.

The second use of traveler profiles was in an optimization model. The survey showed that 40% of pro-AVs travelers are willing to pay extra to have a private ride. In maximizing the total number of served riders, the results always show several rides that are performed with one rider in vehicle. By matching these rides with the travelers willing to pay extra, the operator could increase its incomes.

Methodological contribution

User/human-centered design research suggests that including the user/human in the design loops as early as possible increases the likeliness of the designed solutions in meeting the wants and needs of their users (Abras et al., 2004) (Boy, 2013, p.44). Transportation research community, in turn, emphasizes the urge of integrating the travelers in designing transportation systems (OECD, 2014, p:16). However, both communities do not fully exploit the potential of travelers in bringing valuable insight to the early stages of the design process of urban mobility systems. We propose a triple integration of travelers-in-the-loop;

Travelers as a provider of data

In transportation research, travelers are also used as a source of data. The most frequent way of doing so is to consider travelers as points in space and time. This informs on the modes use, spatial density, travel time, and all the related variables that can be extracted from spatio-temporal variables of travelers. Moreover, travelers are also asked to evaluate their experience using different transport systems in the form of satisfaction or preference surveys (Bradley & Kroes, 1992). These lack, however, asking for detailed feedback about what travelers feel and suggest on the problems they face. Even when they do so, the feedback is not exploited the way travelers are expecting.

We suggest that travelers can also help designers in setting the evaluation criteria under which an urban mobility system can be evaluated. Therefore, travelers should have the opportunity to express themselves about their problems and these should not be neglected. We showed (Chapter V) that even in a stated preference (SP) survey, travelers can add new relevant criteria to evaluate a future mobility system.

Travelers as a source of knowledge

Von Hippel (1986) emphasized early enough the importance of the users as creative consumers that can bring ideas and enlighten designers about their hidden needs. However, the lead-user method is rather focused on developing solutions for pre-defined problems and involves lead users in developing the solution rather than defining the problem (Von Hippel, 1986).

In Chapter III, we interviewed 6 lead users who are urban mobility experts who assumed to tell more about their travel problems than a regular traveler can. We used the insights on their traveler experience to design a taxonomy of archetypal travel problems that served as a support for getting more from regular travelers. This proved travelers can be a source of knowledge and not only a source of data in pre-defined data-structures.

Travelers as stakeholders

Lindenau & Böhler-Baedeker (2014) suggest that it is important to consider travelers as a stakeholders in identifying mobility problems, proposing, evaluating, and implementing solutions that go with a co-constructed vision of the city. Dietz & Stern (2008) suggests that the lack of expertise of travelers may sometimes alter the quality of the decisions that are made with them. However, in user-experience research, this is not a barrier that should prevent a designer from getting the best from users (Sharon, 2012).

We propose a way of overcoming this issue by using the knowledge gained from lead travelers in guiding regular travelers to stimulate their memory and tell more about their experience. This way, we involved travelers not only by using what they say but also by giving them appropriate means to become an active stakeholder whose lack of expertise is not a problem anymore.

Research validation

The scientific quality of a research activity can be evaluated and validated regarding several criteria. Ben Ahmed et al. (2010) identified twenty-six of them to evaluate a model, classified into four blocks; (1) model ontology: the concepts and their formalism; (2) model functioning: the interaction of the model with its users, and with normal and abnormal conditions; (3) model teleology, i.e. how far does the model fulfill its users' needs/goals; (4) model evolution: how far and well the model can evolve.

To fulfil each of the evaluation dimensions, appropriate protocols need to be set and executed. Moreover, most of the research objects of this thesis are qualitative in nature, which makes them even harder to validate (Noble & Smith, 2015). Therefore, what has been done in the time frame of this thesis only covers some of the validation dimensions.

Evolving through the action research cyclic process, the validation of this thesis took three different forms; case study, empirical, and industrial (Table 34). Each of the validation methods covered several research objects. Covering the ontological dimension, the Traveler eXperience Conceptual Model (TXCM) and the Travel Problem Taxonomy (TPT) were validated using one case study on a demand-responsive transport service. To evaluate the functioning of the Travel Problem Generation Stimulus (TPGS) and the Travel Subjective Attributes (TSA) respectively, we conducted a focus group experiment and a model modification trial as empirical protocols. Each of them was respectively applied on a bus shuttle service and a shared autonomous vehicle service. The teleological dimension represented by the TXCM and the TSA was evaluated with the industrial partners of Anthropolis using semi-opened interviews.

Table 34. Research validation *method*s of the thesis

Dimension	Model ontology	Model functioning	Model teleology	Model evolution
Research object	- TXCM - TPT	- TPGS - TSA	- TXCM - TSA	All research objects
Validation method	Case study	- Experiment - Case study	Interview with chair's partners	Action research

Case studies

Case studies served both as an illustration and a validation method of the use of the research objects of this thesis. Following the main research question of thesis and the last one, two case studies cover respectively the diagnosis of an urban mobility system and the use of traveler specific attributes in forecasting a future urban mobility system.

Diagnosing a demand-responsive transport service

The input material used in this case study was a list of eleven travel problems reported by the most experienced bus driver in the service in the Paris area. By depicting these problems through the TXCM, we concluded that:

- The more perspectives we have of travel problems the more readily we can improve the urban mobility system.
- It is vital to have different stakeholders of an urban mobility system together to have a better understanding of travel problems.
- There is a need for archetypes of travel problems in urban mobility systems diagnosis.

This last conclusion generated a research question that we answered through the grounded theory building of a travel problem taxonomy and a causal scheme. We prove, using two of the eleven problems, that by having a repository of travel problem archetypes we obtain a better understanding of naturally formulated travel problems. Indeed, we can either clarify a complex-framed problem or enrich a simple-framed one.

Forecasting the demand on a shared autonomous vehicle service

We conducted an online survey with over 400 inhabitants of the greater Paris region. It served at estimating their willingness-to-use of a shared autonomous vehicle service (SAVS). We used the results of the survey to add subjective travel attributes to an optimization model and an agent-based simulation.

Regression trees allowed us to identify profiles of travelers that are most likely, and other ones that are most unlikely to use the SAVS. Moreover, we were able to hierarchize the reasons behind each of the two choices. Participants had also the possibility to freely identify other reasons apart from the ones proposed to them. This allowed us to identify new important factors that were not expected, such as environmental concern and freedom to drive.

Empirical studies

To prove the value of the research objects that arose from our understanding of the traveler experience and travel problems, we conducted two empirical studies.

The experiment of problem generation stimulation

Relatively to the other validation forms, we chose to concentrate our efforts on evaluating the stimulus supporting travel problem generation (TPGS) because it represents the "design support" as a research object to answer our first research question *"How can traveler experience be modeled to feed travel problems diagnosis?"*.

We designed an experiment with four groups, all using the same urban mobility system, a bus line in this case, in the same route, every day. Two control groups are the baseline for non-stimulated problem generation and two experimental groups are provided with the stimulus. The two sets of groups are composed of one group of urban mobility experts and one group of non-experts. We adapted three metrics from the literature on ideation outputs effectiveness to use them in evaluating the stimulus. We compared the quantity, the variety and the novelty of the generated travel problems in each group. Variety represented the number of dimensions of the traveler experience covering the generated problems in each group. Novelty represented how new the additional generated problems in each traveler experience dimension are regarding the other dimensions.

The groups that did not receive the stimulus represented the classical way participants in focus groups are asked to generate problems. Results showed that these groups score less in variety and novelty of problems than the stimulated groups.

The trial of model modification

Our representation of the traveler experience has been translated into travel subjective attributes as relevant variables to forecast the behavior of a new urban mobility system (the SAVS). These encompass in addition to socio-demographics, the motives of a person to adopt or not an autonomous vehicle solution in the future.

Considering some socio-demographics (age, gender, income) correlations with AVs acceptance, among the agents allowed us to uncover a higher demand in the simulation during off-peak hours. This reflected an actual activity of some travelers who do not need to use transport modes during peak-hours. In the optimization model, we introduced traveler preference regarding sharing or not sharing the ride with other travelers. This allowed us to acknowledge a shortfall for SAVS operator in satisfying overall (ride-sharing users) and specific needs (VIP users) of the users of its service.

Industrial studies

The potential users of the research objects of the thesis are professionals either in an industrial context such as in the companies of the Anthropolis research chair or anyone who has an interest in knowing more about how well urban mobility systems perform regarding the perception of travelers. For this thesis we relied on two populations to evaluate some of its outputs. The first population is composed of 7 professionals working in the R&D, marketing, or innovation services of urban mobility companies that are partners of Anthropolis. The second population is a mix of design students and professionals from a big French energy company (3 students and 3 professionals), in the context of a X-month innovation project.

With urban mobility professionals

We interviewed representatives of the 5 industrial partners after introducing them to the different uses that can be made over the research object of the thesis. We asked them to give free feedback on the TXCM model and the causality network uses, then they reacted on how this could be applied to in their future projects.

The positive feedback was:

- Propose a value for the users that is embedded in the reality of their problems (like Uber did for taxi users).
- Allows to systematically identify travel problems and learn from existing solutions to avoid repeating the same mistakes in next generations of solutions.
- Gives the possibility to zoom in and out to uncover more problems.

The negative feedback was:

- The traveler experience is so personalized that it could generate negative overall results when deployed in the solutions (recommended to see the case of IDZen/Zap (SNCF, 2013)).
- The final objective of introducing a new dimension to some industrial context should be deeply studied and discussed with the professionals.

The different interlocutors proposed some of the projects they work on or know about, on which the model could be applied and tailored. Some of these projects were:

- Autonomous vehicle experimentation with groups of travelers.
- Satisfaction surveys with users of suburban trains.
- Sensorial comfort of travelers in tramway wagons.
- Carsharing mobile application for collaborators.

With energy professionals and students

On a different domain from mobility, we used the travel problem taxonomy as an inspiration to generate more problems related to the indoor air quality of houses. The causal scheme of the taxonomy was presented to participants of a focus group with some adaptations to the context of the study. For example, beyond travel change was replaced by outdoor change. The participants were considered as lead users because of their expertise on the topic. They were given two inputs; a list of six classes of problems and the causal scheme. Each participant was asked to generate as much problems as he could, using his knowledge on indoor air quality and the different problem categories of the taxonomy. Besides the fact that the list of problems has multiplied by 4, the professionals of the participants expressed their interest in the capacity of the causal scheme to account for the combination of the condition of the user and the failure of the system to accomplish a function. This focus group exercise showed somehow that the concept of travel problems as modeled can be also generalized to other contexts besides urban mobility.

Limitations and further research

Several limitations can be identified about this thesis on both the methodology and the research objects. These limitations allowed us to think of future improvements and evolutions.

Measuring the performance of an urban mobility system

The performance of urban mobility systems can have different meanings in the literature. Indeed, each research sets its own definition for “performance” depending on the research focus and purpose.

Satisfaction as performance

We used a satisfaction scale when asking participants of the survey score each satisfaction criterion. However, these criteria were too generic and not mature enough regarding the systems to be evaluated and their relation to AVs. For instance, car drivers had an important criterion for not willing to use an AVs which was the joy of driving. Our diagnosis of car driving as a mode of transport was not accurate enough to put it among the criteria participants had to score. As action research is an open cyclic process, taking into account the additional criteria participants proposed will allow a more accurate next version of the survey.

A list or even a network of travel problems gives an overview of how an urban mobility system fails at satisfying its users. However, the cost and time constraints professionals face in designing new mobility solutions need a method to systematically prioritize these problems. Therefore, there is still a need for the virtues of network theory such as betweenness and closeness centrality (Freeman, 1977) in setting this hierarchization metrics for the causality network of travel problems, beyond the scores that travelers can put for each problem as a node of the network.

Connections with techno-centered indicators

To make sense for transport operators and urban mobility professionals in general, the traveler satisfaction criteria or travel problems metrics need to be connected with their daily practice. What we defined in this thesis is the value the traveler is expecting from an urban mobility system. In the big picture, both travelers and professionals expect value from an urban mobility system (Lindenau & Böhler-Baedeker, 2014).

Although we tried to connect (in Chapter V) the technical-economic variables in optimization and agent-based models to traveler-centered variables we still miss the meaning of this connection at the level of the traveler experience. For example, we do not know for which traveler a time saving of 11% over a trip of 10 minutes is of value. Therefore, there is a need for verification with travelers of what we assume being a traveler-centered approach to transportation models.

Travel problem diagnosis

The proposed design support is used in focus group format of travel problem generation and attempts to enrich transportation models with travel subjective attributes. We demonstrated the value of doing so. However, the diagnosis of urban mobility systems that are used by millions of travelers that have different expectations and perception of travel problems need even more systematic methods. Focus groups work well with small samples to produce knowledge on travel problems but cannot produce reports of diagnosis for large samples. Moreover, to profit from existing data of national transport surveys that have dozens of thousands of participants, it is vital to create the right connections between travel problems and the attributes used in these surveys.

Automation of travel problem identification and causation

The travel problem archetypes proposed in Chapter III are a first version of an ontology that can be automatized with natural language processing. Indeed, the travel problems raw format is a text. Therefore, there is a possibility for automatic semantic detection using the database of travel problems that we linked to each travel problem archetype. With machine learning algorithms, it would be possible to set the travel problem causation network for an urban mobility system using only what travelers write on social media comments for example like in (Kanakaraj & Guddeti, 2015).

Using existing traveler data

For optimization and agent-based models, we proposed to use the existing variables and data such as travel distance, cost, activity-chains, or socio-professional categories. We linked these to our travel subjective attributes to gain more traveler-centered insights. However, we did not propose a way to project these insights on the travel problem level. For example, we used correlation between age, gender, and socio-professional categories to set a different behavior of agent in non-peak hours. This does not inform about travel problems at the scale of travelers. Travel problems can be set as categorical variables and be linked to the existing variables (e.g. socio-demographics, modes of transport, operational performance) through a correspondence analysis for example like in (Diana & Pronello, 2010).

Research evaluation with usability tests

The validation methods we used to evaluate the research objects accounted for scientific arguments. However, in the industrial context, even if a model proves its scientific value, it is not systematically valued among professionals who are meant to be the users of this model. One of the reasons behind this mismatch is that design support material produced long-term effects and that the use of the support is operated in an environment that has multiple uncontrolled variables (Blessing & Chakrabarti, 2009, p.213).

The experiment we conducted in a focus group format proves the value of the stimulus under the set conditions. This means that with different experimental conditions, more uncontrolled variables would arise and modify the results. These experimental conditions are what should be identified from real practice of professionals when they conduct focus groups. Moreover, it could be checked if focus group activities are a common practice for the Anthropolis industrial partners and how important they are for their travel problem diagnosis activities.

Even though we asked for feedback from urban mobility professionals among the industrial partners of Anthropolis, the natural continuity of the cycles of the action-research methodology is to conduct usability tests with professionals (Marcus et al., 2011). The research objects should be evaluated in real-world conditions and profit from their users' expertise. Indeed, a learning process should be established in diagnosing the practices of professionals and determining the gaps that our research object could fill. Then, these should be adapted and tested with real industrial projects such as those identified in the industrial research validation section.

An ongoing collaboration of Anthropolis is established with TUM CREATE, the joint research program between Technische Universität München in Germany and Nanyang Technological University. They are working on an autonomous shuttle in a multidisciplinary team. It is an adapted environment to test the research objects of this thesis in future works of the chair and develop approaches to anticipating AVs use like in (Nelson et al., 2013).

Summary for the Anthropolis research chair

We have directly contributed to 8 deliverables dealing with the state-of-the-art of human-centered urban mobility, user research, and impact assessment. These are mainly related to its first axis (Figure 59) and some of the third one.

All this thesis' choices for observation, experimentation, and interviews sampling were made accordingly to Anthropolis partners consensus.

The survey in Chapter V, is a joined work and contribution common to three PhD students of the Anthropolis Chair, making sense to link engineering design, simulation and optimization issues.

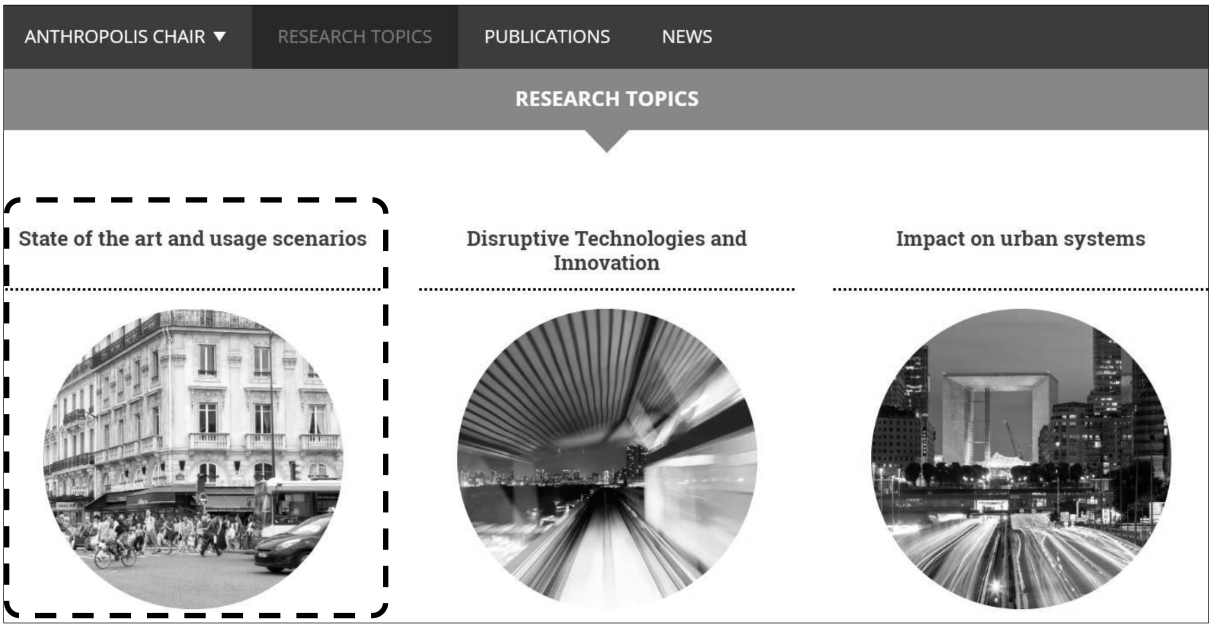


Figure 59. Anthropolis research axes (Anthropolis, 2018)

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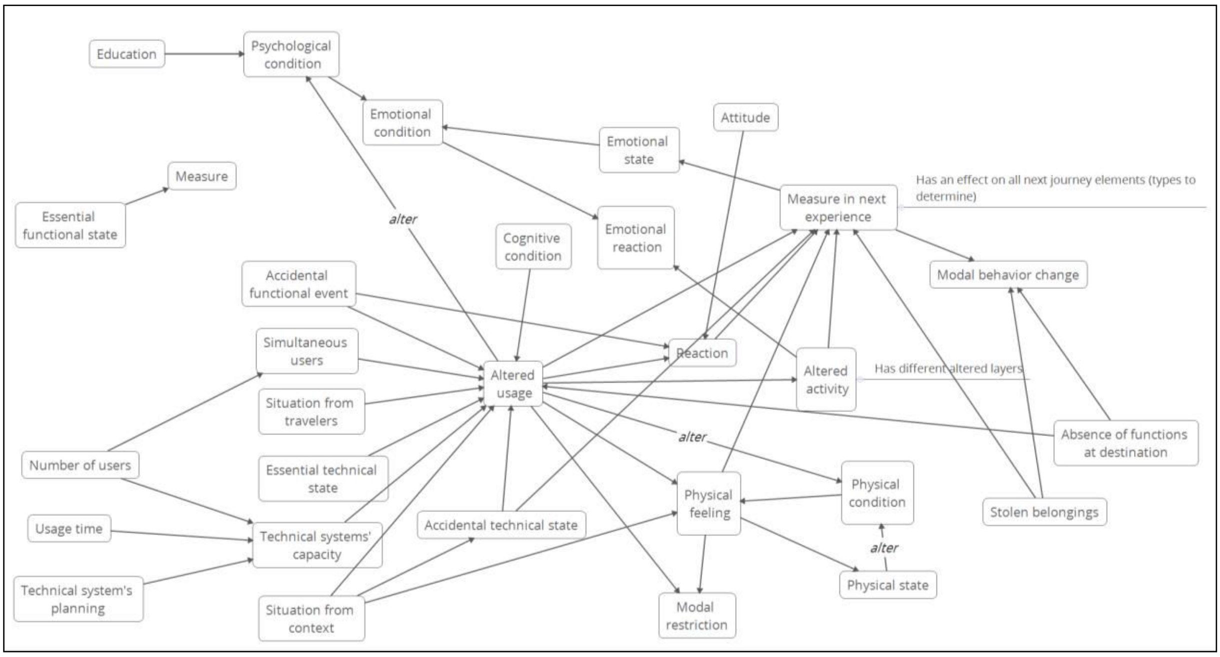
Appendices

1. Travel problems categories from initial and focused codes

Problem	Instances	Definition
Accidental functional event	Train late/canceled, Screen shows wrong information, train terminates before destination	State of the system that is accidental to its intended functioning
Altered usage	Wait/Buy coffee, find alternative, more crowd, cannot listen to podcast, get wet, getting annoyed, hit by a car, getting slowed down, unstable cycling between two cars, slip / fall, hit cyclers / pedestrians, find farther places, interact with traffic, fall	Action that traveler operates when a change in his/her expected travel happens
Altered activity	Arrive late, miss flight, Tasks delayed, stressed all day	Change that is operated on an activity at destination
Reaction	Inform activity, say mean comments/ shout, say sorry/ Smile / be nice	How the traveler reacts to a change in his/her expected travel
Emotional reaction	Ashamed/ afraid of others' perception, disappointed/ angry, worry about parking, getting mad / feel bad / fear	How the traveler reacts emotionally at a change in his/her expected travel
Situation from travelers	Colleagues in same wagon	Situation provoked by fellow travelers
Measure in next experience	Take the "free of colleagues" wagon, avoid tram rail, pay attention to tram rail (use a right angle), pick longer & less hilly routes, cyclers pay attention to trucks, consider big enough buffer, wear appropriate clothes, find new routes, search a safe parking place, watch my steps	Change in next traveler experiences
Situation from context	Rain/Cold wind	Situation provoked by external factor to the system
Physical feeling	Get cold, get injured, sweat	Feeling of the body
Modal restriction	Take the bus instead of walking	Obligation to use a specific mode instead of a desired one for a specific travel
Essential functional state	20 mins two trains gap	State of the system that is essential to its intended functioning
Measure	Plan/wait	Measure taken to bear with the essential state of the system
Simultaneous users	Cycling with pedestrians/cars in shared path, drivers overtaking closely, pedestrians walking slowly / brusque movements in shared path with cyclers	Situation provoked by the simultaneous use of the system by travelers
Essential technical state	Narrow shared lanes for drivers, parked cars and cyclers; slippery tram rails for bikes; hilly city; blind spots in trucks	State of the system that is essential to its design
Technical system capacity	No parking places, no cycling paths	Limitation of the capacity of the system
Absence of functions at destination	No shower at work	Absence of facilities or functions at destination
Stolen belongings	Bike stolen while parked	Stolen belongings

Accidental technical state	Frozen and slippery ground	State of the system that is accidental to its design
Education	Be punctual	How education of traveler conditions his/her behavior
Psychological condition	Low self-reliability	How traveler is conditioned psychologically
Emotional condition	Stressed	Emotional nature of traveler
Emotional state	Not stressed	Emotional state of traveler before travel
Physical condition	Uncomfortable with cold, weak immunity	How traveler is conditioned physically
Physical state	Get sick	Physical state of traveler before travel
Cognitive condition	Kids don't know how dangerous a truck is	How traveler is conditioned cognitively
Modal behavior change	New default route (can be temporal), Use more PT, cycle less, abandon cycling	Change in next traveler modal experience
Attitude	Drivers not accepting cyclers	Attitude of fellow travelers
Number of users	With more cyclers drivers pay attention, new drivers come to the neighborhood	Situation provoked by a big number of travelers
Usage time	People come to work early	Situation provoked by the times travelers use the system
Technical system planning	Parking places are not created	State of the system does not evolve in design or functioning



Travel problems causality scheme from initial and focused coding

2. Travel problems categories after code refinements (Vienna interview only)

Problem	Definition	Instances
Essential functional state	State of the system that is essential to its intended functioning	20 mins two trains gap
Accidental functional state	State of the system that is accidental to its intended functioning	Train late/canceled, Screen shows wrong information, train terminates before destination
Essential technical state	State of the system that is essential to its design	Narrow shared lanes for drivers, parked cars and cyclers; slippery tram rails for bikes; hilly city; blind spots in trucks, No parking places, no cycling paths
Accidental technical state	State of the system that is accidental to its design	Frozen and slippery ground
Technical system planning	State of the system does not evolve in design or functioning	Parking places are not created
Situation from context	Situation provoked by external factor to the system	Rain/Cold wind, colleagues in same wagon, bike stolen while parked
Absence of functions at destination	Absence of facilities or functions at destination	No shower at work
Simultaneous users	Situation provoked by travelers using simultaneously the system	Cycling with pedestrians/cars in shared path, drivers overtaking closely, pedestrians walking slowly / brusque movements in shared path with cyclers
Number of users	Situation provoked by a big number of travelers	With more cyclers drivers pay attention, more crowd, new drivers come to the neighborhood
Usage time	Situation provoked by the times travelers use the system	People come to work early
Active usage change	Action that traveler takes when a change happens in his/her expected travel	Wait/Buy coffee, find alternative, find farther places, inform activity
Passive usage change	Change a traveler undergoes when a change happens in his/her expected travel	Hit by a car, getting slowed down, unstable cycling between two cars, slip / fall, hit cyclers / pedestrians, cannot listen to podcast, get wet, interact with traffic
Activity change	Change that is operated on an activity after travel	Arrive late, miss flight, Tasks delayed, stressed all day, get sick
Modal restriction	Obligation to use a specific mode instead of a desired one for a specific travel	Take the bus instead of walking
Avoidance measure	Measure a traveler takes to avoid a scenario that happened in the past	Take the “free of colleagues” wagon, avoid tram rail, pick longer & less hilly routes, find new routes, search a safe parking place, use more PT, less/abandon cycling
Just-in-case measure	Measure a traveler takes to protect him/herself from a scenario that happened in the past if happens again	Consider big enough buffer, wear appropriate clothes, plan, wait
Cognitive measure	Additional attention a traveler makes preventing a scenario that happened in the past	Watch my steps, cyclers pay attention to trucks, pay attention to tram rail (use a right angle)

Behavioral reaction	How the traveler reacts to a change in his/her expected travel	Say mean comments/ shout, say sorry/ Smile / be nice
Emotional reaction	How the traveler reacts emotionally to a change in his/her expected travel	Ashamed/ afraid of others' perception, disappointed/ angry, worry about parking, getting mad / feel bad / fear, getting annoyed
Physical reaction	How the traveler reacts physically to a change in his/her expected travel	Get cold, get injured, sweat
Psychological condition	How psychological condition of traveler conditions his/her behavior before travel	Low self-reliability, not/stressed, punctual, drivers not accepting cyclers
Physical condition	How traveler is conditioned physically before travel	Uncomfortable with cold, weak immunity
Cognitive condition	How traveler is conditioned cognitively before travel	Kids don't know how dangerous a truck is

3. Saturated travel problems categories

Problem	Definition	Instances
Essential functional state	State of the system that is essential to its intended functioning	20 mins two trains gap, **line packed at peak hours, bus driver does not speak English, limited bus frequency increase, expansive car ownership, expansive car-sharing service, limited zone coverage, large network to be operated, operator not having the information, slow calculation of recovery plan, inconvenient ticket doors closing, intermodal non-synchronicity, need for drivers, bus stop for different buses,**
Accidental functional state	State of the system that is accidental to its intended functioning	Train late/canceled, Screen shows wrong information, train terminates before destination, **breakdowns, new bus driver does not know stations names, train not respecting schedule, (not)inform/ wrongly/ imprecisely, non-consistent displayed times, bus driver not respecting station slot, blocked ticket validation, inertia in strong road curvature, bus driver braking hard,**
Essential technical state	State of the system that is essential to its intended design	Narrow shared lanes for drivers, parked cars and cyclers; slippery tram rails for bikes; hilly city; blind spots in trucks, no parking places, no cycling paths, **no bag-racks, no bar to hang on, labels on reserved seats, limited road lanes, bus not allowing air to circulate, narrow ticket doors/corridors/stairs, incoherent widths, modal transfer under-capacity, need to buy ticket on board, articulated bus, need to hold on a bar, no air conditioner, small bus stop,**
Accidental technical state	State of the system that is accidental to its intended design	Frozen & slippery ground, **bad/weird smell, cold seats,**
Technical system planning	Essential state of the system does not evolve in design or functioning	Parking places are not created, **no new lines, no increase in bus frequency, bad urban planning**
Situation from context	Situation provoked by external factor to the system	Rain, Cold wind, colleagues in same wagon, bike stolen while parked**, traveler playing loud music, children yelling, students shouting,**

Simultaneous users	Situation provoked by travelers using simultaneously the system	Cycling with pedestrians/cars in shared path, drivers overtaking closely, pedestrians walking slowly / brusque movements in shared path with cyclers, **travelers stop moving in/take big space, giant backpacks, not giving seats for people in need, traveler hold phone against you/ want to continue their activities on board/ don't feel the need to squeeze in, non-respect of stroller place, people don't shower, no seated place available, travelers climb slow/fast, queue**
Number of users	Situation provoked by the big number of travelers	With more cyclers drivers pay attention, more crowd, new drivers come to the neighborhood, **population growth, too much physical contact, many people in the way, crowd noise, overdemand**
Usage time	Situation provoked by the times travelers use the system	People come to work early, **peak hour, morning delay**
Active usage change	Decision-based action that traveler takes when a change happens in his/her expected travel	Wait, buy coffee, find alternative, find farther places, inform activity, **check for breakdown possibility, squeeze the way in/out**
Passive usage change	Change a traveler undergoes when a change happens in his/her expected travel	Hit by a car, getting slowed down, unstable cycling between two cars, slip / fall, hit cyclers / pedestrians, cannot listen to podcast, get wet, interact with traffic, **miss train, get pushed, cannot walk faster, more waiting time, cannot do anything, prevented to take alternatives, losing choice, impossible activities onboard, get hit by travelers' bags/arms, wasting time doing nothing, unable to plan activities on board,**
Beyond travel change	Change that is operated on traveler's life before and after travel	Arrive late, miss flight, tasks delayed, stressed all day, get sick, **delay leaving workplace, evening cut shorter, arrive later than supposed, unachieved personal schedule, bad mood at work, waking up remembering travel problems, loose trust in schedules,**
Modal restriction	Obligation to use a specific mode instead of a desired one	Take the bus instead of walking, **take public transport (restricted car use), not having the budget for car ownership, being obliged to use an unsatisfactory solution, not having itinerary alternatives**
Avoidance measure	Measure a traveler takes to avoid a scenario that happened in the past	Take the "free of colleagues" wagon, avoid tram rail, pick longer & less hilly routes, find new routes, search a safe parking place, use more PT, less/abandon cycling, **not use a new car-sharing service, abandon PT**
Just-in-case measure	Measure a traveler takes to protect him/herself from a scenario that happened in the past if happens again	Consider big enough buffer, wear appropriate clothes, plan, wait, **4min just in case**
Cognitive measure	Additional attention a traveler makes preventing a scenario that happened in the past	Watch my steps, cyclers pay attention to trucks, pay attention to tram rail (use a right angle)

Behavioral reaction	How the traveler reacts to a change in his/her expected travel	Say mean comments/ shout, say sorry/ Smile / be nice, **glare, weird looks, check if someone needs the reserved seat, non-respect of queues, not holding on the bar strongly enough,**
Emotional reaction	How the traveler reacts emotionally to a change in his/her expected travel	Ashamed/ afraid of others' perception, disappointed/ angry, worry about parking, getting mad / feel bad / fear, getting annoyed, **nervous, irritated, pressure, frustrated, mood shift,**
Physical reaction	How the traveler reacts physically to a change in his/her expected travel	Get cold, get injured, sweat, **backache, foot pain, muscle shock,**
Psychological condition	How psychological condition of traveler conditions his/her behavior before travel	Low self-reliability, not/stressed, punctual, drivers not accepting cyclers, **hate noise, mood, need peace, afraid to miss the stop, scared to fall, superstitious, do not care, do not want public shaming**
Physical condition	How traveler is conditioned physically before travel	Uncomfortable with cold, weak immunity, **don't like promiscuity, reduced mobility, hardship to stand for long,**
Cognitive condition	How traveler is conditioned cognitively before travel	Kids don't know how dangerous a truck is, **not aware of the surrounding with headphones/on smartphones, perception of personal space, do not speak a foreign language, not paying attention, not knowing alternative routes,**
Activity condition	How what traveler does after travel conditions his/her travel	No shower at work, **need to be on time to work**

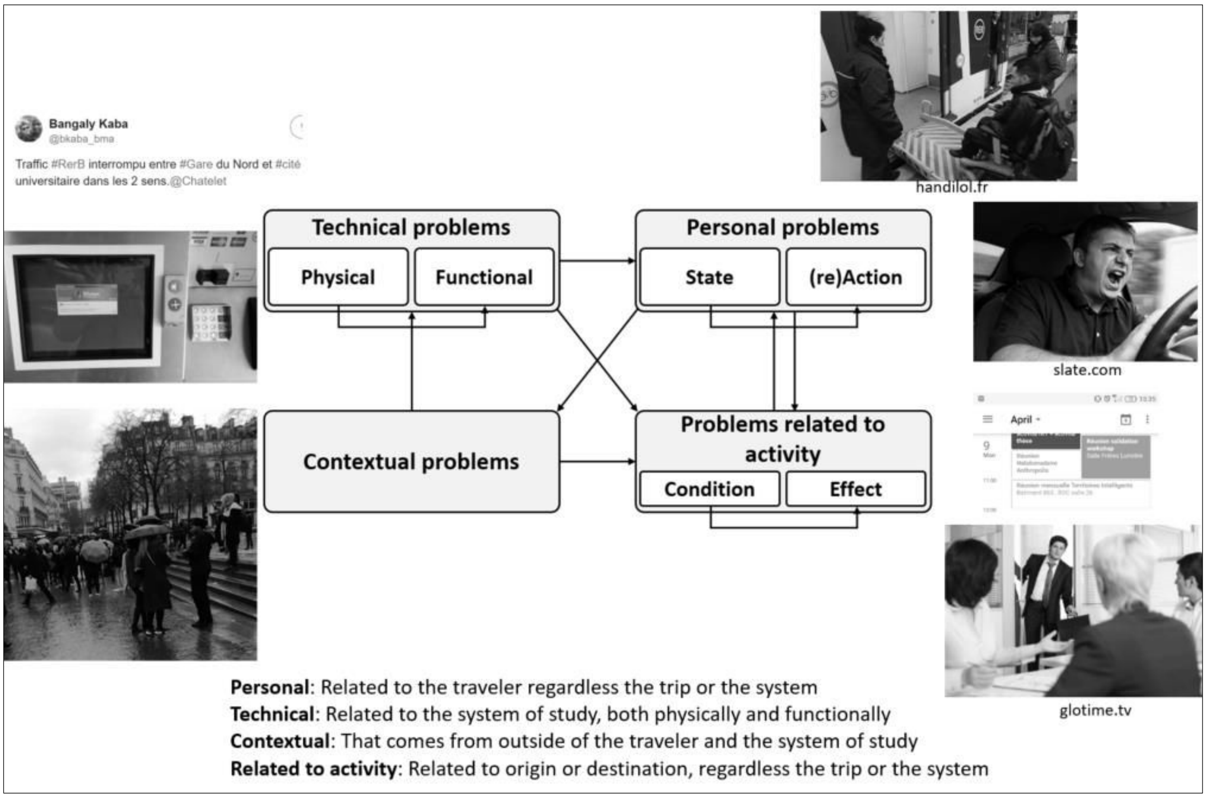
4. Travel problems categories from theoretical sampling

Problem	Definition	Instances
Essential functional state	State of the system that is essential to its intended functioning	20 mins two trains gap, **line packed at peak hours, bus driver does not speak English, limited bus frequency increase, expansive car ownership, expansive car-sharing service, limited zone coverage, large network to be operated, operator not having the information, slow calculation of recovery plan, inconvenient ticket doors closing, intermodal non-synchronicity, need for drivers, bus stop for different buses,**
Accidental functional state	State of the system that is accidental to its intended functioning	Train late/canceled, Screen shows wrong information, train terminates before destination, **breakdowns, new bus driver does not know stations names, train not respecting schedule, (not)inform/ wrongly/ imprecisely, non-consistent displayed times, bus driver not respecting station slot, inertia in strong road curvature, bus driver braking hard, morning delay**
Essential technical state	State of the system that is essential to its intended design	Narrow shared lanes for drivers, parked cars and cyclers; slippery tram rails for bikes; hilly city; blind spots in trucks, no parking places, no cycling paths, **no bag-racks, no bar to hang on, labels on reserved seats, limited road lanes, bus not allowing air to circulate, narrow ticket doors/corridors/stairs, incoherent widths, modal transfer under-capacity,**

		need to buy ticket on board, articulated bus, need to hold on a bar, no air conditioner, small bus stop,
Accidental technical state	Accidental state of the system regarding its nominal state	Frozen & slippery ground, **bad/weird smell, cold seats, blocked ticket validation,** *noisy train braking, air conditioner out of order, slow escalator*
Technical system planning	Essential state of the system does not evolve in design or functioning	Parking places are not created, **no new lines, no increase in bus frequency, bad urban planning**
Situation from context	Situation provoked by external factors to the system and travelers	Rain, Cold wind, bike stolen while parked, new drivers come to the neighborhood, **population growth, overdemand,** *hot sun, strike of train drivers, free tickets day, no-car day, snow, pollution,*
Users behavior	Situation provoked by the behavior of other travelers	Drivers overtaking closely, pedestrians walking slowly / brusque movements in shared path with cyclers, **traveler playing loud music, children yelling, students shouting, , travelers stop moving in/take big space, giant backpacks, not giving seats for people in need, traveler hold phone against you/ want to continue their activities on board/ don't feel the need to squeeze in, non-respect of stroller place, people don't shower, travelers climb slow/fast,**
Simultaneous users	Situation provoked by travelers using simultaneously the system	Cycling with pedestrians/cars in shared path, colleagues in same wagon, more crowd, **no seated place available, queue, peak hour, too much physical contact, many people in the way, crowd noise**
Active usage change	Decision-based action that traveler takes when a change happens in his/her expected travel	Wait, buy coffee, find alternative, find farther places, inform activity, **check for breakdown possibility, squeeze the way in/out**
Passive usage change	Change a traveler undergoes when a change happens in his/her expected travel	Hit by a car, getting slowed down, unstable cycling between two cars, slip / fall, hit cyclers / pedestrians, cannot listen to podcast, get wet, interact with traffic, **miss train, get pushed, cannot walk faster, more waiting time, cannot do anything, prevented to take alternatives, losing choice, impossible activities onboard, get hit by travelers' bags/arms, wasting time doing nothing, unable to plan activities onboard,**
Beyond-travel change	Change that is operated on traveler's life before and after travel	Arrive late, miss flight, tasks delayed, stressed all day, get sick, **delay leaving workplace, evening cut shorter, arrive later than supposed, unachieved personal schedule, bad mood at work, waking up remembering travel problems, loose trust in schedules,**
Avoidance measure	Measure a traveler takes to avoid a scenario that happened in the past	Take the "free of colleagues" wagon, avoid tram rail, pick longer & less hilly routes, find new routes, search a safe parking place, use more PT, less/abandon cycling, people come to work early**, not use a new car-sharing service, abandon PT**
Just-in-case measure	Measure a traveler takes to protect him/herself from a scenario that happened in the past	Consider big enough buffer, wear appropriate clothes, plan, wait, **4min just in case,** *carry an umbrella, go out early in the morning,*

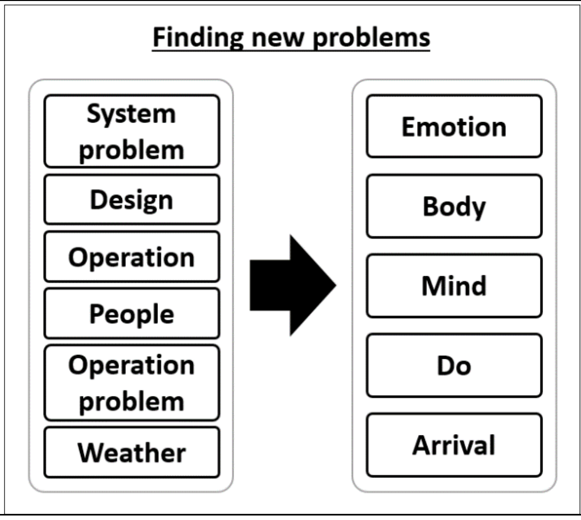
Cognitive measure	Additional attention a traveler makes preventing a scenario that happened in the past	Watch my steps, cyclers pay attention to trucks, pay attention to tram rail (use a right angle), with more cyclers drivers pay attention, *double check schedule*
Behavioral reaction	How the traveler reacts to a change in his/her expected travel	Say mean comments/ shout, say sorry/ Smile / be nice, **glare, weird looks, check if someone needs the reserved seat, non-respect of queues, not holding on the bar strongly enough,**
Emotional reaction	How the traveler reacts emotionally to a change in his/her expected travel	Ashamed/ afraid of others' perception, disappointed/ angry, worry about parking, getting mad / feel bad / fear, getting annoyed, **nervous, irritated, pressure, frustrated, mood shift,**
Physical reaction	How the traveler reacts physically to a change in his/her expected travel	Get cold, get injured, sweat, **backache, foot pain, muscle shock,** *have nausea, motion sickness, allergic reaction,*
Psychological condition	How psychological condition of traveler conditions his/her behavior before travel	Low self-reliability, not/stressed, punctual, drivers not accepting cyclers, **hate noise, mood, need peace, afraid to miss the stop, scared to fall, superstitious, do not care, do not want public shaming**
Physical condition	How traveler is conditioned physically before travel	Uncomfortable with cold, weak immunity, **don't like promiscuity, reduced mobility, hardship to stand for long,**
Cognitive condition	How traveler is conditioned cognitively before travel	Kids don't know how dangerous a truck is, **not aware of the surrounding with headphones/on smartphones, perception of personal space, do not speak a foreign language, not paying attention, not knowing alternative routes,**
Modal condition	Obligation to use a specific mode instead of a desired one	Take the bus instead of walking, **take PT (restricted car use), not having the budget for car ownership, being obliged to use an unsatisfactory solution, not having itinerary alternatives**
Beyond-travel condition	What conditions traveler's life right before and after travel	No shower at work, **need to be on time to work,** *no charging spot at workplace,*

5. Pilot experiment stimulus



6. Experiment—raw stimulus

Category	Source of problems
Do	- When there is a problem with my trip, I react or do something about it - What I do with my trip can cause me problems with it
Body	- My body feels troubled when there is a problem with my trip - I can be physically challenged in my trip
Mind	- My mind feels troubled when there is a problem with my trip - My mind can prove a source of the problem for my trip
Emotion	- My emotions feel troubled when there is a problem with my trip - My emotions can prove a source of the problem for my trip
Arrival	- What I do when I arrive is affected by problems with my trip - My destination facilities & activities I do can cause problems in my trip
People	- The behavior of the people around me can be a problem for me - Problems emerge when many people use the system at the same time
Weather	The weather can cause me problems with my trip
Design	For me, the system is not well designed
Operation	For me, the system is not well operated
System problem	Problems occur accidentally with the system
Operation problem	Problems occur accidentally with the system's operation



7. Travel problems recorded through the experiment

Category	Do	Body	Mind	Emotion	Arrival	People	Weather	Design	Operation	System problem	Operation problem
Code	do	bo	mi	emo	ar	pe	we	de	op	sys	opa

Problem categories codes

0:03:08	Not enough seating	de
0:03:18	Bus always crowded	opa, pe
0:04:29	Temperature sometimes excessive, lack of air conditioning in some buses	bo, we, de
0:05:01	Signage problem: lack of visibility	de
0:05:24	Signage problem: late notification of mission change	op
0:06:35	No queuing, jostling at the entrance of the buses	pe, bo, op
0:07:46	Only the 91.06 bus dock is crowded in rush hour	pe, op
0:08:56	Drivers are uncomfortable at times (aggressive response to a request for information)	pe
0:10:07	Service schedules are difficult to read	de
0:11:18	Aggressive driving, sometimes dangerous. Sometimes sudden braking	pe, opa
0:12:28	Bus status not always satisfactory (buses added to increase frequency)	op
0:13:39	Stops not marked if bus full and no on-demand stops	op
0:16:00	Information screens inside still display excuses: information not available	sys
0:25:21	No adaptation to problems encountered in other modes of transport (RER B!)	op
0:27:53	Unsatisfactory service during off-peak hours	op
0:30:13	Lengthening journey times over time (between Massy and Corbeville)	we, opa
0:32:01	Unpleasant odours -> Maintenance, aeration, cleaning	op, sys
0:32:44	Buying tickets on the bus, complicated ticketing system	op, mi
0:33:28	Price difference between tickets brought on the bus and from the distributors	op
0:34:26	Buses cancelled at the end of the day without warning	opa
0:34:59	Albatrans application gives inaccurate timings	de
0:35:47	Bus shelters inefficient in rainy weather	de, we
0:36:37	Management of alerts in stations during snowy episodes	we, op

0:40:13	Sometimes drivers do not pay attention to on-demand stops	pe, opa
0:40:45	Sometimes drivers do not check for door clearance before closing	pe, opa
0:43:32	Unnecessary congestion of corridors for certain buses	de, op, pe
0:44:13	Sometimes, dangerous parking in Massy during peak hours (lack of space)	opa
0:46:34	Occasional altercations between the driver and passengers who have not validated their ticket	pe, opa
0:47:46	Lack of information for non-French-speaking passengers	de

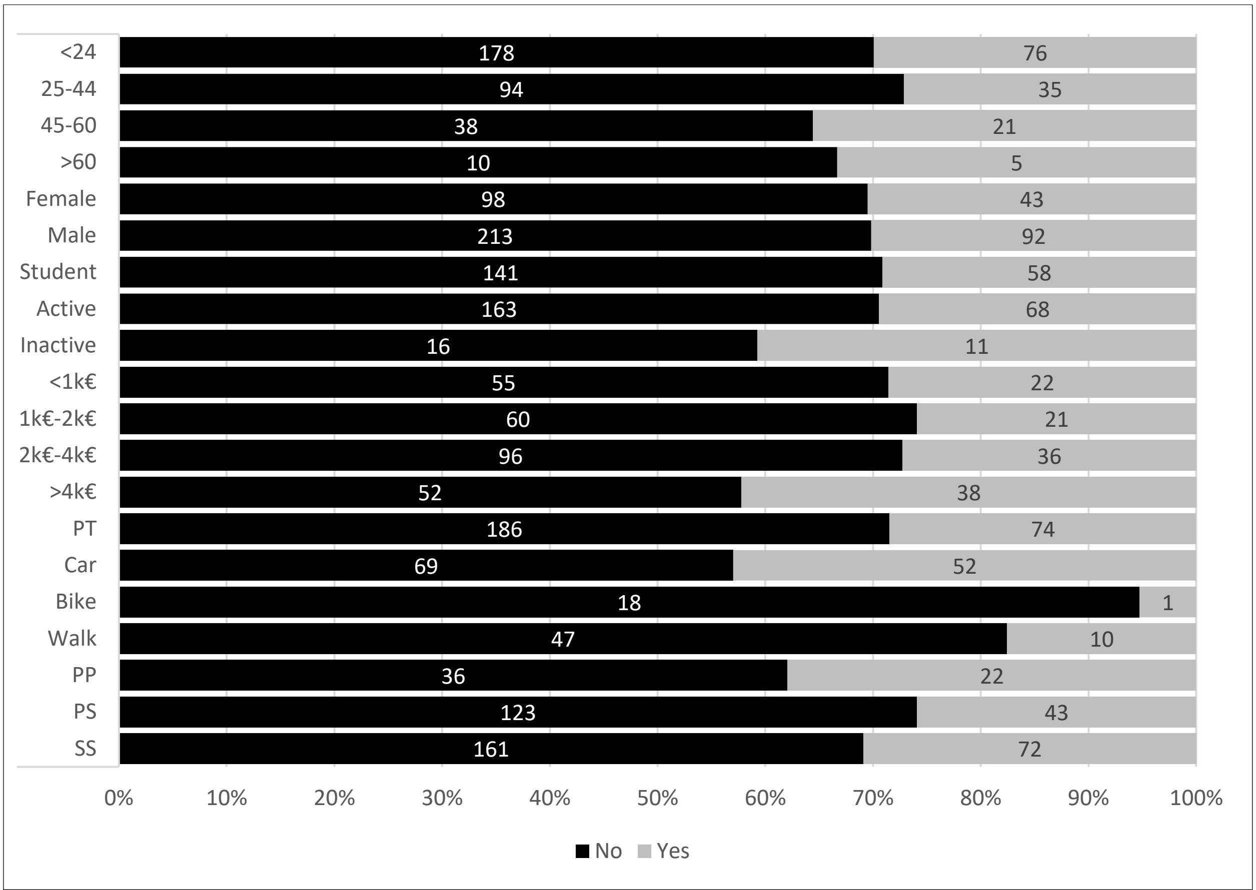
0:08:28	Frequency decrease after 9h45	op
0:09:49	Lack of coordination between RER B arrival and bus departure	op
0:10:42	Unexpected trip changes for 91.10 and you get stuck in the wrong route	opa
0:11:53	Some buses go overcrowded, followed directly by empty ones	op, pe
0:12:53	Bus frequency not properly managed (successive buses)	op
0:13:58	Lack of waiting line (especially in crowded times)	de, op, pe
0:14:50	Sometimes all doors are open, sometimes only front-boarding doors	opa
0:15:20	Driving crazy when crowded	emo, pe
0:26:23	Low frequency after 19:00	op
0:26:56	Poor dispatch of journeys between several lines	op
0:27:57	Sometimes the display is blank	sys
0:28:16	Sometimes the display information is inaccurate	opa
0:29:21	At 17h30 the buses are always overcrowded	pe, op
0:30:29	High travel times when overcrowded (sometimes double)	pe, op, opa
0:31:25	Sometimes validating the Navigo card is impossible because of crowds	pe, do
0:32:08	The smells are horrible, especially in hot weather	we, bo, sys
0:32:21	No aircon in the long buses	de
0:32:57	There's no alternative (other than walking), especially in bad weather	we, do
0:34:14	No information on service cancellation during bad weather (other than online), and on the stop there's no info	opa, we, op
0:35:10	No alternative solutions are proposed during disruptions	op
0:37:06	The application is not user-friendly	de, mi
0:37:13	The app is not in real-time	de
0:37:21	The app usually gives inaccurate timings	sys
0:38:45	Often people run from the RER to catch the bus or from the bus to the RER C, and that may cause panic for some users	do
0:39:52	Bus windows are not tinted, which amplifies the effect of heat from the sun	we, de
0:40:48	Sometimes the door closes before you have the chance to leave	do
0:41:49	No displays in the train stations for the bus lines	de
0:43:49	Sometimes when you don't wave your hand, the bus driver keeps going (is it protocol??)	opa, pe, do
0:45:33	Recently they use old buses without head displays (only a small card)	opa, de
0:46:28	Lack of meaningful signs on the bus	de

0:46:54	Most people go on the bus and asks if it goes to Ecole Polytechnique (why not write it somewhere)	de, mi, do
0:49:41	The bus stop at Massy if too small to accommodate everyone in harsh weather conditions (burning sun and rain)	de, we

0:02:50	Schedules indicated on the stop are not always respected (or rather most of the time)	opa
0:04:05	No real-time bus pass information (no app)	de
0:08:48	Sometimes the bus does not even stop!! Lack of time or overload?!	opa
0:09:16	Shocking driving	opa, pe
0:10:02	There is no air-conditioning and even in winter I think they put the heating off	we, de, opa
0:12:11	Normally the frequency in rush hours is estimated at 5-min intervals between 2 passages, which is unfortunately never the case	op
0:14:20	The bus map is not easy to understand, especially for people who take the bus for the first time	mi, de
0:15:26	The bus display is often out of order	sys
0:15:43	Always crowded, so we arrive without motivation to work	opa, pe, ar, emo
0:16:28	The driver does not pay too much attention to people who want to board, and sometimes we miss the stations where we want to get off	do, pe, opa
0:24:48	Stress related to travel time (we wonder if we will not miss a connection, including the RER C)	emo, do, mi
0:25:59	Start of a stressful day once you take the bus knowing that there will also be more problems before you take the next transport	emo, opa
0:28:22	Take a wrong destination because of the display (destination difference between A and B for example) on the bus	do, opa
0:29:17	Body aches and dizziness from fatigue or having to stand on the way	bo, do
0:31:03	The logic of opening the doors is not clear (the back doors are not always open)	mi, op
0:31:43	When the bus is full, attitudes of a few people can be disturbing (sometimes people do not even say sorry when they push you ...)	emo, pe
0:36:51	The working conditions of the driver also affect the bus user (imposed travel time for example)	pe, op
0:37:53	Sometimes I prefer walking than taking the bus just to stay sane	emo, do
0:39:11	Bus recognition trouble due to brand change	mi, de
0:39:53	It feels like we play sports when we take the bus, so it feels like a physical and emotional effort	bo, mi, do
0:41:13	The dock managers are sometimes disturbing and sometimes make weird decisions and give misinformation	pe, opa; emo
0:43:05	Off rush hour and weekends, there are not enough buses	op
0:45:34	Why don’t we have Wi-Fi by bus, or a little music to relax people !!	de, emo
0:46:14	No voice messages to inform people or manage the trip	de
0:49:07	No respect for sign boarded times	opa
0:50:50	Maybe think of products that limit the contaminations between people (transmission of diseases)	bo, pe, de

0:04:23	Many people waiting for the bus -> full bus	pe
0:04:56	No synchronization between the RER b and this bus line even though it is important as it passes by all the schools	op
0:05:23	No respect for time schedules, no clear schedules	mi, op
0:07:29	Bad interior design (security), no balance, no place to grab -> safety	de, bo
0:08:28	Waiting line not clear -> people get in with no order	pe, do, mi
0:09:43	Not practical for getting in and out (front boarding and back boarding)	de, do
0:10:59	Summer schedules + Sundays -> fewer buses	op
0:12:14	Screens don't work most of the time -> Can't know which is the stop	sys, mi
0:13:29	Waiting times for the next bus don't appear all the time	sys
0:16:00	Buses don't always stop at bus stops (in case another bus is already passing by or full)	opa
0:25:00	We don't always find a place to sit	do
0:25:25	Stations are not well prepared for sun/rain	de, we
0:25:49	Not prepared for disabled people when the bus is full. How do they take the bus?	de, do, pe
0:26:14	After a bad trip, we are not in the right mood for work	emo, ar
0:27:04	Sometimes the bus stops at an unsuitable place for getting off	opa
0:30:55	Bad synchronization between buses in both directions and cars trying to pass	pe, op
0:32:27	Pedestrian passageways neither safe nor practical (near IRT)	de
0:35:04	Some drivers refuse to accept travelers with no ticket and no cash to pay	pe, opa
0:37:58	Prices don't motivate people to take the bus, partially as tickets are expensive (imagine taking the car for two days and the bus for the rest of the week)	mi, op
0:39:31	The bus doesn't always depart from its proper station at Massy	opa
0:42:55	Buses are not well equipped for hot spells/cold snaps	we, de
0:44:38	If we have a lot of stuff, then the bus is not at all a good choice (bringing my lunch to IRT (work))	do, ar, de
0:48:00	The bus could be a good choice on Friday evenings to avoid the traffic	op
0:50:00	We feel less safe/comfortable when there are a lot of people around on the bus	pe, bo, emo

8. Distributions of answers for willingness-to-use a posteriori



9. Adapted presentation of questions to participants depending on transport mode

Car	Criteria in SAVS
Cost	Unlimited subscription (no matter how many trips)
Total travel time	Like a car but without the time it takes to get to the car and find a place to park and then get to your destination after parking, like a taxi
Walking time	There is no walk to do
Parking time	No need for parking
Waiting time	You wait at your place. This time varies during the day without exceeding 10min
Security	The vehicle is equipped with an image processor that captures abnormal behavior and asks for help
Safety	The vehicle would drive better than a human
Comfort	Like in a taxi
Infrastructure	No need for parking or service station
Freedom	You can freely read, work, meditate without hands on the wheel or eyes on the road, but not smoke or speak loudly on the phone

PT	Criteria in SAVS
Cost	Unlimited subscription (no matter how many trips)
Total travel time	Like a car but without the time it takes to get to the car and find a place to park and then get to your destination after parking, like a taxi
Walking time	It takes you in front of your house and drops you off at your destination
Waiting time	You wait at your place. This time varies during the day without exceeding 10min
Security	The vehicle is equipped with an image processor that captures abnormal behavior and asks for help

Safety	It's like driving, there are the same risks of the road
Comfort	An assured seat, clean and air-conditioned, a USB port ... ideally, like the TGV
Freedom	You can freely read, work, meditate without being scolded or spied on by other passengers, but not smoke or speak loudly on the phone

Bike	Criteria in SAVS
Cost	Unlimited subscription (no matter how many trips)
Total travel time	Like a car but without the time it takes to get to the car and find a place to park and then get to your destination after parking, like a taxi
Walking time	There is no walk to do
Waiting time	You wait at your place. This time varies during the day without exceeding 10min
Security	The vehicle is equipped with an image processor that captures abnormal behavior and asks for help
Safety	You are less vulnerable inside a vehicle than by bike
Comfort	Like in a taxi
Infrastructure	No need for dedicated lanes or looking for a safe place to park
Freedom	You can freely read, work, meditate without the head in the handlebars, but not smoke or speak loudly on the phone

Walk	Criteria in SAVS
Cost	Unlimited subscription (no matter how many trips)
Total travel time	Like a taxi, it's about 8 times faster
Waiting time	You wait at your place. This time varies during the day without exceeding 10min
Security	The vehicle is equipped with an image processor that captures abnormal behavior and asks for help.
Safety	It's like driving, there are the same risks of the road
Comfort	Like in a taxi, you can go far, even with luggage
Infrastructure	No need for sidewalks or looking for a bridge to cross, even when there is work
Freedom	You can freely read, work, meditate without having to watch where you put your feet, but do not smoke or talk hard on the phone

10. Participants' extra comments on AVs choice criteria

NO	Criteria
PT	- People on board, parking to pick up / drop people and being able to change directions - Emergency stop (linked to security) - The subway is next to my office - Fluidity of the journey (to be in the traffic jams or in a moving train) - Limit my environmental impact - If it's a metro / train without driver like line 1 or 14 metro Paris I would be for. But if it is a SAVS type car or bus without driver I think neither technologies nor infrastructure are ready to date. - Shared autonomous vehicles do not address the issues of people flows in cities. Vehicles driven by humans are replaced by AIs. We change only technology - Price / time gain: 250 € more for 10 minutes less - Traffic jams - Ecology - Traffic density in Paris raises fears of more frequent accidents - Environmental point of view is an important criterion for my choice - Ecological - Motion sickness on the backseat of cars - 4G connection in the bus currently

	- Reliability of the technology - Clean, non-polluting mode of transport - Ecology - Same problem as the classic car: traffic jams - Ecology (fewer people per vehicle and potentially more traffic than by bus) - Less confidence in safety (if 2 people on the journey, increased risk of aggression and anxiety) - I need to walk to cheer up and move - Waiting time of the car - You will have traffic jams as well as more and more inaccessible areas by car - On this type of journey of about 30 km, public transport type RER are better adapted; for example, they are not subject to traffic jams and therefore faster - Pollution - Energy consumption - Do not want to be driven by a computer - Important to keep a daily walking time - Adaptation to schedule variability - Environment / ecology - Who is responsible if you have an accident? - Environmental impact - The time (rush hour / off-peak time). Indeed, in public transport, no place sits & many people then all the disadvantages that go with it. Works with SAVS - I want to wait to see the efficiency and security of the system before making a choice. Will it have transit-equivalent security? - Trip too long to be done in a single vehicle (not very sustainable) - It pollutes - Do I need a license to use the autonomous car? - Ecology - The dehumanizing side of the thing displeases me. Just as much as the excessive assistance it represents - Unnecessary congestion of roads caused by the postponement of TC users on SAVSs. Let's make room for other activities - PT = observation of the world, of others, chance of encounters, knowing how to wait a little instead of seeking acceleration (should we always go faster from one point to another and more without others?!) - PT + bike is less polluting and better for health - Safety given by the fact that the vehicle is driven by a human - The autonomous vehicle invades roads and cities as well as private vehicles. More vehicles = more traffic jams = lost time and pollution. - Pollution of gasoline or diesel vehicles, production of electricity and hydrogen - Create more unemployment - Fear
Car	- I like to drive - Means to contact and follow the vehicle (mobile application, SMS, website) - The real point is on the availability sure and immediate (in - of 5 or 10 min) which is the true freedom of the personal vehicle or the exclusive autonomous vehicle (not shared) - Service reliability - Here we only talk about the commute Home-Work, I need a vehicle to go for fun board, move my daughters, go on WE, put my speed sail inside full of sand, carry a team of Gym, ... I decide to go to IKEA to bring back a furniture of 3 m long in the minute, ... For me the advantage has not in the sharing but in the autonomy (no need to drive) - Possibility of moving outside the greater Pairs region (more than 150km trip) - The availability of the autonomous vehicle at any time - Driving pleasure

	- I love to drive - If there is an electrical problem, it can cause a serious accident - It's a weekly trip, Paris-Province to my little village so never this type of trip will be proposed (for now) and I like very much to take time to ride at the pace that corresponds to my mood and also to lose myself in the countryside to discover new landscapes and not always have the same monotonous journey - The pleasure of driving - Freedom cannot be 5/5 because many limitations like being able to smoke or listen to the radio / music. The infrastructure cannot be 5/5 either, the number of roads does not change and still need service or charging stations. If the vehicle is shared, comfort is not 5/5. - I enjoy driving my car - Trust. So far, it cannot be said that AVs 100% reliable - Computer attacks - Management of the unexpected (I decide to leave / return earlier to / from the office that the normal time) - Keep your individual freedom (to drive, to move without being connected ...) - Driving pleasure - It seems to me that the safety also comes from other drivers. So, the autonomous vehicle would not improve - I like to drive - Accessibility of the autonomous vehicle - Not trust - I prefer to remain master of my vehicle - Need to access to the reservation system of an autonomous vehicle (smartphone, phone ...) - We do not know if other people are present in the cabin with us - The absence of control of the vehicle by the passengers, the absence of intelligent roads, the mixture of autonomous vehicles, mechanical vehicles - Travel not seamless, need for detour or stop for other passengers - I take pleasure in driving - Sharing constraint
Bike	- My daily journey being very short and pleasant, I do not see the need to change. On a longer trip using public transport that does not work perfectly, the SAVS could have interested me. - Play sport in the morning - Ecology - Sport - Ecology - Wasteful time saving - A bike can sneak in ways / shortcuts unlike a car - Environmental impact - Ecology - Resources required for the manufacture and use of the vehicle - Physical exercise during the journey - My bike (electric) consumes a lot less than a car. In addition, the bike ride allows me to go through bucolic places. The autonomous car would not allow me to use roads. - Health: minimal but regular exercise in daily cycling
Walk	- It's a bit absurd to take the car rather than walk 5 minutes - For a longer trip I find this much more interesting - My journey is very little binding - In fact, I have nothing against AVs, I can simply make my daily walk because I'm on a campus. I am in favor of the development of AVs, which will surely facilitate the lives of people not particularly loving to drive - Environmental / ecology - Journey on very short distance - Take some fresh air and exercise at the same time along the journey

	- The journey is very short - I am a student on a campus, the SAVS is not yet relevant for me - There is a time to get in the vehicle.

Yes	**Criteria**
PT	- Ecology, carbon footprint - Friendliness - Being alone in the autonomous car - AVs becomes more profitable than buying a car. However, I will opt for the autonomous vehicle only if the risks of an accident are very minimal (lower than 0.001%) because we do not joke with these things - Ability to carry luggage easily (big bag / small suitcase) - Environment - Novelty - Pollution - Unlimited use - Availability at all times - Less fatigue
Car	- Ecology - It is important that AVs drive better than humans, and improve road safety - Sharing the car = more sustainable for the environment - My CO_2 consumption - Reliability and punctuality - To be able to select the atmosphere of the SAVS: ZEN "calm", or ZAP "exchanges ..." like some train lines - Reduction of ecological costs with the electronic control of the car - Ecology (less cars and less stoppers) - No stress / irritation in congestions, it is time of work / relaxation and more - Trust in the SAVS - Flexibility (travel / destination matrix) variable during the week - I only have one car so I need it for holidays. The majority cost would remain (insurance and amortization) - Avoids driving fatigue - Meeting ability
Bike	Road holding
Walk	Innovation

Personal publications

For an up-to-date list of these publications, please check this link:

https://www.archives-ouvertes.fr/IRT-SYSTEMX/search/index/q/*/authIdHal_s/ouail-al-maghraoui

Journals

Al Maghraoui, O., Vallet, F., Puchinger, J., & Yannou, B. (2019). *Modeling traveler experience for designing urban mobility systems*. (Accepted in Design Science Journal)

Al Maghraoui, O., Vallet, F., Millonig, A., Puchinger, J., & Yannou, B. (submitted). *Understanding urban travel problems: A grounded theory approach*. (Submitted to Transportation Research Part A)

Al Maghraoui, O., Vallet, F., Puchinger, J., & Yannou, B. (submitted). *Stimulating usage problem generation: An urban mobility case study*. (Under revision in Design Studies Journal)

International conferences

Al Maghraoui, O., Vallet, F., Puchinger, J., & Yannou, B. (2017). Framing key concepts to design a human centered urban mobility system. In *International Conference on Engineering Design (ICED17)* (Vol. 3, pp. 91–100). Vancouver, Canada.

Al Maghraoui, O., Vallet, F., Puchinger, J., & Yannou, B. (2017). Un cadre conceptuel pour concevoir le système de mobilité urbaine. In *Congrès International de Génie Industriel, CIGI17*. Compiègne, France.

Al Maghraoui, O., Vosooghi, R., Mourad, A., Kamel, J., Puchinger, J., Vallet, F., Yannou, B. (2019). Shared Autonomous Vehicle Services and User's Taste Variation: A Survey and Model Applications. (Submitted to EWGT 2019)

Titre : Modéliser l'expérience voyageur pour concevoir la mobilité urbaine

Mots clés : mobilité urbaine, expérience voyageur, problèmes de voyage, génération de problèmes, conception centrée sur l'humain, théorie ancrée

Résumé : Cette thèse aborde le défi de la conception des systèmes de mobilité urbaine. Elle vise à développer un modèle d'expérience-voyageur pour faciliter, dans une démarche de conception, le diagnostic des problèmes de voyage et améliorer la pertinence des modèles de transport pour les voyageurs. En combinant les points de vue de la conception de l'expérience-utilisateur et du transport, elle contribue à approfondir la compréhension de comment les voyageurs vivent leur voyage et particulièrement des problèmes qu'ils rencontrent. Le premier axe d'investigation est lié à la modélisation de l'expérience-voyageur pour alimenter un diagnostic pertinent et riche des problèmes de voyage. Dans un deuxième axe, les voyageurs sont impliqués, par une démarche de théorie ancrée, pour identifier les problèmes qu'ils rencontrent lors de l'utilisation de systèmes de mobilité urbaine au moyen de stimuli appropriés. Un troisième axe introduit des attributs subjectifs de voyage dans des modèles de transport afin d'améliorer leur précision

Cette recherche utilise la recherche-action comme méthodologie. Elle combine revue de littérature dans les disciplines de conception et de transport, quatre observations terrain, quinze interviews en profondeurs aves des voyageurs et experts en transport, cinq ateliers de problématisation, et deux expérimentations, dans une amélioration cyclique des résultats. Les différentes utilisations du modèle ont permis un diagnostic approfondi de trois systèmes de mobilité urbaine (train de banlieue, bus à la demande, navette sur voie dédiée) et la mise au point d'attributs centrés sur le voyageur pour un modèle d'optimisation et une simulation multi-agents qui ont été testé par une enquête de plus de 450 participants.

Title: Designing for Urban Mobility - Modeling the traveler experience

Keywords: urban mobility, traveler experience, travel problems, problem generation, human-centered design, grounded theory.

Abstract: This thesis addresses the challenge of designing urban mobility systems. It aims at developing a traveler experience model to help diagnose travel problems in a design approach and improve the relevance of transportation models for travelers. By combining the views of user-experience design and transportation, it helps to deepen the understanding of how travelers experience their journey and especially the problems they face. The first axis of investigation is related to the modeling of the traveler experience to feed a relevant and rich diagnosis of travel problems. In the second axis, travelers are involved, through a grounded theory approach, to identify the problems they encounter when using urban mobility systems, using appropriate stimuli. The third axis introduces travel subjective attributes into transport models to improve their accuracy.

This research used action research as a methodology. It combines literature review in design and transportation disciplines, four field observations, fifteen in-depth interviews with transport travelers and experts, five problem-solving workshops, and two experiments, in a cyclical improvement of results. The various uses of the model have led to an in-depth diagnosis of three urban mobility systems (suburban train, on-demand bus, dedicated shuttle) and the development of traveler-centric attributes for an optimization model and a multi-agent simulation that was tested by a survey of over 450 participants.