FRAMING KEY CONCEPTS TO DESIGN A HUMAN CENTERED URBAN MOBILITY SYSTEM

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Abstract

Urban mobility poses some sustainability and design practice challenges. Mobility components such as vehicles, urban infrastructure, mobility services or other services delivered along a mobility experience are often designed separately. The performance of a global urban mobility system, at a city scale for instance, is therefore parceled out into components' ones that are not integrated from the perspective of a user who interacts with them in a door-to-door journey. This paper starts with relating different perspectives of urban mobility including, in crescendo, the human in the production of a global design solution. Through the examination of design and transport literature as well as practical examples, the paper highlights complexity factors of urban mobility that challenges engineering design. A second contribution is to identify relevant design objects aiming at providing a language for designing urban mobility.

Keywords: Complexity, User centred design, Design engineering

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1 INTRODUCTION

The worldwide proportion of people living in urban areas is expected to rise in the coming decades, reaching 67% by 2050 (Van Audenhove et al. 2014). This growth gives rise to increasingly challenging situations for urban mobility: (1) People: traffic chaos, insecurity, traffic jam, decreasing quality of life and convenience. (2) Profit: overloaded infrastructures, insufficient public transport capacities, increasing motorization, limited parking places. (3) Planet: air pollution, CO_2 emissions, noise, increasing ecological footprint.

If urban areas are to become socially, environmentally and economically sustainable a holistic and integrated approach of urban mobility is needed. The social dimension covers safety, equality and fairness of both physical and economical accessibility to transportation. The environmental challenge is, for instance, on the use of non-fossil energy for vehicles, lowering the emissions of vehicles and infrastructures, promoting ecological behaviours, and eco-designing vehicles and infrastructure. Finally, the economic issue is about using resources efficiently, maximizing profit for the stakeholders (including taxes) and minimizing costs (e.g. investments in infrastructures) (UNHSP 2014).

A sustainable urban mobility system satisfies current mobility needs of people in cities without compromising the ability of future generations to meet their own needs (Kayal et al. 2014). One way to satisfy travelers' needs is to improve their door-to-door journey experience. However, the urban mobility system is still designed as an aggregation of products and services that are not operating in a user-centred harmony to offer a seamless mobility experience (Preston 2012). For example, in the Paris region, there are several transportation operators for different bus lines. At the exit of a train station, it is frequent to find the information about one operator but not the others. One of the reasons why such problems persist is that each line is designed separately from the others. The same logic applies on interchange between private car and public transportation (e.g. park and ride facility), or the need of different smartphone apps for one trip planning and monitoring (e.g. one for bus real time schedule and one for multimodal transfers). For that reason, 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).

A holistic approach considering urban mobility as a system could be of value to formalize an integrated language of design for urban mobility. Considered as the ease to move from one destination to another or the demand generated from social and economic activities (Hasan et al. 2013) (Cascetta 2009), urban mobility takes different forms depending on the perspectives. This paper defines the Urban Mobility System (UMS) as all what makes possible for an individual to move from a point A to a point B in a defined geographical space (artefacts, information, people, and organizations).

The complexity of the UMS poses challenges defining its design process, models, knowledge or expertise (Sussman et al. 2005). Examples of design for mobility are tackled in (Hollauer et al. 2015), (Barbieri & Campatelli 2015), and (Vidal & López-Mesa 2006) and they relate different sorts of difficulties for design practice. For example, the volume, the diversity and the asynchronicity of urban mobility components such as vehicles, infrastructure or information makes it non obvious to define an integrated design process of the whole UMS. Therefore, there is an opportunity to gain some insight in a global understanding of urban mobility with a design intent.

The first section of the paper develops the complexity factors and dimensions that makes user-centred design of urban mobility a challenging issue. The second section proposes an integrative conceptualization based on three key concepts: mobility components, travel scenarios and travel-centred indicators. Finally, the paper discusses different perspectives of the proposed integration.

2 THE COMPLEXITY OF AN URBAN MOBILITY SYSTEM

A traveler interacts with many products and services while heading to some destination. Indeed, the traveler may be the user of a smartphone application to program the journey or check the schedule of the bus for example. He/she gets in the metro station and interacts with the tickets machine then boards the metro. He/she uses information panels at the station's exit. In this paper, the point of view is a user-centric one in order to include all products and services used during a whole journey.

The complexity of the UMS encompasses different factors through several dimensions. The UMS contains a large amount of diverse and evolving stakeholders, physical components, information, and users, all interacting with each other in an urban context. Another form of complexity emerges from the diversity of combinations of use, the unstoppable usage (people moving 24/7), and a shared form of use. To represent this complexity, the technical aspect of urban mobility is first presented as the Technical UMS (TUMS). It is followed by the interactions with the TUMS through the traveler experience. Then the Socio-technical perspective of urban mobility is introduced. It is the extent to the market, where the TUMS is an offer and the travelers are generating the demand introduces.

2.1 Technical Urban Mobility System

The technical physical components of urban mobility are composed of roads, rail, fuel stations, train stations, bridges, energy and communication network, terminals and facilities etc. On the one hand, buses, cars, trains, trucks, boats, trams on the other hand. . Information and Communications Technology (ICT) (GPS, Internet of Things, mobile networks…) also play an important role in enabling the qualities of this technical system (safety, usefulness, fluidity…) (Kitchin 2013).

However, the aggregation of infrastructure, vehicles and ICT is not sufficient to provide the whole picture of the technical urban mobility system. Indeed, trip-chaining (Primerano et al. 2008) connects the elements of infrastructure and vehicles. It brings out the necessity to have a global understanding taking multi-modality into account and considering a global performance rather than that a single bus line, highway, or hub. 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 global performance indicators. The combined set of bus lines and regional train would then operate with a bad multi-modal 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, such as households, industries, or workplaces (Wegener 2013). The traveler interacts with TUMS and experiences mobility under different conditions, set as follows.

2.2 The user of the Technical Urban Mobility System

The TUMS is designed for different users who interact with its components, individually or collectively or, in different moments of the day, and with different itineraries. The EU-FP7 project METPEX (MEasurement Tool to determine the quality of Passenger EXperience), describes 'traveler experience' by decomposing the journey into different typical stages (Woodcock, Osmond, et al. 2014). The journey is decomposed into (1) the assessment of the need for mobility;(2) the planning stage (time, modes, routes…) and the gathering of the artefact needed during the journey (tickets/car paper, entertainment artefacts ...); (3) the movement from the origin to the transport gateway/car; (4) the interaction with the transport service (payment, ingress…); (5) the traveling in the vehicle. An additional stage can take place: (6) the interchanges which includes finding the location of the next transport mean, schedule information, buying new tickets…). Finally, the egress from the service to destination concludes the journey.

Along the journey, the user of the TUMS, the traveler, gives value to different aspects. (Stradling et al. 2007), (Woodcock, Berkeley, et al. 2014), and (Susilo & Cats 2014) produced a set of values which are: 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 on-board, fellow travelers, seat availability, seat comfort, crowding both at stops and on board, station facilities, information accessibility, safety & security (at stops and on-board), tickets use and buying simplicity, connectivity (network wise and easy transfer).

To analyse the journey experience, (Susilo et al. 2015), based on an activity representation of travel as seen above, considers three variables for each activity. The first one is personal doing such as packing belongings, exit home, walk to station, or going across the road for 'leaving home' activity, for example. The second one is personal thinking like thinking over day's schedule, observing of people waiting, or wondering of the total time spent on waiting. The last one is personal feeling such as concern about hygiene in bus, noise of train arriving, or concern over weather.

While moving from an origin to a destination, travelers collectively generate a demand on the TUMS which constitutes the offer of this mobility market.

2.3 Urban Mobility Market

The World Business Council for Sustainable has proposed a model of the UMS as being a set of three markets Development (WBCSD 2015) :(1) the travel market where spatial-temporal activity of people 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 interactions between the TUMS elements produce both the demand for travel within a given area and the provision of transportation services to satisfy this demand (Cascetta 2009). There are many interactions between the components within the transportation system and between the activity system (the set of individual, social, and economic behaviours 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 interactions generates feedback cycles. For example, travelers who individually choose the most efficient (fast and cheap) path within the available means, might collectively congest it and thereby deteriorate the global efficiency (transportation service performance).

Hasan et al. (2013) gave more attention to the travel demand in its spatial dimension. 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. Mobility is represented as a map of passenger concentration in an urban space (mobility patterns). 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 explain the noticed concentrations.

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

Considering the supply and demand separately in representing the urban mobility has given some information about their interactions. 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.

2.4 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 as set of four main components: the infrastructure, the vehicles, the users and the governance. 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 will not have the opportunity to buy electric cars. These loops permit the propagation of social values trough the global urban mobility.

In a wider perspective, the UMS is a component of a larger 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 for mobility, 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. 2005), the main components of the UMS as a socio-technical system are: technical elements, social elements and actors. 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 the social elements influence the functioning the UMS. Beyond the functional relations (e.g. 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 to take an action (e.g. a passenger has the intention to use a bike between metro station and 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. Thus, from

the socio-technical perspective, the traveler is a part of the UMS and involved in its operation as a consumer and as an actor.

2.5 Challenges of 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 (Table 1).

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 would the respondents 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 analysing 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.

In order to take into account these complexity consequences on design practice, a conceptual proposition to scope the design urban mobility system is proposed in next section.

Table 1. Complexity factors of the urban mobility system

Domain	Perspective	Complexity Factors	References
Technical	Multi-modality	The Global performance of a transportation system depends on modal synchronicity	(Primerano et al. 2008)
	Urban context	The functions of a transportation system depend on other urban systems	(Wegener 2013)
User	Experience	The traveler interacts with a large number of different products and services along his travel	(Woodcock, Osmond, et al. 2014)
	Mobility Value	The traveler values different aspects of mobility	(Susilo & Cats 2014)
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	The social and economic activity of passengers in urban areas creates the demand on transportation supply	(Cascetta 2009)
	Spatial mobility	- The patterns of travelers' mobility are a result of their social and economic activities	(Hasan et al. 2013)
Socio-technical	Multi-dimensional perspective	Technological, social, economic, political, legal and environmental dimensions of mobility are inter-related	(Auvinen & Tuominen 2014)
	Technical and social elements with actors	Intentional and normative interactions happen between urban mobility components	(Ottens et al. 2005)

3   KEY CONCEPTS FOR URBAN MOBILITY DESIGN

In order to help designers handle the complexity of the UMS and overcome the challenges, this section proposes a conceptualization that defines urban mobility design entities. A conceptualization is an implicit form of ontology. It is an abstract and a simplified view of the world, as a knowledge base, for some purpose (Gruber 1993). The user-centred proposition aims to represent the UMS in order to bring out concepts that concerns the traveler experience. Therefore, the entities considered in the conceptualization are the components in direct interaction with the traveler, the travel experience representation, and the performance indicators from the perspective of the traveler. Based on User Experience design, the model proposed by (Ortíz Nicolás & Aurisicchio 2011) provides a relevant framework to organize the previous entities (Figure 1). The traveler is described by the attributes of physical condition, cognition, affection, motivation, expectation, and personality traits.
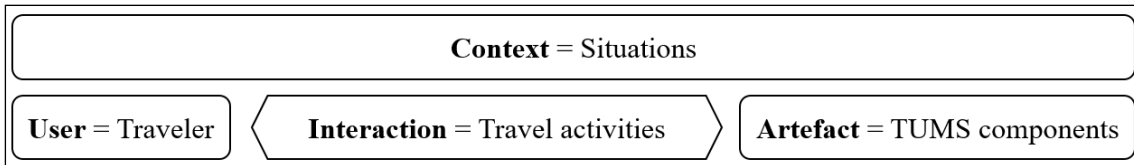

Figure 1. User/traveler experience analogy (Ortíz Nicolás & Aurisicchio 2011)

3.1   Technical Urban Mobility System components

The big picture of the TUMS can be obtained by identifying its components. Therefore, these components should be defined and modelled so that the boundaries of the TUMS are clear. Depending on which scale the TUMS is observed, some components appear or disappear (Figure 2). For example, the road and the parking appear as infrastructures where vehicles move or park, from a helicopter view. Zooming in, other artefacts such as ticket machines or information panels arise. Inside the bus, doors, seats, roll bars, or the line's map become identifiable artefacts. The travel information appear as well, in a smaller scale, on the traveler's smartphone.

In the proposed conceptualization, different transportation means and stages are considered. Therefore, simple artefacts like a gear shifter or a smartphone charging spot belong to the TUMS's components. On the other hand, a dynamic schedule screen, as an integrated product (being connected to multiple servers and offering diverse information) also figures among the components.

Moreover, it is to note that only components directly interacting with the traveler are considered. The layers behind the functioning of the UMS such as the servers, the underground energy network, or the cooling system of a train motor, are not taken into consideration.

Figure 2. Technical Urban Mobility System's components from different scales

The TUMS boundaries encompass components used to operate mobility activities (e.g. walking, driving, or buying a ticket) or to support travel stages. Therefore, are included: an umbrella protecting the traveler from weather while walking; a device to listen to music or a book used in a train or a bus for example. The directional signage is included as well, as long as it helps find the way while driving or walking.

Based on section 2.1, Table 2 shows the decomposition of the TUMS into infrastructure and mobile components. The objective is to bring out the different natures of the technical entities of the TUMS, such that the representation of travel experience takes into account the different scales. This way, no

matter the scale, the object of design is connected to the whole UMS and allows the designer to define its functions related to other TUMS components.

Table 2. Components of Technical urban mobility system

Components	Sub-components	Examples
Infrastructure components	Basic infrastructure	Road, Rail, Subway, Electric network, Station (bus, as, train…), Sidewalk, Parking
	Stationary artefacts	Portico, Ticket machine, Signage, Charging terminal/point,
Mobile components	Vehicles	Car, bus, tram, train, motorbike, bike, scooter
	Mobile artefacts	Umbrella, smartphone, GPS

3.2 Travel Scenarios

The set of components of the TUMS are designed to meet travelers' need for urban mobility generated by their social and economic activities. Therefore, in order to understand how a traveler is using the TUMS for his /her mobility, the interactions between the two need to be modelled.

Figure 3 shows the observable entities of a travel experience. It includes the TUMS components, the activities of the traveler during the trip, the ones after and before the trip, and the situations that may happen around him/her depending on the urban context. Moreover, the traveler may interact with other fellow travelers, using the same TUMS components or a different one.
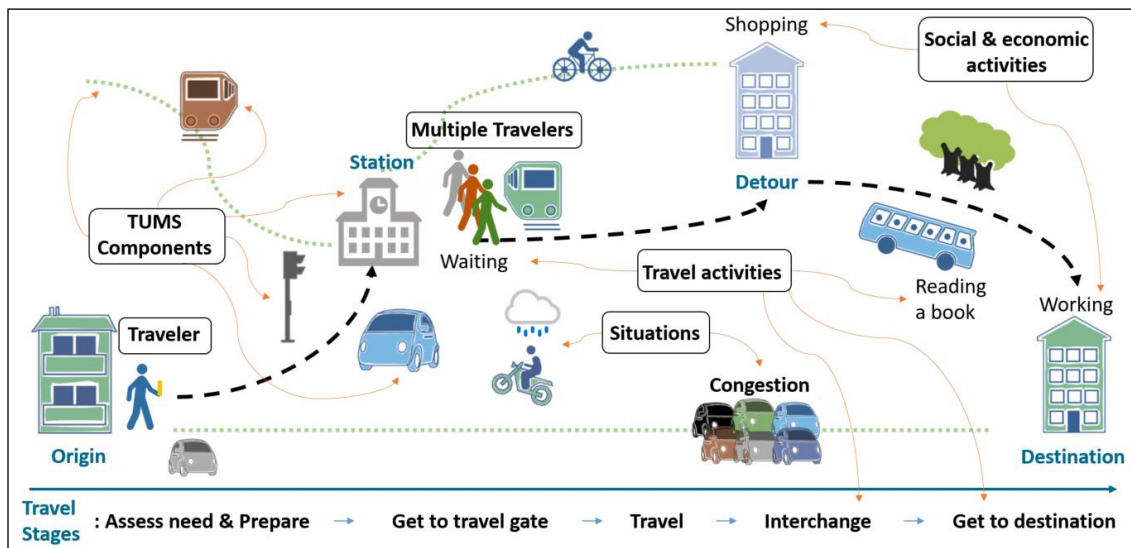

Figure 3. The door to door travel experience

Table 3. Travel scenarios concepts

Concepts	Definitions	Examples
Travel Activities	Actions operated by the traveler from the origin to the destination	Walking from home's door to the bus shelter, reading a book while waiting for the Metro, driving a car looking for some specific train station exit
Social and economic activities	Actions operated by the traveler after and before travel	Shopping Having a work meeting Watching a movie
Situations	State of the surrounding of the traveler or events	Rainy day, the tram is delayed, crowd at the train station, bus drivers' strike, slippery ground

For example, a traveler walks from home to the bus station (activity). It is a rainy day and the size of the bus shelter cannot cover all the passengers waiting for the bus (situation) (Table 3). The combination of the possible travel activities and situations, to perform a social/economic activity, generates the travel scenarios of the TUMS. It should be noted that a travel activity has, in turn different scales like the TUMS components. For instance, if 'interchange' is considered as an activity, then 'walking in the subway corridors' is one of its sub-activities. Moreover, depending on the TUMS component the activity

is made on, the nature of the activity may vary between physical (e.g. walk to bus station), and sensorial/mental (e.g. reading signage).

In order to evaluate how the TUMS is responding to traveler's expectations, a system of indicators is needed, defined as follows in a traveler-centred way.

3.3 Traveler centred indicators

Based on the aspects reported in section 2.2 the indicators proposed include relevant aspects to describe how travelers appreciate the travel experience. This travel appreciation is translated here by 'travel value'. (Table 4) sets a list of the values the TUMS can bring to the traveler.

Getting to destination as fast as possible at the lowest price are the classical rational values travelers expect from a transportation system (Spickermann et al. 2013). So, bike sharing service, for example, is one cheap way to move in the city. Post pay pass allows one to pay, at the end of the month, only the trips made instead of a fixed fare that might be higher than what have been used. E-tickets are a way to spare the public transportation travelers queues and wasting time at the travel gate buying tickets.

Comfort, both physical and sensorial, is valued by travelers. A wheelchair lift is meant to spare the reduced mobility travelers the pain of pushing hard or asking for help to get in the bus. Shelters at tramway or bus stations protect travelers from rain or sun. Art at metro station and tunnels, whether it is music or paintings or photography, enhances the diversity of station's landscape.

Cognitive comfort is necessary to travel, especially regarding information availability. Whether it is about the destination's location, or the schedule of public transport means, or the itinerary, or the real-time of the traffic jam etc. Google Maps, for example, is an integrated tool that provides the major information needed to move from a point A to a point B.

Availability, both spatial and temporal, is an important value for travelers. Demand Responsive Transport (DRT) like Uber or taxis are vital when there is no public transport is available, by night for example.

Safety and security are important values travelers expect from a mobility solution. A seat belt or a helmet are in this case reinforcing the feeling of safety while protecting against accidents.

Finally, components improving travel activities are contributing to the improvement of the whole travel experience. A Wi-Fi hotspot in a train station or in a bus could, for instance, be valuable to travelers.

Table 4. Traveler centred urban mobility performance system

Value	Description
Travel time	Reducing travel time (includes service and vehicle speed)
Travel price	Reducing price, fair price
Physical comfort	Enhancing the comfort of the body
Sensorial comfort	Enhancing the comfort of the senses
Cognitive comfort	Improving psychological comfort (ease of use, travelers interactions, information)
Temporal availability	Increasing frequency of the travel mean and make it available out of peak hours
Spatial availability	Improving access to underserved regions
Safety/security	Reducing the risk of injuries (caused either by material of people)
Improvement of travel activities	Enhancing travel activities

4 DISCUSSION AND CONCLUSION

Design research gained expertise upon dealing with artefacts, services, and even product-service systems. This paper proposes a way to consider design challenges that might be faced when dealing with urban mobility at the scale of a city.

Several complexity factors have been identified. The diversity and the large number of UMS components and travelers make the understanding of the TUMS a difficult task. Thus, the influence of the users on the TUMS substantiate the relevance of including the traveler in modelling the UMS as a socio-technical system or as a market. The systemic modelling would allow to identify the existing links between UMS's entities of different natures such as stakeholders, a user, and a service.

The contribution of the paper is a proposition of interrelated key concepts to set the scope of design for urban mobility (Figure 4): traveler, TUMS components, travel scenarios and travel-centred indicators. The identification of the TUMS components brings out the need to consider their diversity and their large number. Some components are used at the same time (e.g. vehicle on road), some others sequentially (e.g. bus station, bus, then train station). Moreover, one component is used continually by different users.

Moreover, including social and economic activities of the travelers allows to enlarge the value proposition of transportation solutions and therefore connect the UMS to other urban systems. For instance, a famous GPS-based geographical navigation application includes a mobile marketing feature. Drivers are suggested shop and restaurants that are more likely to interest him/her depending on his/her driving patterns.
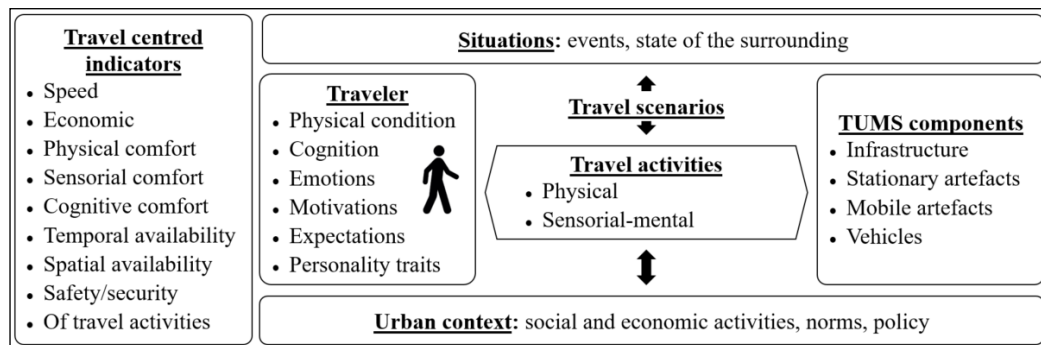

Figure 4. Key concepts for urban mobility design

Some limitations have be reported. Firstly, the large number and the diversity of travelers poses the question of what profiles to consider in order to shape the travel scenarios. A classification of travel activities and situations can be useful to capture the variety of travel scenarios and travelers' profiles. This should be further investigated. Secondly, the travel scenarios describe the way the travelers can use the TUMS. However, the combination of situations and activities does not consider what the traveler thinks and feels, contrary to UX design models (Ortíz Nicolás & Aurisicchio 2011). The representation of traveler experience can be enhanced by linking thoughts and emotions to the activities and situations. Thirdly, the traveler-centred indicators evaluate how the traveler appreciates the experience of using the TUMS. For example, temporal availability of a tram line for a group of travelers during a time interval would be an alternative to the indicator of frequency and regularity. The proposed values are meant to describe if the TUMS components improve traveler experience (and how). Therefore, these need to be linked to the activities, situations and components.

In conclusion, the preliminary step tackled in this paper was to provide engineering designers a holistic view of TUMS components. This was achieved through the hybridization of a UX conceptual model with acknowledged mobility concepts.

Future work aim at developing an ontology that links components to travel scenarios and to the indicators system, in order to obtain a traveler-centred model of the UMS. The goal of the ontology is to capture the diversity of issues in urban mobility experiences in a need-seeker mode (as developed in (Bekhradi et al. 2015) for elderly falls for example). Several applicative situations are envisaged.

An innovation department in the automotive sector may use the approach to define the coverage ability of new driverless shared solutions over a cluster of usage segments. In a context of market opening for competition, a public metro or train operator may analyse issues of mobility experiences to gain knowledge into determinants of modal choices over usage segments, or foster the design of new integrated offers.

Developing innovative products and services that ensure well-being of travelers is indeed a strategic challenge for urban mobility practitioners (industrials, operators, start-ups etc.) that is guiding future developments of this research.

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