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DOCTORAL THESIS

SUMMARY

Advanced methods and techniques for estimating daily mobility dynamics

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1. INTRODUCTION

1.1. Necessity and opportunity of the research topic

In the modern world characterized by globalization, both spatial and organizational structures have significantly expanded their geographic reach. Today, almost all urban agglomerations present the same mobility problems:

- the expansion of cities (extension of the peripheries) generates longer distances for the inhabitants;
- increasing the motorization index at the household level, especially in developing countries;
- lifestyle diversification, which contributes to congestion (Raicu and Costescu, 2014).

Perceived as a symbol of individual freedom, the use of cars opens numerous polemics regarding the departure from collective values, with dire social and psychological consequences (Raicu and Costescu, 2020). This addiction affects the economy, the environment and the health of the population by generating traffic congestion. According to the literature, the medium and long-term forecasts related to mobility and traffic are worrying. It is estimated that by 2050 the world's urban population will increase by 2.5 billion people, and the total number of kilometers traveled in the urban environment is expected to triple by 2050. Public authorities have at their disposal a whole range of limiting measures to the use of the car, but they do not always put into practice. Among them can be mentioned:

- replacing the need to travel by work from home (WFH);
- actions to promote ecomobility;
- penalty pricing for cars traveling in congested areas;
- improving public transport offers (Raicu and Costescu, 2020).

Among the recommended techniques to support sustainable urban mobility are the promoting of walking or cycling, but also the use of public transport, instead of personal cars (Dragu et al., 2014). In the context of the overcrowding of urban space, but also of the COVID-19 pandemic that marked the entire planet, travel trends are migrating to new mobility practices. The evolution of travelers' expectations towards individualization and sustainability requires the expansion of the portfolio of mobility services, as well as the transformation of the business model (Van Audenhove et al, 2014). People's social and psychological norms lead them to optimize travel time, not distance travelled, and a solution to this problem lies in combining transport services with travel as prosumers. Among the new mobility practices promoted on a large scale by the authorities are also non-motorized trips, with the aim of reducing emissions and improving the quality of air and life, but also to reduce the degree of traffic congestion, if we refer to travel services included in "micromobility". The relatively new concept of Mobility-as-a-Service (MaaS), as well as urban public transport (UPT) and shared mobility, all aim to mitigate the impact of travel demand and propose a more efficient and user-centric mobility paradigm (Crist, 2021).

The development of multimodal and intermodal modeling is generating much more general and relevant conclusions. Most studies in the literature lack scenarios based on combined travel modes, and whose modes' utilities are calculated and compared as alternatives, which does not actually correspond to intermodal choice behavior (Liu et al, 2019).

However, the recent COVID-19 pandemic has reinforced the idea that transport forecasting cannot be done with 100% certainty and that certain events can seriously, even temporarily, affect operating schedules, or more generally speaking, travel demand. A "new normal" for the transport sector is expected. One of the goals of the study is to highlight the implications of transportation policies for metropolitan development, as a strategy for resilience and mitigation of future pandemic outbreaks and other disruptions, and to design more sustainable transportation systems. Experts reported that for all countries/regions, transport system measures for public health threats prior to the COVID-19 pandemic were very poor. Policymakers should take these measures and the impact of possible new pandemics seriously.

According to literature, all kinds of transport modes are available in the biggest cities (metro, buses, trams, trolleybuses), and the use of public transport exceeds that of cars. This is not the case, however, for medium-sized cities, where conventional types of UPT are not so varied. And as the transformation of "ex-ante" demand into "ex-post" demand is conditioned by the technical landscaping in the territory (Raicu and Costescu, 2014), the urban area enters a vicious circle of urban decline, with the number of cars continuously increasing and generating even more congestion and pollution (Polydoropoulou et al, 2019). The electric car is a good start in reducing carbon emissions, but a single-occupant vehicle that weighs several times the passenger's weight, that needs to be recharged often, and still does not solving the congestion problem, is not sustainable enough (Tuncer and Brown, 2020).

Cities, even the medium and the small ones, have become overwhelmed by traffic and congestion. Innovative solutions are needed, and the recent studies have focused on sustainable approaches. From these considerations arose the opportunity of this thesis, whose case study aims to develop an intermodal travel/transport model consisting of an UPT service combined with an electric scooter sharing service. The main purpose of the model is to compare two travel alternatives (car and UPT+electric scooter), calculating their associated levels of utility. The methodology is based on a Multinomial Logit model, implemented in Matlab software, using results from an online mobility survey (to extract the socio-economic characteristics of potential electric scooter users). The additional aim is related to the assessment of the inhabitants' availability to shift from car (either personal or work) to an intermodal service or to simple electric scooter service. The developed micromodel is performed in a medium city located in the North-East of Romania, Iași city. Several pricing strategies were analyzed in order to find their influence on users' mobility behavior. It turned out that the price of renting an electric scooter is too high at this moment to be used for daily travel. Without a price decrease and the public authorities' implication in facilitating the intermodality, the electric scooter remains only an entertainment activity (Harpalete, 2003).

1.2. Literature review

The state of research in the field is presented in correlation with the concepts used in the thesis. Relevant and recent works on some topics are exhibited, such as: mobility and urban accessibility, travel surveys, micromobility, electric scooters, intermodal travel, travel/transportation policies. These are grouped and presented in table 1.1.

Tab. 1.1. The main bibliographic references studied, grouped by topic

Thematic group	Bibliographic references
1. Mobility and urban accessibility	Bonnel, 2001; Ceder, 2001; Raicu and Popa, 2009; Ortuzar and Willumsen, 2011; Parvathy et al., 2013; Aditjandra et al., 2013; Van Audenhove et al., 2014; Nykl et al., 2015; Saghapour et al., 2016; Danielis et al., 2018; Nian et al., 2020; Raicu and Costescu, 2020; Abbasi and Rashidi, 2021; Cao et al., 2023
2. Land use/transport integration models (LUTI)	Rodrigue, 1997; Wegener, 2004; Iacono et al., 2007; Raicu and Popa, 2009; Aditjandra et al., 2013; Acheampong and Silva, 2014; Brandi et al., 2014; Renner et al., 2014; Wang et al., 2014; Johansen et al., 2015; Guzman et al., 2016; Saujot et al., 2016; Tillema, 2016; Niu and Li, 2019; Basu and Ferreira, 2020
3. Travel survey	Stopher and Greaves, 2006; Choujaa and Dulay, 2009; Ferrer and Ruiz, 2014; Mokhtarian et al, 2014; Cottrill et al., 2015; Kagerbauer et al., 2015; Armoogum et al., 2018; Capponi et al., 2019; Sanders et al., 2020; Song et al., 2020
4. Intermodal travel	Krygsman, 2004; Clifton și Muhs, 2012; Kagerbauer et al., 2015; Feltus et al., 2019; Liu et al., 2019; Naumov, 2019; Bakogiannis et al., 2020; Jie et al., 2021; Shokouhyar et al., 2021; Kilani et al., 2022; Ma et al., 2022; Reck et al., 2022; Hamadneh și Jaber, 2023
5. Micromobility – electric scooters	Bajpai, 2016; James et al., 2019; Fearnley et al., 2020; Sanders et al., 2020; Tuncer și Brown, 2020; Christoforou et al., 2021; Mitra and Hess, 2021; Esztergar-Kiss et al., 2022; Choi et al., 2022; Harpalete, 2023
6. Transport policies	Banister, 1998; May et al., 2003; Lopez-Ruiz and Crozet, 2010; Poli, 2011; Banister and Hickman, 2013; Bertolin et al., 2019; Aifadopoulou et al., 2020; Stephen and Townsend, 2020; Zhang et al., 2021; Axhausen, 2021; Awad-Núñez et al., 2021; Choi et al., 2022; Kilani et al., 2022

A series of papers aim to determine the relationships between urban mobility and its influencing factors. Ceder (2021) provided future perspectives on urban public transport, justifying the considerable changes in people's lifestyles. Danielis et al. (2018) applied several techniques to estimate a composite urban mobility indicator for 116 Italian provincial cities. Abbasi and Rashidi (2021) examined factors affecting urban mobility, such as travel attributes and socio-demographic characteristics, in the Melbourne metropolitan area. Cao et al. (2023) used scaling laws to assess the internal growth logic of a city and specifically to determine the link between urban indicators and population growth. Nian et al. (2020) described an urban mobility assessment model based on taxi traffic in the city. Nykl et al. (2015) developed a method for analyzing accessibility in urban intermodal travel based on a complete and detailed representation of the transportation system. Sagapour et al. (2016) worked on a study on public transport accessibility that considered the frequency of public transport service, but also considered population density as an important distributional indicator. Another study based on an indexing system was conducted by Parvathy et al. (2013) for the Thiruvananthapuram urban area, India.

Travel surveys are essential tools in mobility studies, providing valuable information about the travel habits of the population and how they move between different locations. Sanders et al. (2020) conducted a survey of e-scooter commuting in Tempe, Arizona, where they divided respondents into groups based on ridership frequency to examine the relevance of the experience. Choujaa and Dulay (2009) provided a paper on human activity recognition based on mobile phone data. A study based on measuring the entropy of movement of mobile phone users indicates that the predictability of transportation behavior can reach 93% on average (Song et al., 2020).

In urban mobility research, the study of intermodal transport is an indispensable subject, which requires a complex and essential approach for understanding and improving transport systems in the urban environment. Naumov (2019) developed a model that estimates the demand characteristics of transfers in public transport networks. Kagerbauer et al. (2015) showed that 22% of trips were made with several modes of travel, but also that walking and cycling are underrepresented in the share of modes. Bakogiannis et al. (2020) wrote about the cooperation between public transport and rental bicycles in Athens as a solution for suburbanites to be more motivated to use public modes more often, becoming less dependent on cars. Hamadneh and Jaber (2023) studied transport choice behavior in Budapest, Hungary using decision tree technique and discrete choice modeling. Jie et al. (2021) studied the current and potential impact of different forms of shared mobility, focusing on Wanneroo County in Western Australia. Ma et al. (2022) envisioned an intermodal travel model, connecting subways with shared electric scooters. Reck et al. (2022) contributed by collecting a large data set with matched GPS routes, booking data and survey data for over 500 travelers and estimated a model of first choice among eight travel modes, including electric scooters.

Esztergar-Kiss et al. (2022) conducted a stated preference survey to reveal user utility for using electric scooters in five large cities (Copenhagen, Munich, Barcelona, Tel Aviv, Stockholm) and applied 3 types of Logit model (Multinomial, Mixed and Nested) to extract the coefficients.

Before 2010, there were four researches on taxes and green transport, scenario building for sustainable transport, climate change and hydrogen transport. From 2016 to 2020, transport studies using expert surveys increased to 28 papers, including topics of sustainable mobility, autonomous and electric mobility, intelligent transport, energy and CO_2 emissions, transport public, intermodality and travel behavior etc. The number of papers in the period 2016-2020 is more than three times higher than in the period 2010-2015 (Zhang et al, 2021).

2. MOBILITY. LAND USE/MOBILITY INTERACTIONS

2.1. Mobility. Conceptual clarifications

A city without mobility is not a city, but a territory without networks as a field of blurred and blind spots (Raicu and Costescu, 2020). Population mobility is the sum of individual mobilities and is defined as the need to travel for different purposes. It is structured relatively stably over time, based on direct and inverse correlations between the activity system and the transport system (Wegener, 2004).

Urban mobility plays a key role in the development and adaptation of cities to cope with such a rapid increase in congestion and urbanization. Sustainable development solutions are increasingly in demand in cities to facilitate a better urban experience. Cities are increasingly facing problems caused by traffic and transportation, with mobility needs to reduce congestion, accidents and pollution (Vaidian, 2019). Technological advances also play a significant role in improving urban mobility. Electric vehicles, autonomous cars and ridesharing services can bring major transformations in the way people travel in cities, reducing the impact on the environment.

2.2 Forms of mobility

2.2.1. Spatial mobility

There are four forms of spatial mobility and they can be defined as it follows:

- sedentary mobility (commuting trips),
- cosmopolitan mobility (of the businessman);
- reversible mobility (specific to the tourist);
- reimplantation mobility, corresponding to the migrant.

2.2.2. Social mobility

2.2.3. Intellectual or professional mobility

2.3. Land use/mobility interactions

2.3.1. Motivations

The structure of a city obviously influences mobility behavior, and the location of activities is one of the main factors that determine people's trips. On the other hand, the transport system plays a very important role in accessing these activities: the transport offer influences the choices of transport locations, moving the economy of the city, the structure of urban settlements and, consequently, the social environment. So, it is clear that land use and transport system are closely connected and there is a growing need to be integrated in order to achieve a sustainable environment (Brandi et al., 2014).

Coordinated land-use and transportation planning has been an important strategy for reducing travel demand and car dependency for decades. This aimed at better living conditions, improvement of the urban environment, less traffic congestion, better accessibility for everyone and reduction of greenhouse gas emissions (Johansen et al., 2015). The mediating factor in determining changes in activity location and travel demand is accessibility, which measures the situation of a location in relation to other activities or opportunities (work, shopping etc.) distributed in space (Iacono et al., 2007).

2.3.2. LUTI models

2.3.2.1. Purpose. Structure

Over the past six decades, several LUTI models have been developed, calibrated, and applied in policy analysis at different spatial scales. Most operational LUTI models have three main components or sub-models, namely land use, socio-demographic and transport. These sub-models are either fully integrated or loosely coupled with each other to provide input-ouUPTt links during model execution (Acheampong and Silva, 2014).

Land use planning is the key to controlling transport demand as well as its impact on the environment. Although the inter-relationship between land use and transport is complex, it is well established. An inherent interaction or feedback process occurs between land use and transport, where one influences and depends on the other. Many works refer to this interaction as the land use – transport feedback cycle, illustrated in figure 2.7 (Heyns and Jaarsveld, 2017).

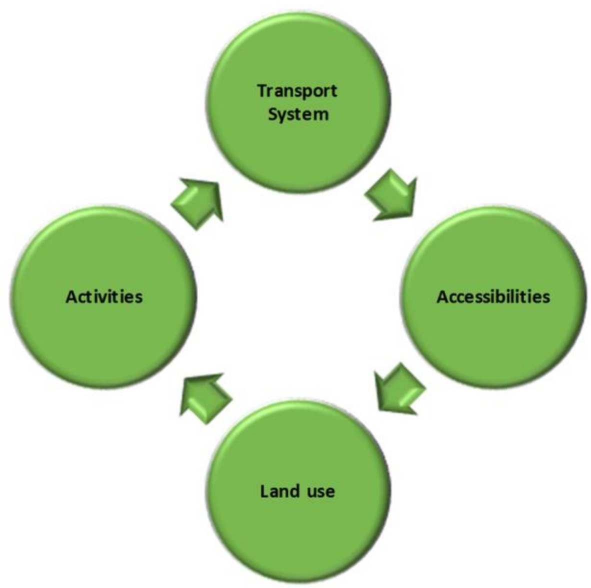

Fig. 2.7 Land use – transport feedback cycle (source: Heyns și Jaarsveld, 2017)

Starting at the end of the cycle (Land Use), population households and employment locations determine the origins and destinations of most trips in travel patterns (Activities). Transport system modeling allows the calculation of accessibilities, which describe how accessible an area is to all other areas. Accessibility shapes land use as both households and businesses seek accessible locations (Heyns and Jaarsveld, 2017).

2.3.2.2. Types of LUTI models

2.3.2.2.1. Multinomial Logit and Nested Logit type LUTI models

The nested logit model is a common logit model developed as a nested model and aims to examine two things:

1) To what extent the choice of travel mode and residential location have a mutual causal effect;
2) To what extent the choice of travel mode and residential location introduced the effect of self-selection. The model is simple, that is, using the basic model of the common logit model and attached to the nested structure. Common logit is a technique where the analyst has a multidimensional choice set with shared observed attributes.

2.3.2.2.2. Activity-based LUTI models

This LUTI planning model that can be adopted as an effective decision support tool by urban planning administrations and able to promote the use of public transport in urban areas. The idea is to relocate a subset of activities from urban areas with strong appeal but poorly connected to the city's transport system to urban areas close to existing public transport links with available residual capacity. The aim is to move, with the relocation, a sufficient part of trips from private transport to public transport (Niu and Li, 2019).

2.3.2.2.3. Agent-based LUTI models

The object modeled with LUTI models is the urban system. The natural environment, legal regulations and infrastructure are the stage on which economic actors (individuals) or groups of actors (households, companies) carry out their activities. The natural environment includes all the elements that would exist without human beings. It is the basis of human activities and itself an extremely complex subsystem. Agent-based LUTI models fall into two categories. At the level of individual agents we are talking about multi-agent systems or disaggregated/microsimulation models, and at the level of representative agents we have the aggregated models.

2.3.2.2.4 LUTI models based on neural networks

A data-driven approach focuses more on creating relationships, using empirical data sets rather than solid theoretical frameworks. Rodrigue (1997) states that urban structure and its evolution should not be considered as given, but as the result of complex interactions. It is precisely those aspects where most of the LUTI transport operational models are deficient. Lack of theory prevents models from becoming standard. Rodrigue introduces the possibility of creating a self-adaptive spatial model. An example of data-driven self-adaptive techniques are artificial neural networks.

3. MOBILITY DEMAND ESTIMATION

3.1. Scenarios for the evolution of mobility in the medium and long term

People speculate on the future, but it is increasingly less certain and harder to predict, as it is influenced by an ever-widening range of factors, some of which can have quite an impact on lifestyle. The classic estimation method involves using information from the past and extrapolating it into the future. The problem with this approach is that it works in the short term, but in the longer term it is not enough, given the problems of mobility, climate change or the cost of transport (Banister and Hickman, 2013).

Three basic types of scenarios can be identified, but in different applications there are different approaches used to combine elements of each type so that the process is tailored to the particular situation under investigation. This flexibility in approach is characteristic of the construction of scenarios (Banister and Hickman, 2013; Raicu and Costescu, 2020):

- forecasting scenarios;
- exploratory scenarios;

- prospecting scenarios or retro-forecasting (backcasting).

All scenarios for prospecting the future of urban mobility in the medium and long term have identical objectives: sustainable mobility and quality of life in urban agglomerations. Two lines of demarcation must be considered in the evolution of urban mobility. One is about collective behavioral choices, and the other is about public policy. Combining the two disjoint alternatives of the two demarcation lines results in four synthetic scenarios of urban mobility policies:

- **Scenario 1**: "Technological Voluntarism" (Homo Technicus)
- **Scenario 2**: "Cost Awareness" (Homo Oeconomicus)
- **Scenario 3**: "Mobility control through individual transactions" (Homo Contractor)
- **Scenario 4**: "Mobility control through a collective urban transaction" (Homo Politicus).

3.2. Travel surveys for urban mobility estimation

3.2.1. Household travel surveys

3.2.1.1. Evolution and objectives

The first household surveys on mobility, limited to some urban areas, were carried out in the United States starting in the 1950s. Local investigations multiplied almost everywhere in the 60s. In parallel, national censuses began to collect information on "commuters". Then national behavioral surveys (without representations of origins and destinations) were carried out. These household mobility surveys provide information on three statistical levels: household, individual and trips.

The urban travel survey has two main objectives. One is to find sources of data from the perspective of travel planning, and the other is to analyze and study the explanatory factors of travel behavior. The main purpose of travel planning is to ensure the various functions of the space in optimal economic and social conditions, with the reserve of anticipation and reflection, leading to various fields:

- the design of transport schemes, whether it is a modal or much more current approach, the intermodal one;
- management of road infrastructures or public transport companies;
- regulation of travel demand both in the short term (or even in real time) and in the long term;

- pricing of urban trips (for all modes of travel);
- organization and management of connections between travel modes;
- reflection on the interactions between urban planning and travel (Rodrigue, 2020).

3.2.2. Experimental methods and techniques

Engineering and technology have changed drastically in the 21st century. New means and procedures for collecting data for travel assessment have developed, such as new data sources from mobile devices (including smartphones and tablets), sensors embedded on vehicles, advanced GPS technologies, but also other information and communication technologies (figure 3.4).

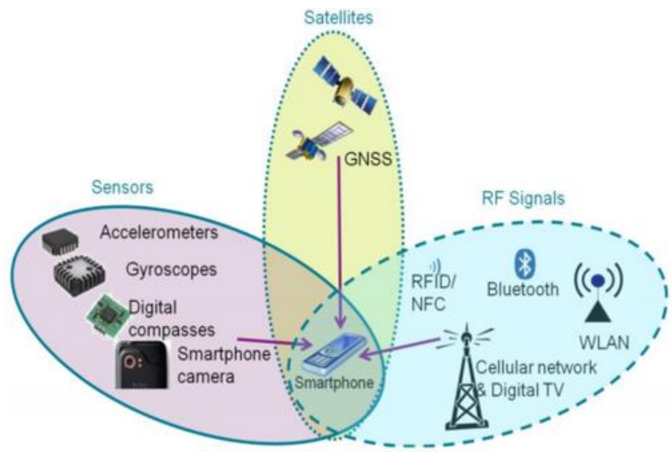

Fig. 3.4 Data collection systems and techniques from mobile phones (source: (Huntzinger and Donnelly, 2014).

By applying data from mobile phones, researchers can simulate trips generation and distribution in a different way. In other words, the OD (origins-destinations) matrix can be derived from data obtained from mobile phones, and then the simulated results are validated by comparison with other data sets, such as observed traffic numbers extracted from traffic videos. Moreover, some studies have been conducted to model the last two steps from the classic model with data from mobile phones, namely modal distribution and route allocation (Huntzinger and Donnelly, 2014).

3.2.3. Advanced systems for data collection

3.2.3.1 GSP-based travel demand estimation

3.2.3.1.2. The use of GPS systems in travel surveys

The use of GPS has been examined in several small-scale pilot projects to date. Clearly, one promising avenue for survey research is GPS-based surveying. It began with the proof-of-concept experiment conducted by the US Department of Transportation in Lexington, Kentucky in 1996 (Wagner, 1997). Since then it has evolved significantly (Wolf, 2004; Stopher and Greaves, 2006) and there have been a considerable number of surveys carried out in the USA, the Netherlands and Australia at least, using GPS devices to record the movements of individuals. An excellent summary of these approaches can be found in Wolf (2004).

The advantages of GPS-based surveys are obvious. The devices provide a very precise position of the start and end points of the trip and also provide detailed data about the route used (data that until now could not be collected). The ability to identify the actual origin and destination of travel may make it possible to move away from using the traffic analysis area as the basis for urban travel analysis and move instead to the continuous representation of space in our travel models. The devices also provide highly accurate information about when the movement occurred and how long it lasted.

One of the major problems with GPS devices is signal loss or severe signal degradation in various circumstances, including tunnels, urban passages, canopies of massive trees, in certain types of vehicles, and loss of information due to position detection delays at the start of a trip.

3.2.3.1.3. Travel surveys based on dedicated GPS devices

When talking about a travel survey based on dedicated GPS devices, participants receive a passive GPS device with a single on/off button, which represents a major investment (most devices are not even recovered) (Chibane and Gwiazdzinski, 2014). Next, there are presented 4 of the GPS devices used mainly in the investigations of the last years: IGOTU, Route 66, TrackStick MINI and BT-Q1000X (figure 3.7).

Fig. 3.7 Examples of dedicated GPS devices (source: Nguyen-Luong, 2012)

A separate pre-survey questionnaire is required to ask about the most frequented places and addresses: home, work, school, two frequent shopping locations. A follow-up Internet survey is indicated to specify some information about objectives, methods, etc. Participants view their GPS routes on the Internet and they are asked to confirm them or not (Liu et al, 2013).

3.2.3.1.4. Travel surveys based on smartphones

Most of the modern phones include all the communication technologies and peripherals needed for a travel survey: GPS, GSM/GPRS, Wifi, Bluetooth, antennas, inertial sensors. All that is missing to start a GPS-based travel survey is a tracking application that merges information from all available integrated technologies and obtains its own records, continuously and invisibly to the user.

In a smartphone-based survey, participants download, install, and use a specially developed smartphone app. Each participant regularly logs into the survey website to verify and validate their activities and travel. The smartphone uploads the data to a server, which uses several analysis algorithms (Cottrill et al, 2015; Patterson and Fitzsimmons, 2016) (figure 3.8).

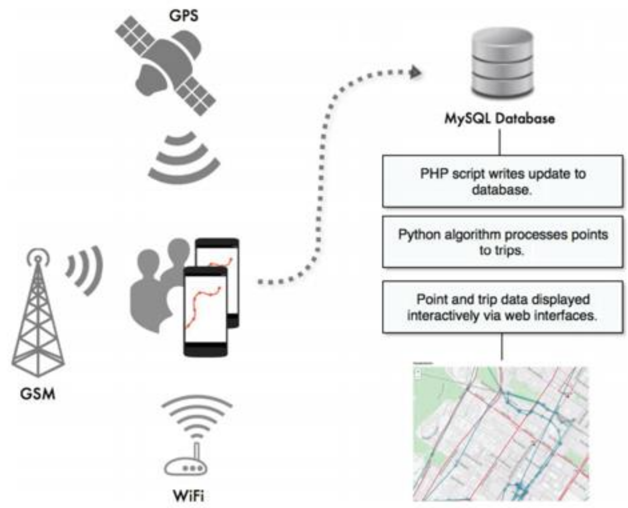

Fig. 3.8 Mobile application architecture for data processing
(source: Patterson și Fitzsimmons, 2016)

3.2.3.1.5. Travel surveys based on vehicles and blockchain technology

A modern trend in travel surveys is to use in-vehicle GPS modules to collect travel data, as it is less cumbersome for participants and can be conducted over a longer period of time (Gong et al, 2017). Today, vehicles are equipped with computers (ECU – Electronic Control Unit), sensors and communication equipment to collect, process and share data. At the heart of all these emerging connectivity technologies is an embedded hardware and software system called the Telematic Control Unit (TCU) (Saberi et al, 2019). It uses the V2X standard for mobile networks to provide connectivity for data exchange between on-board and off-board systems. This computer also collects telemetry data from the car such as position, speed, engine data, connection quality and more. The on-board telematics system consists of a navigation satellite (GNSS) unit, a GSM mobile communications antenna and an electronic processing unit (Gao et al, 2019).

Blockchain technology can support the collection, storage and management of data, responding to the growing needs of Big Data (Saberi et al, 2019). Blockchain has the power to transform the IoT through an open, trusted and auditable shared platform where any information exchanged is traceable and secure (Mistry et al, 2019). At the Road Side Units (RSU) level, a Blockchain network is implemented. These RSUs manage the certification and revocation of vehicles. The various Blockchain ledgers are used to store certificates, admission, authentication and revocation lists, ledgers that can be accessed by vehicles and authorities using Blockchain transactions.

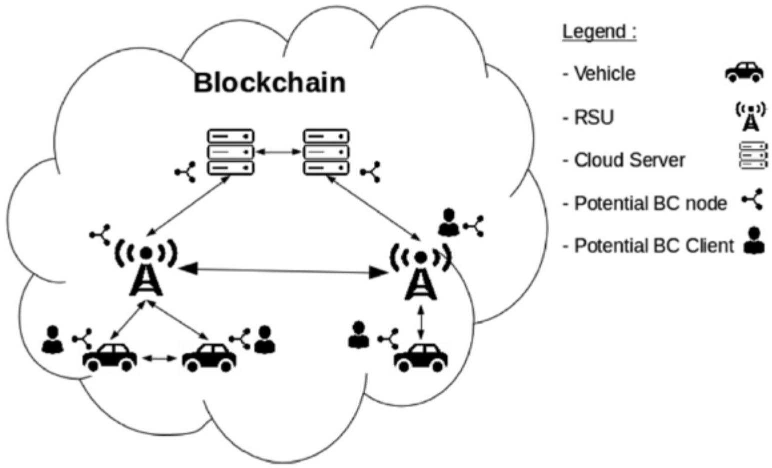

Fig. 3.10 Implementation of the blockchain technology in vehicular networks

As it can be seen in the table 3.2, there are many more differences than similarities between a smartphone-based and a vehicle-based GPS survey.

Tab. 3.2 Comparație între ancheta GPS cu smartphone și ancheta GPS cu vehicule

	Smartphone GPS-based travel survey	Vehicle GPS-based travel survey
Alikes	Both mobile phones and vehicles are equipped with GPS receiver and also with accelerometer	
Differences	Participants can use any mean of transportation	Participants use only the personal vehicle
	Participants can be anyone, since everybody has a smartphone	Participants are harder to find, as not all vehicles are equipped with a Telematic Control Unit
	Participants download a survey app from the phone manufacturer's app platform	Participants have to insert a stick drive in the USB of the Multimedia interface to run the survey App

	The GPS data are sent directly to the data collection server	The GPS data are sent through different layers and technologies, Blockchain networks being needed
	The battery of the smartphone is depleted very fast	The battery of the vehicle discharge much slower, being recharged by the alternator (in case of thermic engine vehicles)

3.2.3.2. Other equipments and integrated technologies used for travel demand estimation

Basically, there are two systems that can monitor the location and movement of mobile phone users: the positioning system and the movement system (Wang and He, 2017). In terms of positioning systems, RF radio frequency signals are often used to determine the location of mobile devices. These radio frequency signals include signals from cellular networks, GPS, WiFi, and Bluetooth. As for the motion system, built-in sensors are used to track the motion types of each smartphone device. Here we include accelerometers, magnetic sensors and compasses (Wang and He, 2017).

4. SOLUTIONS FOR PROMOTING SUSTAINABLE MOBILITY

4.1. Public transport and individual trips with light and non-bodied vehicles

4.1.1. Mobility-as-a-Service vs Mobility-on-Demand

A key component of future mobility and its metabolism is what is known as Mobility-as-a-Service (MaaS), representing emerging opportunities for travel modes in the cities of the future (Barreto et al, 2018). Mobility-as-a-Service (MaaS) is a digital service that guides users to plan, book and pay for a range of mobility services, often connected to each other (figure 4.1).

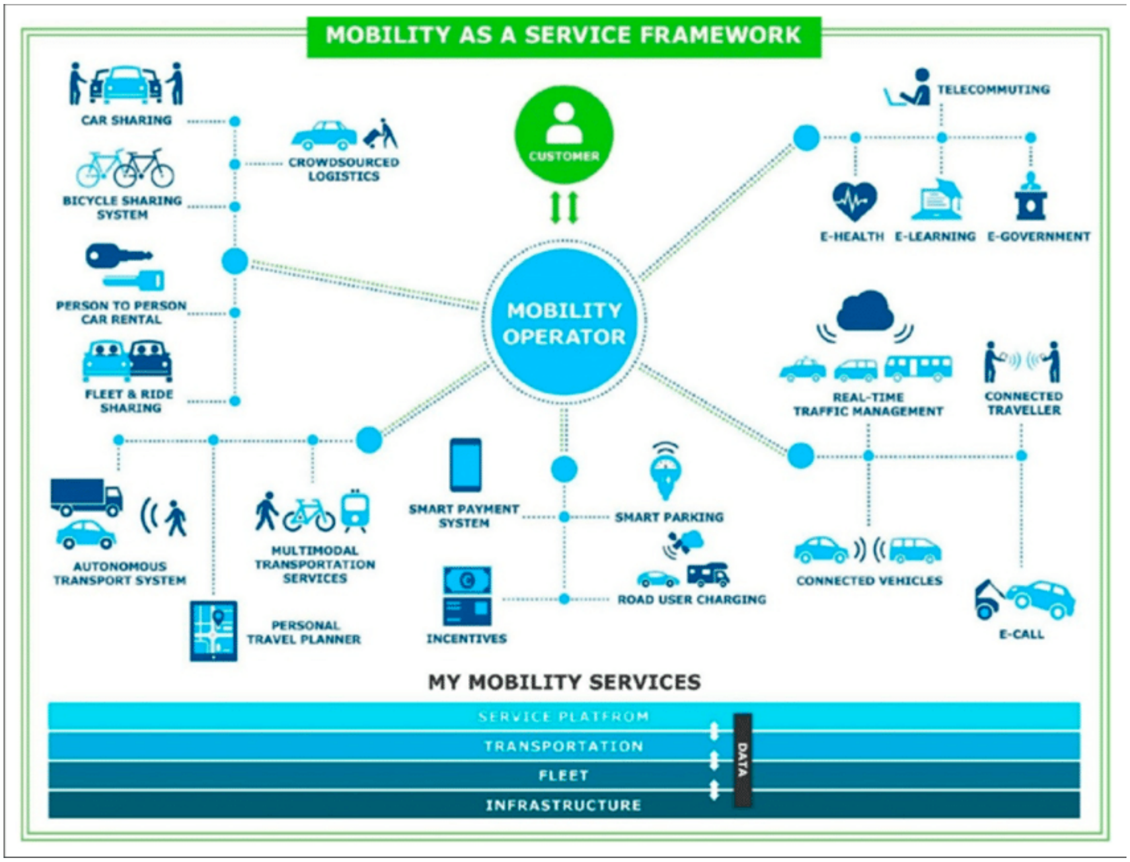

Fig. 4.1 Mobility-as-a-Service framework (source: Garcia et al, 2019)

4.1.2. The expansion of the use of electric scooters

The main purpose of micromobility is to cover short distance trips, including the first/last km issue. This problem refers to the access and egress stages of a journey, which together with waiting and transfer times are considered the weakest parts of an intermodal UPT chain, while their contribution to the total utility of travel is substantial (Krygsman, 2004). The e-scooter movement started in the United States in 2017, was present in 33 cities in 2018 and over 90 cities in 2019, rapidly expanding throughout Europe. They are dockless and can be used on streets, while bicycles are restricted to be used on cycle paths (Ma, 2022). The e-scooter is a convenient way to get around, especially in hot weather, to replace walking and gets people to their destination 22% faster than cycling (Sanders et al., 2020).

4.1.3 The main problems encountered in the use of electric scooters

The main problem with electric scooters is similar to that of electric vehicles. Their electric batteries have a short lifespan and their recycling is not very environmentally friendly (Christoforou et al., 2021). They are useful if they replace car trips in areas with accessibility difficulties to public transport, but if they mostly replace walking, then the environmental impact becomes negative. At the same time, the introduction of electric scooters triggered considerable public debate, because it started to have an impact on other users of public space, such as pedestrians who no longer feel safe on the sidewalks, because some electrical scooter users drive irresponsibly (Tuncer and Brown, 2020).

4.2. Intermodal travel (chained trips)

Intermodal travel, although on an upward trend, has been somewhat neglected over time in travel demand research (Clifton and Muhs, 2012). An intermodal trip involves changing the mode of travel at least once, considering only one trip from the origin to the destination (a single activity) (figure 4.4). This should not be confused with linked trips, which are actually different stages of a tour, involving several activities.

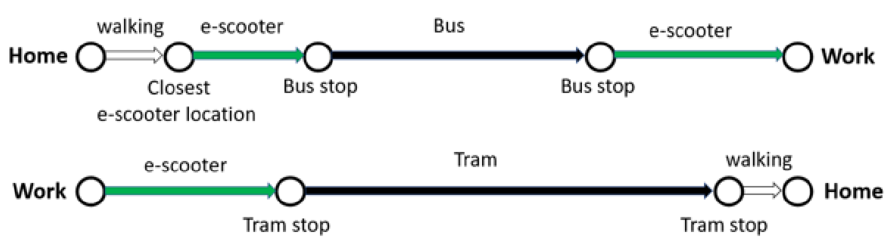

Fig. 4.4 Examples of intermodal transport that includes the electric scooter

For the purpose of the study, an intermodal travel/transportation model consists of a chain of services, with transfer at UPT stations. According to the definition above, the service chain contains the following components:

- a mode of access, the electric scooter taken from home or close to home to the nearest bus or tram stop;

- a main mode, i.e. the longest part of the trip, represented by bus or tram, from the closest station to the user's home to the closest station to the destination;
- a mode of egress, another electric scooter taken from the immediate vicinity of the UPT station where it got off, to the destination.

4.3. Discrete choice modeling

4.3.1. General notions

Utility is a term used in microeconomics to measure the additional amount of satisfaction a person would get from purchasing a good or service (Stephen and Townsend, 2020). This utility is derived from the characteristics of the alternatives and the characteristics of each individual, resulting in a linear combination of variables.

The simplest version of random utility theory postulates Homo Economicus individuals, q, rational and endowed with complete information and an observer, who must assume alternative utilities of the following form (equation 4.6) (Ortuzar and Willumsen, 2011; Sharma et al, 2017):

$$U_{iq} = V_{iq} + \varepsilon_{iq}, \tag{4.6}$$

where:

V_{iq} – the observed (deterministic) part of alternative i

ε_{iq} – unobserved random error distributed with a certain density function (disturbance)

The prediction of the alternative that will be chosen is done by calculating the utility of each option, and then the probability value between 0 and 1. This will have an S-shaped distribution and is determined using a Logit model (equation 4.2) or other forms:

$$P_1 = \frac{\exp\,(V_1)}{\exp(V_1)+\exp\,(V_2)} \tag{4.2}$$

To analyze a discrete choice problem, there are three main steps to follow:

1. Specifying the set of possible choices
2. Formulation of a model about how the decision-maker chooses the mode of travel
3. Estimation of the unknown structural parameters of the model, which describe the decision-maker's behavior, preferences etc.

4.4. Case Study. Estimating travel demand for an intermodal travel/transportation model, including electric scooters in Iași city

4.4.1. Study area and descriptive statistics

4.4.1.1. Demographic data for the city of Iași

The city of Iași is in a continuous population growth, almost doubling its number of inhabitants in the last 10 years (table 4.1). If at the last census in 2011 it had 290,422 inhabitants, in 2019 it had already reached 507,100 inhabitants. The most numerous age category is the one between 30-34 years old, with 43253 inhabitants in 2021, followed by the one between 35-39 years old, with 30374 inhabitants. Also, the younger age groups are more numerous than the older ones, which means that the population is predominantly young and growing. The city expanded in all directions, starting with the neighborhoods of Copou, Sărărie, Țicău, Tătărași, and continuing with Păcurari, Frumoasa-Poitiers, Socola, Bucium, Galata, Alexandru cel Bun, Dacia etc.

Tab. 4.1 The resident population in Iași by age groups in 2021

Age group	Sex	Residential environment	Region	Year 2021 Number of persons
0- 4 years	Total	Urban	Iasi	26480
5- 9 years	Total	Urban	Iasi	21682
10-14 years	Total	Urban	Iasi	18845
15-19 years	Total	Urban	Iasi	15354
20-24 years	Total	Urban	Iasi	15066
25-29 years	Total	Urban	Iasi	26988
30-34 years	Total	Urban	Iasi	43253
35-39 years	Total	Urban	Iasi	30374
40-44 years	Total	Urban	Iasi	28441
45-49 years	Total	Urban	Iasi	24490
50-54 years	Total	Urban	Iasi	25259
55-59 years	Total	Urban	Iasi	15789
60-64 years	Total	Urban	Iasi	21297
65-69 years	Total	Urban	Iasi	22491
70-74 years	Total	Urban	Iasi	16147
75-79 years	Total	Urban	Iasi	7890
80-84 years	Total	Urban	Iasi	6660
85 years and over	Total	Urban	Iasi	5055

4.4.1.2 The evolution of the public transport system in Iași

The current street network of Iași, developed on the basis of the one in the Middle Ages, has become insufficient during peak hours, due to the increasing number of cars, leading to traffic jams in the main intersections. Starting from 2017, the Public Transport Company Iași operates 8 tram routes and 25 bus lines in the municipality (table 4.2).

Tab. 4.2 Public passenger transport in Iași (source: https://iasi.insse.ro/produse-si-servicii/publicatii-statistice/anuarul-statistic-al-judetului-iasi/)

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
Length of the lines (km)						
Trams	83	83	83	79	79	79
Number of vehicles						
Trams	150	151	124	126	126	126
Buses	278	207	161	169	169	166
Passengers (thousands)						
Trams	60576	65107	75281	73721	35472	28025
Buses	89238	88667	89292	101373	46180	36061

The number of cars registered in circulation in the city of Iași has also continuously increased, from almost 80,000 in 2007 to over 200,000 in 2020 (figure 4.7) (Wikipedia).

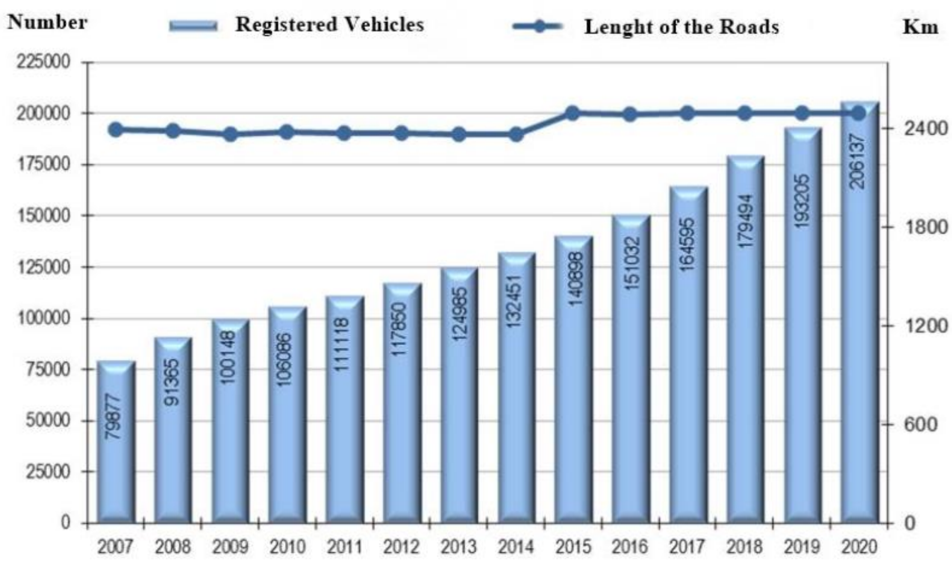

Fig. 4.7 The official number of cars registered in circulation in Iași (light blue) and the length of public roads (dark blue) (source: https://iasi.insse.ro/produse-si-servicii/publicatii-statistice/anuarul-statistic-al-judetului-iasi/)

Starting from April 8, 2022, electric scooters supplied by the company Lime are available for rent in Iași. To be able to use this service, the user must download the "Lime" mobile application, in which he will be able to see the location of the available scooters, thanks to GPS technology, choose the nearest scooter and unlock it with his phone, scanning a QR code on it.
At the end of the ride, the electric scooter can be left anywhere within the defined perimeter, and a photo of it in a suitable place is required to end the ride. Usage costs are 0.68 RON/minute, and unlocking costs 2 RON. For Romania, the costs are not considered the most affordable for long distances, at this moment, considering a 30-minute journey, for example, the cost would be 22.4 RON, for an hour, 42.8 RON.

4.4.2. Determining the accessibility indicators of the city of Iași

4.4.2.2 Examining residents' accessibility to city points of interest through isochrones (QGIS)

The first step in determining the relevant isochrones for the city of Iași consists in identifying the public transport lines that connect the suburbs, with reduced accessibility, and the city's points of interest. The 8 points of interest (POI) identified were: Palas Mall, Copou Park, Central Railway Station, Botanical Garden, Alexandru Ioan Cuza University, Metropolis of Moldova, Iulius Mall and Union Square.

The QGIS software package was used to mark on the map of the city of Iași each UPT station (red circles ●), the links between them (broken line ---), but also the 8 main points of interest (green stars ★). The QGIS application uses the OpenStreetMap (OSM) geographical database, which is available in open source format (free), to which point layers can be added, points between it can be calculated the distance, shortest route, isochrones etc. For each route of the UPT and its stations, special layers have been created so that it can be easily added and removed from the map (figure 4.11).

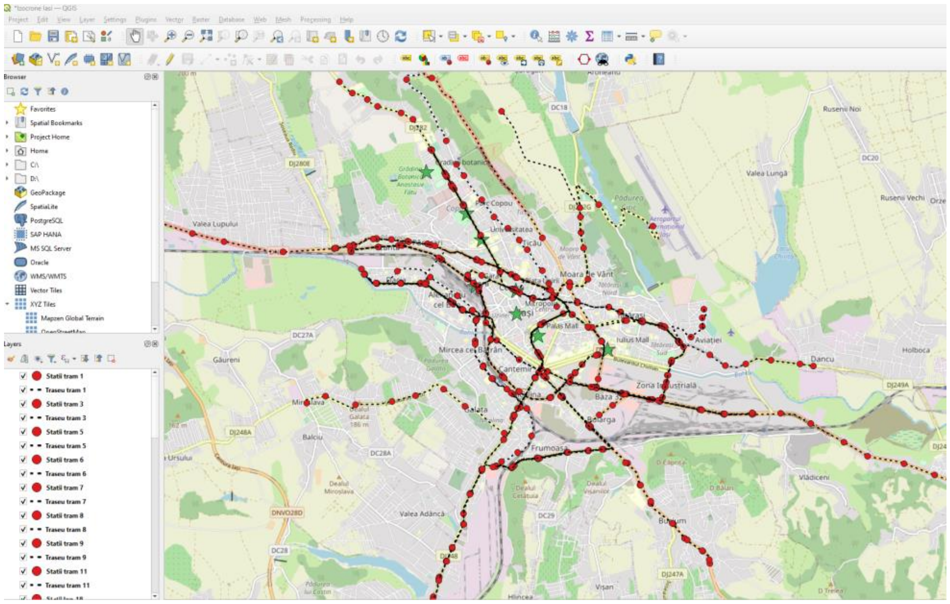

Fig. 4.11 Stations and routes of UPT in Iași

The interest consists in determining the accessibility of the inhabitants of the neighboring areas of Iași to the points of interest of the city, by UPT and intermodal. Thus, we identify 9 areas with reduced accessibility and the transport lines that connect them to points of interest: Dancu, Valea Adâncă, Miroslava, Tomești, Breazu, Lunca Cetățuii, Bucium, Moara de Vânt and Țicău (figure 4.12).

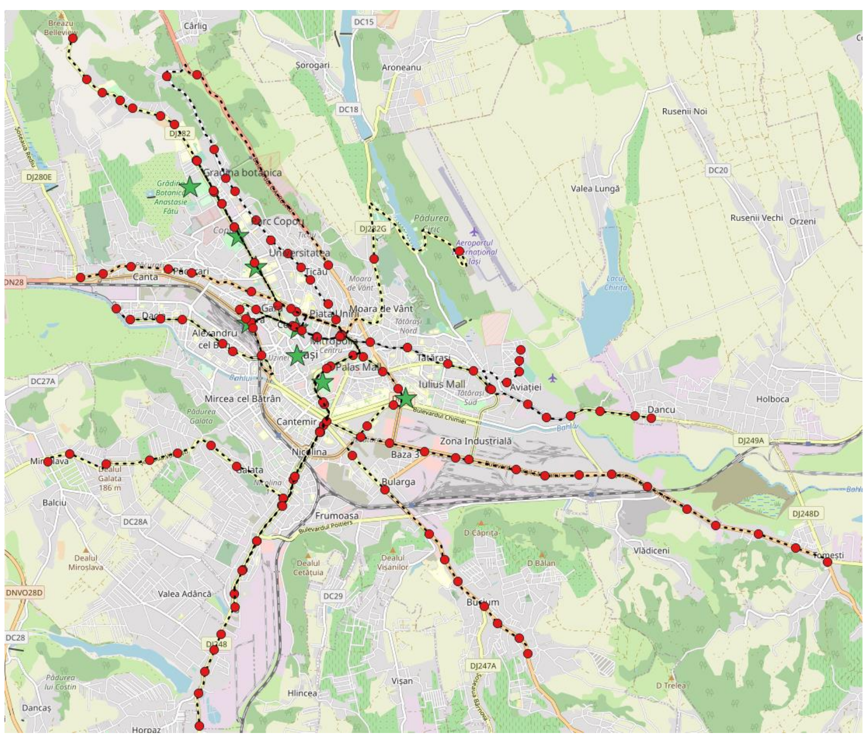

Fig. 4.12 Map of the routes chosen for calculating the isochrones

The isochrones for the 9 identified peripheral areas of the city of Iași are calculated, areas with reduced accessibility, with the destination Union Square, located in the center of the city and considered its 0 point. The aim is to determine and compare total and partial travel times, considering as the mode of access firstly the walking and then electric scooter. For this, we use the ORS Tools option in the QGIS software package. By default, it was considered a travel time of 45 minutes for these areas, keeping in mind that it's a medium-sized city. Where public transport times alone exceed this value, the total times considered was longer (eg 65, 70 minutes).

Example:

Bus line 23: Miroslava – Tudor Neculai - Podu Roș + tram 9 -> POI: Union Square (center) (figure 4.15)

Total travel time = 65 min

Waiting time in the station = 24 min

Commercial tram speed = v_c = 15 km/h

Travel time by UPT = Distance / v_c

Average walking speed = 4,5 km/h = 1,25 m/s = 75 m/min

The average speed of the electric scooter = 25 km/h = 6,94 m/s = 416 m/min

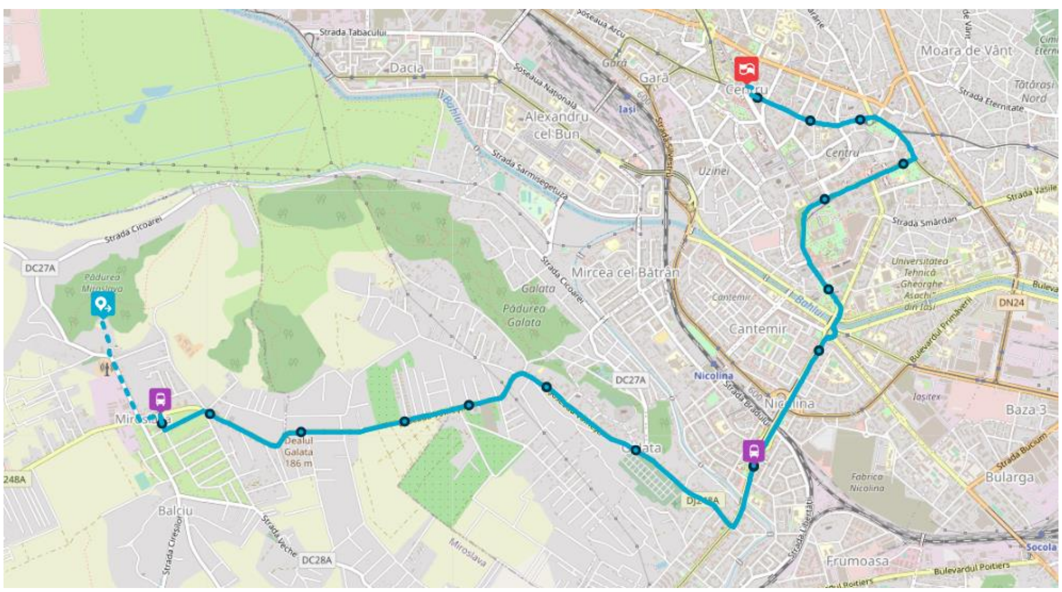

Fig. 4.15 The route Miroslava – Union Square

The following sequence of isochrones is obtained, made in the QGIS program, with the ORS Tools plugin *(figure 4.16).*

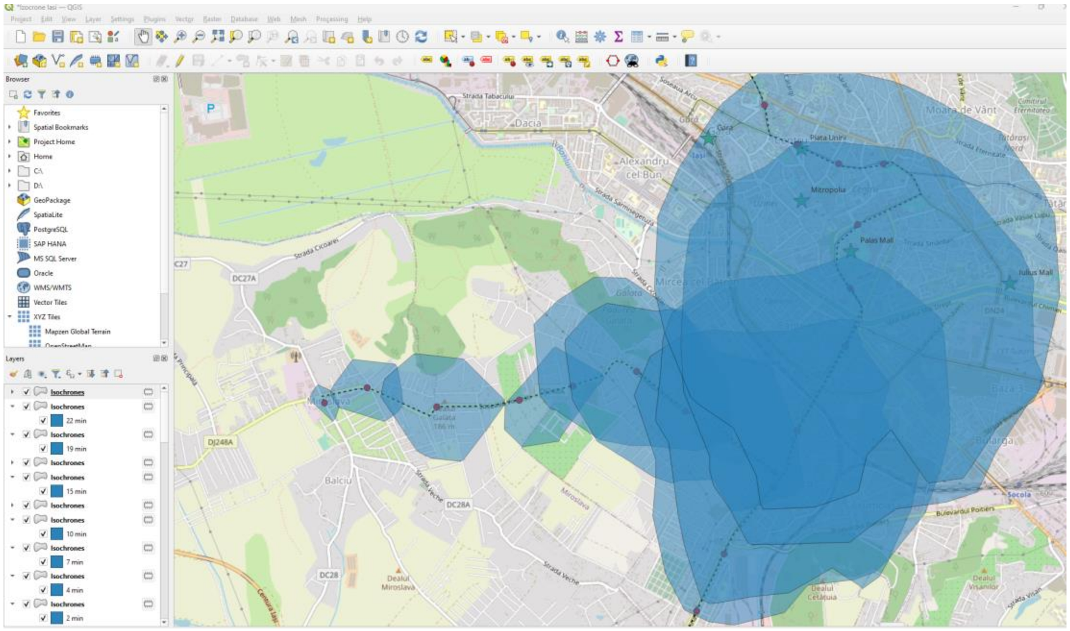

Fig. 4.16 Bus 23 isochrons for UPT travel + walking

It can be noticed that for the Miroslava area, the point of interest Piața Unirii is not accessible for a total travel time of 65 minutes by bus 23. The isochrones are regenerated, but this time considering a combined electric scooter+UPT trip (figure 4.17) .

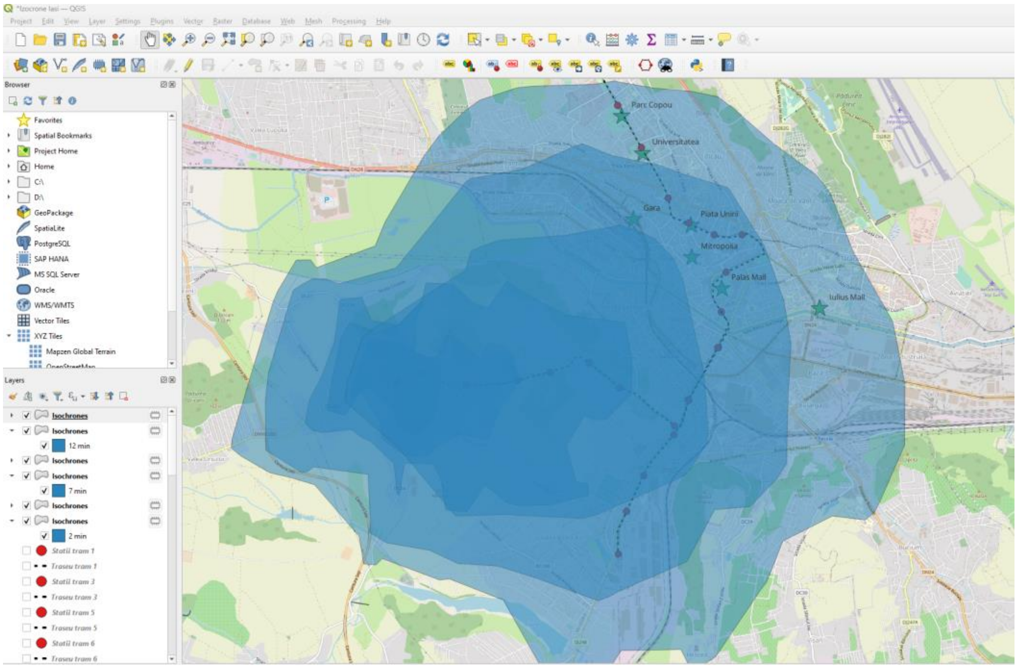

Fig. 4.17 Bus 23 isochrons for an intermodal travel UPT + electric scooter

It can be seen that in this case, for the Miroslava area, the point of interest Union Square becomes accessible for a total travel time of 65 minutes, or even less.

Analyzing travel times for all studied areas (neighourhoods), the following statistics are obtained:

- the average of the maximum walking time to the nearest public transport station is 22.2 minutes;
- the average of the maximum total durations considering a trip made up of walking and the use of public transport means of 74.3 minutes;
- the average of the maximum travel time with the electric scooter to the nearest public transport station is 5.1 minutes;
- the average of the maximum total durations considering a travel composed of the use of an electric scooter and the use of UPT is about 57.2 minutes.

It is concluded that using an electric scooter (rental or personal) to the nearest UPT station reduces the travel time by 17.1 minutes on average.

4.4.2.3 Examining residents' accessibility to mobility services

A useful indicator for determining accessibility to mobility services concerns the percentage of the population with easy access to public transport (tram, bus) and is calculated with the following formula:

$$Acf = \frac{\sum_i PAf_i * Q_i}{pop}, \qquad (4.11)$$

where:

Acf = accessibility index [% of population]

Paf_i = the number of people living in area i

Qi = degree of appreciation of the ease of accessibility to mobility services. This degree is predefined and takes the following values:

- *Qi = 1, if access is very easy [0-200m];*
- *Qi = 0.5, if access is easy [200-400m];*
- *Qi = 0, if access is not easy [>400m];*

Following the travel survey carried out in the city of Iași, it was determined a percentage of 9.6% of the population living at a distance of 0-200m from the nearest public transport station, and 16.5% living at a distance of 200-400m. The other categories are not taken into account, since Qi = 0. Thus, it results:

$$Acf = \frac{[xx\%*pop]*1+[xx\%*pop]*0.5}{507100} = \frac{48681.6*1+83671.5*0.5}{507100} * 100 = 17{,}8\%$$

It is concluded that 17.8% of the population has very easy access to public transport, not a very high percentage, considering the expansion of the city towards the outskirts, without the expansion of UPT routes also.

4.4.3. The travel survey carried out in Iași

An online travel survey was conducted in the city of Iași, using the online application Google forms, which contains 17 questions and was posted on various Facebook groups of the city of Iași. This obtained 492 responses, within 2 months (April-May 2022). The form can be viewed by accessing the following link: https://docs.google.com/forms/d/e/1FAIpQLScL-TgG2Bx3mcip3bzU5b2IAkxUbE82NrypCiGPbjKQ-y22ng/viewform

This method of posting the survey on different social media groups on different topics and purposes ensures the necessary degree of diversity of participants. The most relevant results of the online survey can be found in the table below (table 4.6). Also, the results from the last Romanian Census of 2022 were presented for comparison, when they were found available.

Tab. 4.6 Descriptive statistics of the online travel survey

		N	Survey	INSSE		N	Survey	INSSE
Sample size		492	100%					
Sex:	Man	263	53.5%	47.3%	Distance to UPT			
	Woman	229	46.5%	52.7%	0 – 200 m	47	9.6%	
Age:	18-30	171	34.8%	18.3%	200 – 400 m	81	16.5%	
	30-40	174	35.4%	19.1%	400 – 600 m	115	23.4%	
	40-50	63	12.8%	13.8%	600 – 800 m	142	28.9%	
	50-60	53	10.7%	15.4%	800 – 1000 m	74	15%	
	> 60	31	6.3%	12.1%	> 1000 m	33	6.7%	
Income:	< 1000	29	5.9%	11.5%	Distance to work			
	1000 - 2000	120	24.4%	13.2%	(average)	492	5.3 km	

	2000 - 3000	184	37.4%	18.2%	e-scooters in the area		
	3000 - 4000	103	20.9%	21%	-Yes	213	43.3%
	4000 - 5000	38	7.7%	32.1%	- No	279	56.7%
	> 5000	18	3.7%	4%	e-scooter willing to use		
Car owning	-- Yes	*283*	57.5%	64.9%	(work)		
	-- No	*209*	42.5%	35.1%	-Yes	66	13.4%
e-scooter owning					- No	426	86.6%
	--Yes	36	7.3%		e-scooter willing to use		
	-- No	456	92.7%		+ UPT (work)		
UPT pass	--Yes	226	45.9%		-Yes	108	22%
	-- No	266	54.1%		- No	384	78%
Work travel mode					e-scooter willing to use		
	- walking	52	10.6%		(leisure)		
	- UPT	215	43.7%		- Yes	162	32.9%
	- car	197	40%		- No	330	67.1%
	- others	28	5.7%		e-scooter willing to use		
Leisure travel mode					+ UTP (leisure)		
	- walking	58	11.8%		- Yes	111	22.5%
	- UPT	158	32.1%		- No	381	77.5
	- car	234	47.6%				
	- others	42	8.5%				

The two most receptive age groups were those between 18-30 and 30-40 years (~35%), while the percentages of the Iași population in these categories are much lower (~18-19%). Among the declared results, as means of travel used mainly for work trips, 43.7% answered that they use UPT, 40% use the car, and the rest use walking or other means of travel. Regarding the questions about electric scooters, 43.3% of the population saw electric scooters available in their home area, but small percentages of people would use one for different activities. Only 13.4% would use an electric scooter from home to work, 22% would use an electric scooter as a mean of access to UPT, respectively 12.4% as egress from UPT, and 32, 9% would pay for an electric scooter for other activities, for example for fun, riding or testing. When asked why they would not use electric scooters, 51.4% blamed the high cost, 14.4% said that scooters are not available in their area, 13% consider them dangerous, 6.9% said they prefer walking on foot, while 5.9% live too close to a UPT station to need it as a mode of access/egress.

4.4.4. Maximizing the utility of intermodal transport

4.4.3.1. Estimating the Multinomial Logit model

A Multinomial Logit model is used when the utility depends linearly on the socio-demographic characteristics of the respondents and the attributes of the different intermodal alternatives.

4.4.3.2. Parameterization of the MNL model for the city of Iași

To model the problem of discrete choice of travel mode in the city of Iași, the three steps of the model are followed:

A. Determining the set of alternatives

The following modes of travel are considered: walking, electric scooter, private car, UPT and intermodal UPT+e-scooter.

B. Formulating the model on the basis of which users choose from the set of alternatives

The following utility formulations are constructed for the modes considered, to estimate the Multinomial Logit model:

Walking

$U_{WA} = \beta_{WA} + \beta_{timeWA} * time_{WA} + \beta_{confortWA} * comfort_{WA},$ (4.12)

cu:

$\beta_{WA} = \beta_{WA0} + \beta_{sexWA} * sex + \beta_{ageWA} * age + \beta_{carWA} * hh_{car} + \beta_{ESWA} * hh_{ES} + \beta_{incomeWA} * income$ (4.13)

e-Scooter

$U_{ES} = \beta_{ES} + \beta_{timeES} * time_{ES} + \beta_{costES} * costs_{ES} + \beta_{comfortES} * comfort_{ES},$ (4.14)

cu:

$\beta_{ES} = \beta_{ES0} + \beta_{sexES} * sex + \beta_{ageES} * age + \beta_{carES} * hh_{car} + \beta_{incomeES} * income$ (4.15)

$\beta_{cost} = - e^{\beta cost0 + \sigma cost * \zeta 1}$ (4.16)

Car

$U_{PC} = \beta_{PC} + \beta_{timePC} * time_{PC} + \beta_{costPC} * cost_{PC} + \beta_{parkingPC} * parking_{PC} + \beta_{comfortPC} * comfort_{PC},$ (4.17) cu:

$\beta_{PC} = \beta_{PC0} + \beta_{sexPC}*sex + \beta_{agePC}*age_{PC} + \beta_{incomePC}*income + \beta_{PTpassPC}*PTpass$ (4.18)

$\beta_{cost} = - e^{\beta cost0 + \sigma cost_{*}\zeta 1}$ (4.19)

Walking + UPT

$U_{WA+PT} = \beta_{WAPT} + \beta_{distancePT}*distancePT + \beta_{timeWA}*time_{WA} + \beta_{comfortWA}*comfort_{WA} + \beta_{waitPT}*wait_{PT} + \beta_{timePT}*time_{PT} + \beta_{costPT}*cost_{PT} + \beta_{crowdingPT}*crowding_{PT} + \beta_{comfortPT}*comfort_{PT}$ (4.20)

cu:

$\beta_{WAPT} = \beta_{WAPT0} + \beta_{sexWAPT}*sex + \beta_{ageWAPT}*age + \beta_{carWAPT}*hh_{car} + \beta_{WAPT}*hh_{ES} + \beta_{incomeWAPT}*income + \beta_{PTpassWAPT}*PTpass$ (4.21)

e-Scooter + UPT

$U_{ES+PT} = \beta_{ESPT} + \beta_{distancePT}*distancePT + \beta_{timeES}*time_{ES} + \beta_{costES}*costs_{ES} + \beta_{comfortES}*comfort_{ES} + \beta_{waitPT}*wait_{PT} + \beta_{timePT}*time_{PT} + \beta_{costPT}*cost_{PT} + \beta_{crowdingPT}*crowding_{PT} + \beta_{comfortPT}*comfort_{PT}$ (4.22)

cu:

$\beta_{ESPT} = \beta_{ESPT0} + \beta_{sexESPT}*sex + \beta_{ageESPT}*age + \beta_{carESPT}*hh_{car} + \beta_{incomeESPT}*income + \beta_{PTpassESPT}*PTpass$ (4.23)

C. Estimation of unknown structural parameters of the model (marginal utilities)

The utilities of using the following travel modes were calculated: walking, electric scooter, private car, UPT+walking and UPT+electric scooter, using a Multinomial Logit (MNL) model. Variable values are extracted from the survey asnwers and represent the factors affecting travel mode choice. In order to be able to estimate the model and the coefficients with the Matlab code, "dummy" type variables are defined.

4.4.3.3. Results of the MNL model applied in Matlab

For the parameter's estimation, the Matlab code is run for the chosen MNL model and the utilities of the modes, direct and combined, are calculated in 2 cases: travel to work (table 4.9) and leisure travel (table 4.10). In Matlab, the function for the MNL model is "[beta, dev, stats] = mnrfit (X, y);", and the function for estimating the probability of choosing each travel mode is "p = mnrval(beta, X);". Since the use of electric scooters is of main interest, the survey responses regarding the presence of electric scooters in their area and their willingness to use them, as a benefit of Mobility-as-a-Service, are used as a criterion.

Tab. 4.9 Results of the MNL model for choosing the mode of travel to work

Variables	**Walking**		**e-Scooter**		**Car**		**Walking+UPT**		**e-Scooter+UPT**	
	Coef	P	Coef	P	Coef	P	Coef	P	Coef	P
male	ref		ref		ref		ref		ref	
female	0.65	0.003	-0.1	0.011	1.1	0.002	1.4	0.002	-0.05	0.003
Age1: 18–30	ref		ref		ref		ref		ref	
Age2: 30–40	1.56	0.001	0.9	0.003	1.4	0.013	0.9	0.005	0.89	0.009
Age3: 40–50	0.6	0.030	0.05	0.002	1.23	0.002	0.09	0.005	0.15	0.008
Age4: 50–60	-0.2	0.010	-0.03	0.001	1.4	0.002	1	0.007	-0.002	0.002
Age5: > 60	-0.01	0.008	-0.06	0.002	1.41	0.003	1.2	0.009	-0.004	0.003
Income1: < 1000	ref		ref		ref		ref		ref	
Income2: 1000-2000	1.2	0.001	-0.003	0.002	0.9	0.003	1.3	0.001	-0.001	0.002
Income3: 2000-3000	0.9	0.004	0.04	0.005	1.23	0.058	1.01	0.001	0.06	0.002
Income4: 3000-4000	0.6	0.001	0.4	0.005	1.38	0.003	0.91	0.002	0.48	0.005
Income5: 4000-5000	0.4	0.001	0.9	0.003	1.4	0.001	0.63	0.013	1.03	0.021
Income6: > 5000	0.3	0.006	1	0.001	1.43	0.016	0.45	0.014	1.09	0.020
Nocar	ref		ref		ref		ref		ref	
Car	-0.001	0.012	-0.01	0.014	-		-0.03	0.007	-0.02	0.003
noES	ref		ref		ref		ref		ref	
ES	-0.2	0.010	-		-		-0.2	0.001	-	
noPTpass	ref		ref		ref		ref		ref	
PTpass	-		-		-0.02	0.005	1.32	0.001	1.32	0.020
Dist1: 0–200	ref		ref		ref		ref		ref	
Dist2: 200-400	-		-		-		1.69	0.002	0.22	0.005
Dist3: 400-600	-		-		-		1.4	0.004	0.93	0.021
Dist4: 600-800	-		-		-		0.9	0.009	0.99	0.015
Dist5: 800-1000	-		-		-		0.2	0.012	1.05	0.009
Dist6: > 1000	-		-		-		0.1	0.016	1.28	0.005
Travel time	-0.311	0.003	-0.201	0.003	-0.172	0.006	-0.085	0.001	-0.069	0.004
Waiting time	-		-		-		-0.012	0.005	-0.012	0.007
Parking search time	-		-		-0.08	0.001	-		-	
Cost	-		-2.23	0.001	-1.90	0.004	-1.76	0.005	-2.01	0.001
Comfort	-0.81	0.002	0.92	0.002	1.89	0.001	-0.02	0.007	0.01	0.002
Crowding: Fear0	ref		ref		ref		ref		ref	
Crowding: Fear1	-		-		-		-0.001	0.003	-0.001	0.005
Crowding: Fear2	-		-		-		-0.001	0.003	-0.001	0.006
Crowding: Fear3	-		-		-		-0.002	0.004	-0.002	0.008
Crowding: Fear4	-		-		-		-0.003	0.002	-0.003	0.004

Tab. 4.10 Results of the MNL model for leisure travel mode choice

Variables	Walking		e-Scooter		Car		Walking+UPT		e-Scooter+UPT	
	Coeff	P	Coeff	P	Coeff	P	Coeff	P	Coeff	P
male	ref		ref		ref		ref		ref	
female	0.68	0.001	-0.08	0.001	1.1	0.005	1.4	0.002	-0.15	0.001
Age1: 18–30	1.78	0.001	0.9	0.002	1.1	0.001	1.3	0.004	0.9	0.003
Age2: 30–40	1.6	0.002	0.8	0.002	1.5	0.001	0.7	0.002	0.69	0.002
Age3: 40–50	0.9	0.002	0.05	0.004	1.33	0.002	0.04	0.007	0.11	0.006
Age4: 50–60	0.2	0.009	-0.03	0.004	1.5	0.001	0.7	0.007	-0.05	0.005
Age5: > 60	ref		ref		ref		ref		ref	
Income1: < 1000	ref		ref		ref		ref		ref	
Income2: 1000-2000	1.3	0.003	-0.002	0.003	0.9	0.005	1.2	0.001	-0.001	0.004
Income3: 2000-3000	1.2	0.005	0.06	0.006	1.34	0.010	0.97	0.001	0.01	0.002
Income4: 3000-4000	0.8	0.006	0.8	0.002	1.41	0.002	0.82	0.012	0.04	0.001
Income5: 4000-5000	0.39	0.006	1.04	0.001	1.51	0.002	0.46	0.003	0.34	0.002
Income6: > 5000	0.2	0.004	1.1	0.002	1.74	0.002	-0.01	0.003	0.03	0.004
Nocar	ref		ref		ref		ref		ref	
Car	-0.001	0.003	-0.01	0.002	-		-0.03	0.002	-0.02	0.003
noES	ref		ref		ref		ref		ref	
ES	-0.5	0.002	-		-		-0.5	0.002	-	
noPTpass	ref		ref		ref		ref		ref	
PTpass	-		-		-0.02	0.004	1.1	0.001	1.1	0.009
Dist1: 0–200	ref		ref		ref		ref		ref	
Dist2: 200-400	-		-		-		1.54	0.004	0.2	0.018
Dist3: 400-600	-		-		-		1.26	0.004	0.75	0.010
Dist4: 600-800	-		-		-		0.61	0.003	0.79	0.005
Dist5: 800-1000	-		-		-		0.24	0.009	0.89	0.005
Dist6: > 1000	-		-		-		-0.02	0.021	0.92	0.003
Travel time	0.06	0.014	-0.174	0.007	-0.16	0.003	-0.025	0.003	-0.03	0.015
Waiting time	-		-		-		-0.005	0.003	-0.013	0.010
Parking search time	-		-		-0.03	0.003	-		-	
Cost	-		-1.05	0.001	-1.2	0.005	-0.09	0.030	-1.33	0.002
Comfort	-0.38	0.008	0.94	0.001	1.66	0.001	-0.01	0.004	0.005	0.003
Crowding: Fear0	ref		ref		ref		ref		ref	
Crowding: Fear1	-		-		-		-0.001	0.005	-0.001	0.005
Crowding: Fear2	-		-		-		-0.001	0.005	-0.001	0.005
Crowding: Fear3	-		-		-		-0.002	0.005	-0.002	0.004
Crowding: Fear4	-		-		-		-0.003	0.004	-0.003	0.006

Analyzing the socio-economic variables, we noticed that for female we have negative values for e-scooter trips, no matter if it is direct or combined, for work (-0.1; -0.05) or for leisure (-0.08; -0.15), which means that the women are more afraid of using this travel mode. When looking over the age groups, it can be seen that the utility decreased with the age increase, going even to negative for the categories over 50 years old. As expected, the values of the coefficients increase with the income. For the leisure trips, the intermodal choice electric scooter+UPT has lower coefficient values than the ones for work, meaning that people would not prefer this combination to go shopping or to go to the park.

Travel time is one of the most important attributes in a travel/transportation model, followed by travel cost (Sharma et al., 2017). This study reinforces that travel time and travel cost are the most influential and important attributes, having the largest negative impact on the utility of modes (coefficient -2.23 for the cost of the electric scooter for work).

4.4.4. Transport policies and pollution reduction

4.4.4.1. Cost sensitivity analysis

In the case of Iași, although the integration of electric scooters into UPT trips reduces the need to expand the infrastructure to the outskirts, the considerable cost makes this alternative often inaccessible. For this reason, some price change hypotheses are tested to see how the probabilities of choosing each travel mode change. The utility functions and choice probabilities of the travel modes were recalculated, taking into account the following fare/price changes (table 4.11):

- decrease / increase in the fare of electric scooters by 10% (0.612 / 0.748 RON/min);
- decrease / increase in the UPT pass by 10% (72 / 88 RON/month);
- decrease / increase in the price of fuel by 10% (0.684 / 0.836 RON/km).

Tab. 4.11 Cost policy modification analysis

Change of cost	**walking choice probability**	**e-scooter choice probability**	**car choice probability**	**waking+UPT choice probability**	**e-scooter+UPT choice probability**
Before change of cost	*13.5%*	2.4%	38.8%	40.2%	5.1%
Fare of e-Scooter +10%	*14.7%*	1.1%	39.1%	41.5%	3.6%

Fare of e-Scooter -10%	*12.6%*	3.9%	35.8%	38.3%	9.4%
PT pass cost +10%	*15.4%*	2.5%	43%	37.1%	2%
PT pass cost -10%	*9.7%*	2.1%	37.2%	43.5%	7.5%
Cost of Car fuel +10%	*17.2%*	2.7%	29.3%	44.4%	6.4%
Cost of Car fuel -10%	*12.7%*	2.2%	41.9%	39%	4.2%

It can be noticed that initially, before simulating the cost change, the highest probability of travel mode choice was walking+UPT at 40.2%, closely followed by car at 38.8%. The probability of choosing UPT in combination with the electric scooter was quite low (5.1%) and even lower when it comes to the electric scooter alone (2.4%). A 10% decrease in the price of electric scooters would increase the probability of their use, but not by more than a few percent (9.4% in combination with UPT and 3.9% for use without UPT).

4.4.5.2. Willingness-to-Pay for using electric scooters

The concept of “Willingness-to-Pay” (WTP) is an indicator for various policies or product/service options, about how much respondents are willing to pay for a service or product. It the case study, the interest is to determine the willingness to pay of the residents of Iași for the use of the electric scooter, calculating the value of the travel time (VTT). In order to be able to determine the value of VTT, a survey of stated preferences was needed. Two attributes and 3 levels for each one were defined, according to table 4.13.

Tab. 4.13 The levels of the travel time and travel cost attributes

Attribute	Level 1	Level 2	Level 3
Travel time	65 min	60 min	55 min
Travel cost	9 RON	12 RON	15 RON

To generate unique combinations of alternatives with different attribute levels, we use the combinatorial method was used in Matlab, calling the "combnk" function. 6 different alternative combinations are generated from which each respondent will have to choose. The two modes of movement analyzed are walking + UPT (basic alternative) and electric scooter + UPT (the new studied alternative), with different levels of attributes (figure 4.26).

Fig. 4.26 Sample question from the stated preference survey

In simple linear models, the VTT value is calculated as the ratio of the estimated coefficients of the parameters related to travel time and travel cost, considering as constants all other variables. The utility function takes the following form:

$$U_i = \beta_{dd}DD + \beta_{cd}CD + \varepsilon \quad (4.26)$$

where β_{dd} și β_{cd} are the coefficients to be estimated.

The coefficients were calculated by maximizing the likelihood function, using the Matlab program, then they were used in the following formula, to obtain the travel time value:

$$VTT = \frac{\beta_{dd}}{\beta_{cd}} * 60 \ \ [RON/oră] \quad (4.29)$$

Applying formula 4.29 for the determined coefficients, it results a VTT value of 8 RON/hour for travel to work and 6 RON/hour for leisure travel. According to the literature, a reasonable estimate of the average value of commuting time is about half the value of time based on salary (Brownstone et al., 2003). For the city of Iași, considering the average net salary of the inhabitants (3776 RON/month) and reported to a number of 40 working hours per week, the result is an average hourly salary of 21.78 RON/h. Compared to previous research, it is concluded that the value of travel time for work (8 RON) represents 36.7% of the hourly wage value, and the value of the leisure travel time (6 RON) only 27.5%. The percentages obtained for the city of Iași are at the lower end of the range of results in the literature.

4.4.5.3. Environmental impact analysis of electric scooters

Next, the purpose is to determine the impact on the environment of substituting the various modes of travel with the shared electric scooter, for the purpose of commuting to work. The percentages of the use of the various modes are extracted from the survey of revealed preferences (figure 4.21) and are related to the number of employees. Previously, it was determined that the city of Iași had in 2022 a number of 184,637 employees. Table 4.16 summarizes the percentages of each mode, as well as the number of people corresponding to each category.

Tab. 4.16 Percentages and actual number of people using the modes of travel

Travel mode	Survey usage percentage [%]	Number of users out of total employees
Walking	10,6	19571
UPT	43,7	80686
Car	40	73854
Others	5,7	5998

Analyzing the responses from the revealed preferences survey, it was found that, in total, 83.7% of trips are made with motorized modes of travel, for which the degree of CO_2 emissions can be calculated. In order to be able to estimate these emissions corresponding to work trips, the total number of kilometers traveled by the chosen sample during a year by each means of travel must be calculated, and multiplied by the specific factor of CO_2 emissions (equation 4.30).

$$ECO_2 = \sum_i \left(\sum_j D_{i,j} * Nt_j \right) * EF_i \qquad (4.30)$$

where:

ECO_2 is the annual carbon dioxide emissions generated by motorized travel modes

$D_{i,j}$ are the distances in km traveled by each travel mode i for each trip j

Nt_j is the annual number of trips j

EF_i is the specific factor of CO_2 emissions for each travel mode i (Bertolin et al., 2019).

We use the gross emission values of each travel mode from Reck et al. (2020) and calculate the amount of annual CO_2 emissions for each mode of travel:

- for walking+UPT: $ECO_{2\ UPT}$ = 23 kTone CO_2
- for cars: $ECO_{2\ AUTO}$ = 39.5 kTone CO_2
- electric scooter: $ECO_{2\ ES}$ = 2.5 kTone CO_2,
- electric scooter+UPT: $ECO_{2\ TE+UPT}$ = 1.8 kTone CO_2.

It is obvious that the mode of travel by car pollutes to the greatest extent. We consider again 3 modal change scenarios, namely the adoption of the intermodal mode of travel consisting of electric scooter and UPT in percentages of 10, 15 and 20%, substituting 50% of these percentages for car travel and 50% for walking + UPT. Redoing the calculations, the following results are obtained (tables 4.18, 4.19 and 4.20).

Tab. 4.18 Scenario of replacing a passenger car with an electric scooter+UPT – 10%

Travel mode	Current repartition [%]	Current emission quantity [CO_2/pkm]	Repartition after the substitution 10% [%]	Resulting emissions quantity [CO_2/pkm]
Walking	10,6	0	10,6	0
Walking+UPT	43,7	23 kTon	38,7	20,3
Car	40	39 kTon	35	34,5
e-Scooter+UPT	5,7	1,8 kTon	15,7	8,7
Total	100	63,8 kTon	100	63,5 kTon

Tab. 4.19 Scenario of replacing a passenger car with an electric scooter+UPT – 15%

Travel mode	Current repartition [%]	Current emission quantity [CO_2/pkm]	Repartition after the substitution 10% [%]	Resulting emissions quantity [CO_2/pkm]
Walking	10,6	0	10,6	0
Walking+UPT	43,7	23 kTon	36,2	19
Car	40	39 kTon	32,5	32,1
e-Scooter+UPT	5,7	1,8 kTon	20,7	11,5
Total	100	63,8 kTon	100	62,6 kTon

Tab. 4.20 Scenario of replacing a passenger car with an electric scooter+UPT – 20%

Travel mode	Current repartition [%]	Current emission quantity [CO_2/pkm]	Repartition after the substitution 10% [%]	Resulting emissions quantity [CO_2/pkm]
Walking	10,6	0	10,6	0
Walking+UPT	43,7	23 kTon	33,7	17,7
Car	40	39 kTon	30	29,6
e-Scooter+UPT	5,7	1,8 kTon	25,7	14,3
Total	100	63,8 kTon	100	61,6 kTon

There is, therefore, a decrease in the total amount of CO_2 emissions with the adoption of the electric scooter, a decrease resulting from the replacement of some trips by car. Displacing walking actually adds emissions to the pollution level, so it is preferable that car users see an opportunity in this new mode of intermodal travel, rather than those who used to walk. Even considering a substitution of 50% of car tips and 50% of walking, it results in a reduction of 300 tons of CO_2 per year in the case of increasing the use of electric scooters+UPT by 10%, 1200 tons of CO_2 per year for 15% and 2200 tons of CO_2 per year for a 20% increase. To imagine how much a ton of CO_2 means, one can imagine a cube with sides equal to a telephone pole. This is how much a metric ton takes up, as this is the unit of measurement used by specialists to measure the amount of CO_2 (MIT Climate Portal).

5. FINAL CONSIDERATIONS

5.1 Conclusions

The doctoral thesis aimed, without having aspirations of perfection, to study the dynamics of daily urban mobility, it's estimation methods, accessibility indicators, advanced techniques for determining mobility behavior, but also modern solutions for strengthening sustainability.

In the following section, the main approaches, reflections and relevant findings of the research undertaken for the preparation of the doctoral thesis are briefly presented:

1. Land use and transport system are indispensable one to each other and there is a growing need to be integrated in order to achieve a sustainable environment.
2. The success of surveys related to the mobility of individuals, with the aim of obtaining information necessary for decision-making, requires that survey methods continuously adapt to new technologies. Different modern technologies and concepts can be interconnected and used together for a secure collection of data from the vehicles GPS system. Blockchain, the distributed ledger technology, aims to provide a secure, reliable and scalable environment to meet these needs. The demand for travel should increase in favor of public transport, walking, cycling or e-scootering, but not by using the car.
3. The concept of Mobility-as-a-Service (MaaS) provides the necessary flexibility, taking into account the current trend of travel demand. It allows users to plan and organize their own trips for their convenience, offering customized hyper-convenient mobility solutions.

4. The current trend in mobility options is to supplement urban public transport with shared electric scooters.
5. Transport policy makers should pay more attention to small cities in a regional planning framework, well coordinated with industry policy making and other public policies.

5.2. Original contributions

The thorough and rigorous study of bibliographic references in the field, the publication of articles in national and international magazines, participation to internal and international conferences, but also participation in European training projects in order to acquire applied research skills, with practice at private economic agents from transport field, I am entitled to consider the following contributions:

1. Making a synthesis of the current state of research in the fields related to the research theme and their main results, without the claim of exhaustiveness.
2. Presentation of the opportunities offered by integrated land use/transport modeling (LUTI), the main types of LUTI models, but also the difficulties in their application.
3. Examining medium and long-term mobility evolution scenarios, with an emphasis on sustainable city and mobility concepts.
4. Evaluation of the main advanced methods and techniques for data collection necessary for mobility estimation. Advanced data collection systems are analyzed.
5. Designing a travel survey model based on modern vehicles and integrating various advanced technologies such as TCU, IoT/IoV, V2X, 5G and blockchain.
6. Conducting a case study for the city of Iași, which aims to determine the degree of acceptance and adoption by residents of shared electric scooters (rental), as a solution to reduce congestion and pollution. The original contributions made in the case study are:
    - Determining the accessibility indicators for the city of Iași, through various techniques and methods, focusing especially on the level of accessibility of the residents on the outskirts; the main method was the generation of the isochrones in the peripheral areas, using the QGIS program. Thus, the isochrones generated

for walking could be compared with those that took into account the use of a shared electric scooter as an access mean to the nearest public transport station;

- Data collection with the help of an online questionnaire, made in the Google Forms application and posted on different Facebook groups specific to the city of Iași, to ensure the degree of diversity of the participants;
- Compared to the most relevant studies on this topic, this research improves by integrating a unique utility function for the electric scooter and UPT intermodal travel option; all the utility functions for the travel modes were integrated into the Multimonial Logit model and calculated by Matlab software;
- The utility functions were built with the maximum number of dependent variables, in order to cover as many influencing factors of utility as possible;
- Interpretation of the coefficients of the variables involved in the utility functions of the travel modes;
- Analyzing cost policies for shared electric scooters, by recalculating the probabilities of choosing travel modes in the event of an increase/decrease in usage rates for each mode considered;
- Estimating the Willingness-to-Pay ("WTP") of the inhabitants of the city of Iași to reduce travel time;
- Estimation of the impact on the environment generated by the substitution of some modes of travel by adopting the shared electric scooter, with the purpose of travel for work;

5.3 Future research directions

As a result of establishing the current state of research in the field and the results obtained especially in the case study, the following recommendations and directions for future research are outlined:

- Research that allows the monitoring of aspects with a character of uncertainty;
- Using mixed modal surveys to obtain the data needed by the investigator;

- For future studies, a travel survey based on GPS technology integrated into shared e-scooters is recommended;
- The degree of adoption of electric scooters, also considered in the intermodal context, should be studied periodically, as it has many chances to increase;
- In travel/transport policy studies, a broader view of the concept of VTT is needed, taking into account the importance of subjective "well-being" and all factors that can influence the experience of a trip (comfort, safety etc.).

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