Article

Building a Model of Integration of Urban Sharing and Public Transport Services

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Abstract: The intense growth of cities affects their inhabitants to a considerable extent. The issues facing the traveling population include congestion and growing harmful emissions. Urban transport requires changes towards eco-friendly solutions. However, even though new forms of traveling (sharing services) are being implemented, their integration with public transport remains problematic. On account of the large number of available services combined with the absence of their integration, city inhabitants are faced with the dilemma of choosing between one or several transport modes which would enable them to make the given trip. The main goal of this article is to propose a model for integration of different transport services which could support those who intend to travel in the decision-making process. Therefore, the parameters of a model of urban sharing services were identified and classified. The parameters discussed in the paper with reference to an extensive literature review describe how individual sharing services are functioning. What has also been identified is the location-specific factors as well as those related to the potential area of operation which affect the integration with public transport. In order to take all the relevant parameters into account and find a solution to the problem at hand, a multi-criteria decision-making approach has been proposed. To this end, scores and weights determining their impact on the model have been established. For purposes of the solution in question, the relevant calculations were conducted by referring to an actual need to travel between selected locations.

Keywords: sustainable transport; sharing services modeling; transport modes; environmental-friendly traveling options; geographical information systems; travel planning

1. Introduction

In large and highly urbanized municipalities and metropolitan areas of the world, transport modes should provide their inhabitants with opportunities to reach their destinations of choice without problems. Contemporary transport systems are assumed to enable the users to choose between the available options according to such criteria as price or travel length. An efficient and well-functioning urban transport system influences the municipality’s further development (e.g., by attracting new investors and inhabitants), which has been investigated among others by Kepaptsoglou et al. [1]. As Zarabi et al. [2] said, it is a frequent phenomenon that the satisfaction with living conditions among the inhabitants of a certain territory increases in association with the quality of traveling. Municipalities have been introducing new components into their transport policies, known as (Griggs et al. [3]) Sustainable Development Goals, in order to foster sustainable development of their transport systems. Members of contemporary society do not always need their own cars. Another way to implement transport policies in urban areas, identified by Okraszewska et al. [4], is introducing Sustainable Urban Mobility Planning, which is sometimes supported with transport models. Collective public transport does not always make traveling convenient, but it is invariably an important element of urban transport.
Kampf et al. [5] claimed that accessibility, price, and reliability significantly affect the perception of public transport among inhabitants.

People living in large cities who do not travel regularly over long distances by individual means on a daily basis and who face problems in finding free parking spaces prefer not to own their own vehicles, and use the benefits of sharing services rendered in their area instead, since they provide them with higher traveling flexibility. Kervella et al. [6] identified that private cars remain parked 95% of the time, instead of being actually in operation, and they are typically used by only two persons. Large cities must also face the problem of congestion, which is counteracted by municipal decision makers resorting to such transport policy measures as those listed by Jorge et al. [7]: establishing paid parking zones, vehicle-free zones, or eco-friendly vehicle only zones. According to Quak et al. [8], the goal of such policies is to reduce the share of individual transport and hamper the increase in the number of vehicles per capita in the population. Boitror et al. [9] noticed that the changing lifestyle of residents as described has increased the demand for more diverse transport assumed to meet their transport needs.

In an attempt to address the aforementioned problems, the Mobility as a Service (MaaS) concept has been developed. In line with MaaS, mobility is treated as a single service. Thanks to this change, people are no longer tightly attached to private transport modes, like their own cars, and can flexibly choose the mode of transport that caters to their current needs at any given moment.

There are many sharing services in the transport system (see Golightly et al. [10]), and they are not always connected with one another. This article focuses on the sharing services that are currently delivered in the urban space, disregarding prototype services such as, for instance, highly autonomous vehicles, fully autonomous vehicles, or vertical take-off and landing aircrafts. What has been additionally highlighted is the influence of collective public transport on sharing services. The most common transport sharing services (assuming that specific transport modes are rented) are: bicycles (broken down by Feng et al. [11] into regular human-powered bicycles: docked, can be left anywhere; as well as electric bicycles: docked, can be left anywhere), cars/vehicles for rent (broken down by Shaheen et al. [12] into conventional cars, electric cars, light commercial vehicles, electric motor scooters), stand-up scooters and others (electric stand-up scooters, Segway type vehicles described by Shellong et al. [13]).

Besides the aforementioned services, where the transport mode is rented directly, there are those which involve travel sharing: ride-hailing, where one is driven to the chosen destination on demand (e.g., Uber), and the driver is not headed for the same destination as the passengers, with no additional drivers joining on the way; ridesharing, where shared travels are organized by multiple drivers, and a passenger may be paired with several drivers and some other passengers; car-pooling, where drivers are not employed, typically performed on a local basis (neighbors, co-workers), supported by matching applications, e.g., Scoop.

The use of sharing services is also significantly affected by public transport, which exerts a major impact on how city inhabitants move around. The most common collective public transport systems are: bus system, urban railway, metro, trams, trolleybuses.

The lack of integration between transport services and transport modes, as well as the extensive range of technology- and price-differentiated offerings make it difficult for consumers to choose between one or several transport modes which would enable them to reach the chosen destination (some problems faced are discussed by Kepaptsoglou et al. [1] and Kampf et al. [5]). Depending on their specific needs, what they seek is such a chain of transport modes that could allow them to complete the travel as quickly or as cheaply as possible (criteria described by Zarabi et al. [2] and Golightly [10]). The changes taking place in cities, e.g., the impact of demographic changes and the territorial suburbanization, require innovative strategies (what Griggs et al. pointed out in [3]). In order to solve any related problem, one should first develop a mathematical model to find the
best solution for the problem at hand by considering the criteria previously identified, as well as the weights and limitations assigned to them.

2. Literature Review

In order to solve the problem addressed in this paper, a literature review was performed with the aim of searching for criteria, limitations and parameters of both sharing services and collective public transport.

2.1. Urban Sharing Services Parameters

The summary provided in Table 1 identifies the parameters which describe and affect the use of sharing services and collective public transport.

The above parameters (Table 1) of sharing services and collective public transport are based on the literature review. The tabulation represents the general parameters and problems associated with the use of the given system.

Fishman [14], Saberi et al. [15], Laporte et al. [16], and Caspi et al. [17] highlight the capacity of bike sharing docks as one of the main aspects in this discourse, but also point out the need for dedicated bicycle booking applications.

In all the systems and services described above, another important aspect is their availability, in terms of both the space and the number of vehicles offered.
| Sharing Services Parameters | Bike Sharing | Car Sharing | Scooters and Others | Travel Sharing Services | Collective Public Transport |
|-----------------------------|--------------|-------------|---------------------|-------------------------|---------------------------|
| Bicycle dock capacity (the larger the more rentals) | Fishman [14], Saberi et al. [15], Laporte et al. [16], Caspi et al. [17] | - | - | - | - |
| Proximity to business centers and downtown area; availability understood as the system’s vehicle count | Saberi et al. [15], Caspi et al. [17], Wang et al. [18], Faghih-Imani et al. [19], Abolhassani et al. [20] | Mattia et al. [21] | Caspi et al. [17], Aguilera-García et al. [22] | Kaan et al. [23] | Daraio et al. [24] |
| Possibility of using different vehicle models | - | - | - | - | - |
| Infrastructure (bicycle paths, stops) | Abolhassani et al. [20] | - | - | - | Yannis et al. [26] |
| Impact on road traffic (reducing congestion) | Sochor et al. [27] | Ferrero et al. [28], Giesecke et al. [29] | Aguilera-García et al. [22] | Chan et al. [30] | Daraio et al. [24] |
| Safety (higher compared to public transport) | Abolhassani et al. [20], Cieśla et al. [31] | Cieśla et al. [31], Mattia et al. [21] | Cieśla et al. [31], Orr et al. [32] | Yannis et al. [26] |
| Terrain topography | Li et al. [33] | - | - | - | - |
| Dock/station location | Abolhassani et al. [20], Wang et al. [34] | - | - | - | Verbas et al. [35] |
| Weather | Saberi et al. [15], Corcoran et al. [36], Li et al. [33], Shen et al. [37] | - | - | - | - |
| Environmental impact (reducing pollution) | Li et al. [33], Cieśla et al. [31] | Ferrero et al. [28], Hensher [38], Huwer [39] | Aguilera-García et al. [22], Cieśla et al. [31] | Kaan et al. [23], Ritzinger et al. [40] | Yannis et al. [26], Daraio et al. [24], Echaniz et al. [41] |
| Higher quality (generally) compared to public transport | Li et al. [33], Cieśla et al. [31] | Mattia et al. [21] | Cieśla et al. [31] | - | Daraio et al. [24], Echaniz et al. [41] |
| Trip | - | Melis et al. [42] | Aguilera-García et al. [22] | Chan et al. [30] | - |
| Traveling distance and time (up to 10 min for bicycles); scooters—10 km | Caulfield et al. [43], Shaheen et al. [44] | Michaelis et al. [45] | Shen et al. [37] | - | Daraio et al. [24], Michaelis et al. [45], Chuangjiao et al. [46] |
| Range and battery charging related difficulties | Li et al. [33] | Melis et al. [42] | Aguilera-García et al. [22] | - | - |
| Sharing Services Parameters | Bike Sharing | Car Sharing | Scooters and Others | Travel Sharing Services | Collective Public Transport |
|-----------------------------|--------------|-------------|--------------------|------------------------|---------------------------|
| Traveling destination       | Caulfield et al. [43] | Sochor et al. [27] | Aguilera-Garcia et al. [22] | Kaan et al. [23] | - |
| Frequency of cargo transport and cargo size | - | Giesecke et al. [29] | - | - | - |
| Travel planning, elimination of unnecessary transfers | - | Yannis et al. [26] | - | - | - |
| Short waiting time compared to public transport | - | Fleury et al. [47] | - | Jung et al. [48] | Echaniz et al. [41], Cevallos et al. [49], Fleurent et al. [50], Saharidis et al. [51] |
| Effect on the health of users | Li et al. [33] | - | - | - | - |
| Passenger’s frequency of traveling | Abolhassani et al. [20], Ahillen et al. [52] | Sochor et al. [27] | Orr et al. [32], Ahillen et al. [52] | Wolfler Calvo et al. [53] | Daraio et al. [24] |
| Economic (own vehicle not required, operating costs, cost sharing) | Abolhassani et al. [20], Li et al. [33], Cieślak et al. [31] | Shaheen et al. [12], Huwer [39], Shaheen et al. [54], Kamargianni et al. [55] | Cieślak et al. [31] | Ritzinger et al. [40] | Daraio et al. [24] |
| Demographics (age): elderly people may find it difficult to use and accept new technologies | Caspi et al. [17] | Mattia et al. [21], Utirainen et al. [56] | Caspi et al. [17], Aguilera-Garcia et al. [22], Kostrzewska et al. [57] | - | Yannis et al. [26], Porru et al. [58] |
| Location of the place of residence, population density | Li et al. [33] | Sochor et al. [27] | - | - | Yannis et al. [26], Daraio et al. [24] |
| Data sources | | | | | |
| Information availability | Caulfield et al. [43], Shaheen et al. [44] | Yannis et al. [26], Fleury et al. [47] | Shen et al. [37], | - | Echaniz et al. [41] |
Bicycle and scooter rental services display high sensitivity to weather conditions (according to research conducted by Saberi et al. [15], Aguilera-García et al. [22], Li et al. [33], Corcoran et al. [36], Shen et al. [37]). The above parameters characterizing the use of specific transport modes imply that they are in fact used significantly less frequently during rain or snowfall.

With regard to all the aforementioned systems and services, scientific publications highlight their positive environmental effect (among others Kaan et al. [23], Ferrero et al. [28], Ciesla et al. [31], Li et al. [33], Hensher [38]). This effect is perceived as the greatest in the case of bicycle and scooter rental services, since these vehicles are either human-powered or electrically propelled. Public transport is ranked second in this respect for its low CO₂ emission impact per passenger. Travel sharing services, on the other hand, offset the negative effect of one-person car traveling. Vehicle rental services make it possible to reduce the number of vehicles put into service.

All of the analyzed services and public transport solutions like described by Sochor et al. [27], Ferrero et al. [28] and Giesecke et al. [29], exert a positive environmental effect by reducing road congestion, by making use of additional space (footpaths, bicycle paths), and by reducing the number of vehicles using roads.

Each of the analyzed services and transport modes has some economic impact on users (Abolhassani et al. [20], Huwer [39], Ritzinger et al. [40]). Cost reduction is conditioned by the service choice and may depend, for example, on not having to purchase a vehicle, not having to cover operating costs, or sharing travel costs.

In terms of perceived safety, with regard to bike and car sharing systems, one may speak of some advantage over the public transport modes on account of the absence of contact with other travelers. This is also connected with the number of accidents and collisions (Mattia et al. [21], Aguilera-García et al. [22], Orr et al. [32]). Another important aspect taken into consideration is the technical condition of vehicles (Abolhassani et al. [20], Ciesla et al. [31]).

For each service and transport mode subject to analysis, quality proves to be an important aspect (Mattia et al. [21], Daraio et al. [24], Li et al. [33]). Research highlights diversified passenger needs, for instance in terms of heating, air conditioning, or ease of use.

Kim pointed out in [25] that an additional parameter considered for the vehicle rental service is the possibility of using different vehicle models.

What appears to be an important aspect for modern transport services as well as for public transport is demography (Caspi et al. [17], Mattia et al. [21], Utriainen et al. [56], Porru et al. [58]). New technologies as well as the necessity of using dedicated applications are not favorable to elderly people. Research also highlights the diversification in the use of sharing services according to the users’ age.

For vehicle rental and travel sharing services, an important parameter (Chan et al. [30], Melis et al. [42]) is their large territorial coverage (larger than that of public transport) and reduced time of travel to the destination point. What matters for scooters is the increased territorial range enabled by access to footpaths.

With regard to the contemporary electric transport modes used by bicycle, vehicle and scooter rental services, Aguilera-García et al. [22], Li et al. [33], and Melis et al. [42] refer to a parameter related to the range limitation on account of the need to recharge the vehicle when it is used to cover longer distances.

Each element of the analyzed services and public transport is described by the frequency of its use for traveling. Abolhassani et al. [20], Sochor et al. [27], and Wolfler Calvo et al. [53] emphasize the high rates of use of bicycles and scooters in peak hours due to high congestion.

An important aspect for the choice of a sharing service is the traveling destination (Aguilera-García et al. [22], Kaan et al. [23], Sochor et al. [27]). Given the dense network of transport routes in cities, this parameter is not addressed for public transport, since availability is considered more important.
Population density affects the number of bicycle and car rental service points as well as the use of public transport (Daraio et al. [24], Yannis et al. [26]).

The literature mentions that the use of sharing services and public transport varies depending on the travel time or distance planned (Shen et al. [37], Caulfield et al. [43], Michaelis et al. [45], Shaheen et al. [54]). For short transfers, referred to as the first or last mile, bicycle and scooter systems prove to be most suitable.

The available infrastructure, i.e., bicycle paths and stops (roofed or without shelter), is an important element for bike sharing and public transport systems. What also matters from the perspective of the stationary facilities of these systems is the location of bicycle docks and stops, which should take many factors into account, e.g., density of development and proximity of public utility buildings (Wang et al. [18], Abolhassani et al. [20], Verbas et al. [35]).

Using car rental services makes it possible to eliminate redundant traveling. Users try to make only necessary journeys, since traveling is subject to fare (Fleury et al. [47]). Bicycle sharing systems, and particularly those which render human-powered vehicles, have a positive impact on the health of users [26]. This service is also essentially linked with the topography of the given area.

Another important aspect described by Fleury et al. [47], Jung et al. [48], Cevallos et al. [49], Fleurent et al. [50], and Hart et al. [59] is the time of waiting for a ride, which can effectively rule out certain types of traveling services.

For all services (except shared services, due to their local nature in most cases) and public transport, information is considered important (Giesecke et al. [29], Echaniz et al. [41], Carrignon et al. [60]) However, it can be understood in various ways, e.g., as instructions for use, information on the availability of a certain transport modes, or on delays.

Moreover, not only is the range of these services very extensive, but there are many smaller privately-owned companies whose offering is customized and oriented towards highly specific services (e.g., Lime, Next-Bike, Venturillo, Bolt). According to Simon et al. [61], and Sierpiński [62] it is possible to improve the modal split factor in favor of modern eco-friendly transport by increasing awareness among potential users (information campaigns), improving availability and accessibility of sharing services, improving the infrastructure (separated bicycle paths), increasing safety, reducing travel costs with user-friendly offers (introducing cheaper subscriptions for regular users, bundling offers for different transport modes).

2.2. Users and Integration of Sharing Services

The criteria which describe users are difficult to establish because of the huge variety of traveling forms, and yet some patterns can be discerned. These are also associated with the theory of travel decision making (Schneider [63]). Users can be characterized by four main groups of factors:

- Economic: demographics (diversified age-dependent financial capabilities) (Echaniz et al. [41]), number of household members, number of children, income (Kim et al. [64]), fact of currently owning a car (Echaniz et al. [41]), a bicycle, discounts on public transport tickets;
- Convenience: demographics (diversified age-dependent needs), weather (Lu et al. [65]), available forms of payment (Echaniz et al. [41]) (applications are more convenient than a standard paper ticket);
- Lifestyle: person’s activeness level, demographics (diversified age-dependent transport needs), social media (Chung et al. [66]), education level, technological literacy (Kuijer et al. [67]), accessibility of stops (Kopp et al. [68]), traveling destination (Echaniz et al. [41]), fact of holding a driving license (Krueger et al. [69]);
- Environmental sustainability: hierarchy of traveling needs, awareness of environmental impact, knowledge of sharing services (Krueger et al. [69]), indicated users pay attention to emissions (Miralinaghi et al. [70], Sinha et al. [71]).
For purposes of making efficient use of the available services, an application concept has been proposed to users who, once they have defined the start and end point as well as the relevant conditions (price, travel time), will be able to choose an option they find most convenient. This article discusses the concept of integration of urban sharing services, including the identification and classification of their parameters. Such a system should also offer features enabling the use of sharing services on an everyday basis, e.g., vehicle selection within the chosen mode of transport (according to comfort level and size), or a booking system (Shaheen et al. [12]).

Sochor et al. [27] have proposed five levels of integration for MaaS: integration of social goals (policies, initiatives), integration of service offerings (subscriptions, contracts), integration of booking and payment options, integration of information (travel planners, price information), no integration (separate services).

Integration of transport services is only possible if there is access to real-time updated supply and demand data from different sources and organizations (Hilgert et al. [72]), considering the diversity of user-specific needs, e.g., luggage transport required to complete a travel chain. What also matters for integration is the aspect of ticket distribution and payment (Hensher [38], Piazza et al. [73]). In terms of the available forms of payment for service use, one can speak of the following alternatives: ticket and payment integration (single smart-card ticket including public transport), ICT integration (enabling one application to be used to manage multiple services), and mobility package integration (the user can pre-pay for a travel against a set time or distance) (Fishman [14]).

Articles addressing the problem of choosing transport modes has been typically limited to the choice between individual and collective transport (Echaniz et al. [41]). Fewer papers elaborate on the concept of the choice of sharing services and on its integration depending on the available collective public transport services.

As implied by the literature review performed, the factors most frequently mentioned in the multi-criteria decision model (MCDM) model in the sphere of transport-related problems (Yannis et al. [26]) are: economy, efficiency, safety, social factors, impact on traffic, as well as accessibility and availability (Yannis et al. [26], Daraio et al. [24]). What the literature clearly lacks is greater orientation towards the user. Cieśła et al. [31] have discussed the possibility of using the model to rationalize mobility management related decisions made in order to implement sustainable urban solutions. The MCDM model proposed in article considers four general parameters describing transport modes: safety, quality, financing, and ecology.

Among the publications concerning services, there are also analyses of decision making in cases of buying a second car or joining a car sharing system (Kim et al. [64]).

Sochor et al. [27] analyzed transport behavior patterns of passengers who used car sharing and those who did not use it. The persons who used these services were characterized by markedly better education, income, and access to public transport. Additionally, the car sharing users were more likely to live in more densely populated areas.

There are publications in the literature which concern the problem of shared mobility optimization. Mourad et al. [74] have presented optimization opportunities for services based on a single mode of transport, i.e., a car (e.g., carpooling, vanpooling, ridesharing, shared taxi). They list the following four main optimization constraints: time, capacity, cost, and synchronization. On the other hand, Esztergár-Kiss [75] has proposed a concept of chaining of daily travels.

This paper identifies and classifies the parameters of a model for the integration of urban sharing services, taking existing public transport systems into account.

3. Classification and Parameterization of Sharing Services

Based on the preceding literature review, the parameters of sharing services and collective public transport were identified and classified. The parameters were divided into
the following groups pertaining to location (four parameters), demographics (two parameters), traveling (six parameters), economy (four parameters), quality (eight parameters), lifestyle (six parameters).

All these parameters were then described from a user’s point of view, considering their potential choice of the mode of transport vis-à-vis an intent to complete a journey within the travel chain. Parameters are defined in Table 2.

Table 2. Defined parameters of sharing services.

| Parameter | Name | Description |
|-----------|------|-------------|
| Loc1 | existing infrastructure | describes the infrastructure used when traveling |
| Loc2 | terrain topography | describes the inclination of pavements |
| Loc3 | parking availability | describes the availability of parking areas, the possibility of leaving the vehicle parked, and the impact of potential problems associated with leaving the vehicle |
| Loc4 | available driving range | considers potential problems associated with charging/fueling of vehicles while traveling |
| D1 | age | specific age pre-defines the likelihood of a user actually using a specific mode of transport |
| D2 | gender | specific gender pre-defines the likelihood of a user actually using a specific mode of transport |
| T1 | travel time | pre-assumed travel time estimated using a travel planner, indicating whether or not a specific mode of transport is suitable |
| T2 | distance | pre-assumed distance to be covered, which indicates whether or not a specific mode of transport is suitable |
| T3 | travel start point | parameter describing the time of walk from the point of origin to the vehicle, dock, or stop |
| T4 | travel end point | parameter describing the time of walk from the vehicle, dock, or stop to the destination point |
| T5 | travel planning | parameter determining the impact of travel planning on the choice of the mode of transport |
| T6 | size of cargo | parameter determining the impact of the size of the cargo to be transported on the choice of the mode of transport |
| E1 | travel cost per 1 km | parameter determining the impact of the price per 1 km of the ride on the choice of the mode of transport |
| E2 | parking costs | parameter describing the need for parking charges to be covered and their impact on the choice of the mode of transport |
| E3 | discounts held | parameter describing whether or not one has any discounts, e.g., statutorily granted, and if this affects the choice of the mode of transport |
| E4 | travel cost sharing | parameter describing whether it is possible to share the travel costs, and if this affects the choice of the mode of transport |
| Q1 | weather | parameter describing the impact of weather conditions on the choice of the mode of transport |
| Q2 | user flexibility to potential change of means/mode of transport | parameter which takes into account the data entered by the user concerning their willingness to possibly change the transport modes |
| Q3 | road congestion | describes the current traffic intensity which affects the choice of the mode of transport |
| Q4 | road safety | determined by the number of collisions involving the chosen mode of transport on the selected route |
| Parameter | Data Source |
|-----------|-------------|
| **Q5** | personal safety | number of assaults/thefts committed on those traveling by the given transport modes, established on the basis of police statistics for the chosen area |
| **Q6** | waiting time | describes the impact of the user’s waiting for the ride time on the choice of the mode of transport |
| **Q7** | congestion (pedestrian traffic) | describes the impact of pedestrian congestion on the route planned to be covered on the choice of the mode of transport |
| **Q8** | payment forms | describes the impact of the available fare payment forms on the choice of the mode of transport |
| **L1** | eco-friendliness | describes the environmental impact of using the chosen mode of transport |
| **L2** | car ownership | describes the impact of owning a car on the choice of the mode of transport |
| **L3** | bicycle ownership | describes the impact of owning a bicycle on the choice of the mode of transport |
| **L4** | information | describes the impact of the availability of information on the choice of the mode of transport |
| **L5** | driving license | describes the impact of having a driving license on the choice of the mode of transport |
| **L6** | user health | describes the impact of the chosen mode of transport on the user’s health |

Each parameter from Table 2 is described with an additional value which determines its positive or negative impact on the user’s capacity to use a sharing service (e.g., bad weather has a large impact on ride sharing) or collective public transport in the travel chain. Additionally, specific data acquisition sources were proposed for the parameters identified above. The user of the aforementioned travel planner would only enter basic data at the first launch, and then define the destination and the origin of the travel planned along with the applicable restrictions as well as set the selected optimization function (as defined in Section 5). Appendix A summarizes the parameters classified by the authors and specifies their implied effect on the utility of individual services. The impact of each parameter has been described and evaluated using a scale where the score of 1 indicates a positive impact on the use of the given service, while 0 is the worst score. Certain modes of transport, for which no problematic effect was established for the given parameter, received the score of 1. The scale-based assessments were developed with reference to an extensive literature review and some preliminary local observations under the research projects performed. For each of these parameters, a potential data source for acquiring has been suggested in Table 3.

| Parameter | Data Source |
|-----------|-------------|
| **Loc1** | Road network operator |
| **Loc2** | Numerical terrain model |
| **Loc3** | OSM data |
| **Loc4** | Users |
| **Loc5** | Travel planner, based on travel start and end point |
| **Loc6** | Service provider |
| **Loc7** | Police database |

**Loc1**—existing infrastructure, **Loc2**—terrain topography, **Loc3**—parking availability, **Loc4**—available driving range, **D1**—age, **D2**—gender, **T1**—travel time, **T2**—distance, **T3**—travel start point, **T4**—travel end point, **T5**—travel planning, **T6**—size of cargo, **E1**—travel cost per 1 km, **E2**—parking costs, **E3**—discounts held, **E4**—travel cost sharing, **Q1**—weather, **Q2**—user flexibility to potential change of means/mode of transport, **Q3**—road congestion, **Q4**—road safety, **Q5**—personal safety,
Q₆—waiting time, Q₇—congestion (pedestrian traffic), Q₈—payment forms, L₁—eco-friendliness, L₂—car ownership, L₃—bicycle ownership, L₄—information, L₅—driving license, L₆—user health.

The pre-defined parameters characterized by the scores provided in Appendix A were used under the integration method along with optimization of the use of sharing services. Table 3 defines the potential sources of these parameters. The data from service providers are obtained by means of an API link with the provider of a specific service, e.g., weather forecasts for a specific area.

4. Integration Method Including Optimization of the Use of Sharing Services

The main goal of the method proposed is supporting the process of decision making by a user who intends to travel. It is frequent that a single main criterion is adopted in travel planning processes. In urban systems, one can clearly notice deficiency in terms of using multimodal forms of traveling, i.e., those which involve different transport modes. The solution proposed below assumes that the parameters defined in the previous section of this article are used under the method which allows them to be taken into account to an extent which depends on the user’s (i.e., traveling person’s) preferences.

The algorithm applied has been illustrated in Figure 1. First, the relevant information is retrieved from the user. This information includes the levels of importance (LI) of individual sub-criteria which are then subject to conversion into the weights of criteria. In the case of implementation in a mobile application, the levels of importance can be memorized by the system, which enables the given user to skip this step when using it again. The main information which must be retrieved from the user concerns the origin and destination locations and the time of the travel planned. Further steps are managed by the application, and they require retrieving databases of supplementary values for the selected sub-criteria and databases enabling the process of establishing travel variants to be performed. To identify the set of potential travel variants, a built-in travel planner is used. All the data acquired to that point make it possible to use the algorithm for selecting the best travel variant. Multi-criteria methods are used increasingly often towards transport-related problems (e.g., see Ciesla et al. [31], Wątrobki et al. [76]) as alternative or complementary to simulation models. The method in question assumes the application of multi-criteria methods of decision-making support based on the utility function. The said methods are found to be particularly useful where the variants subject to assessment are comparable (Kobryń [77]), which is the case taken into consideration. The parameters described in Appendix A assume the form of sub-criteria when one applies the multi-criteria decision-making model. The “magical number seven, plus or minus two” (Saaty and Ozdemir [78]) implies that defining too many criteria makes them more difficult to perceive and apply independently of one another. According to the rule, the sub-criteria were grouped under six global criteria (location, demographics, travel, economy, quality, and lifestyle) of the following form:

\[ K = \{K_{Loc}, K_{D}, K_{T}, K_{E}, K_{Q}, K_{L}\}, \]  

where:

K—set of global criteria used in the model.
The meaning of the flowchart blocks' colors: blue—user data; yellow—data from other sources (maps, road network, information on road accidents, weather service, etc.); green—calculations in accordance with the proposed method; red—result.

4.1. Normalising the Values of the Sub-Criteria Weights and Determining Normalised Weights for the Global Criteria

There are weights assigned to individual sub-criteria in the model. These weights can be determined with the help of the user, indicating the importance levels of individual sub-criteria to be used as the input data in the algorithm. The scale enabling the level of importance (LI) to be established may be user-defined as well, and the usual scale of 0–100 was proposed, where 0 means an unimportant sub-criterion and 100 corresponds to a very important sub-criterion. These values are then subject to normalization (2):
\[ w_j = \frac{L_{ij}}{\sum_{s=1}^{m} L_{is}} \quad [1] \]  

\[ \sum_{s=1}^{m} w_s = 1, \quad [2] \]

where:
- \( w_j \) — weight of the \( j \)th sub-criterion;
- \( L_{ij} \) — sub-criterion’s level of importance according to the user;
- \( m \) — number of sub-criteria.

However, the weight of the \( i \)th global criterion is established as the normalized value of the average of weights for the sub-criteria which belong to the group of the same global criterion (4):

\[ W_i = \frac{\sum_{s=1}^{p_i} w_s}{p_i} \times \frac{1}{\sum_{i=1}^{n} \frac{\sum_{s=1}^{p_i} w_s}{p_i}}, \quad [3] \]

where:
- \( w_i \) — weight of the \( i \)th global criterion;
- \( p_i \) — number of sub-criteria in the group of the \( i \)th global criterion.

### 4.2. Establishing a Set of Solution Variants (Potential Travel Variants)

The variants in the multi-criteria decision-making model will be the set of the travels defined by means of the travel planning tool (5) which can be completed assuming the user-specified points of origin and destination as well as the travel start time (which is relevant given the applicable collective transport timetables or travel sharing service plans).

\[ W = \{W_1, W_2, ..., W_n\}, \quad [4] \]

where:
- \( W \) — set of travel options (varying from case to case);
- \( n \) — number of variants which can be completed in the given case.

In order to obtain the variants, one must use a travel planning tool which takes into account the travel options described in the article. This implies the need to implement traveling by foot, bicycle, public transport, car (for planning of travel sharing services), as well as using bike-sharing and car-sharing options. Most importantly, one should also consider the aspect of integration into travel chains, since only then is it possible to complete travels linked in chains, e.g., by using public transport to cover longer distances and then switching to the bike-sharing service. One of the tools which can enable just that is ETPlanner—a multimodal travel planner developed under the international project entitled “Electric travelling—platform to support the implementation of electromobility in Smart Cities based on ICT applications”.

### 4.3. Normalising the Sub-Criteria Values and Establishing the Global Criteria Values for All Travel Variants

Knowing the specific travel variants, one can establish the values of individual sub-criteria for them (some depending on the travel route). The sub-criteria provided in Appendix A assume values from the range of 0–1, and they have been standardized in terms of their importance, where the higher the value the better the score. The values of the global criteria defined in Equation (1) for individual travel variants are determined using Equation (6):
Consecutive calculations can be completed depending on the selected multi-criteria decision-making method. The approach proposed by the authors is based on an aggregate function which assumes the form of an adjusted summation index. This is also referred to as Simple Additive Weighting or Weighted Linear Combination. According to the literature, such a form of the index is recommended for synthetic assessments, being the one used most frequently in multi-criteria spatial analyses (Kobryń [77]), and in the case considered, the choice pertains to the routes defined in the urban transport network. Consequently, the utility function for six global criteria assumes the following form (7):

\[ U_k = \sum_{i=1}^{6} K_{k,i} \cdot w_i, \quad [-] \] (7)

where:

- \( U_k \) — utility function for the \( k \)th travel option.
- \( K_{k,i} \) — the \( i \)th global criterion from set (1) for the \( k \) travel variant;
- \( K_{SUB} \) — sub-criterion from the given global criterion’s group.

The last step in the method proposed is ranking the variants by a decreasing value of the utility function and selecting the most favorable variant.

5. Example and Discussion

In order to make the method proposed more transparent, a computational example has been prepared, based on the following scenario. A user would like to travel from point A (coordinates: 50.25525880, 19.03366428) to point B (coordinates: 50.28613108, 18.9698268) on 16 February 2021, and start the travel at 10:00 hrs. Assuming that the method proposed by the authors has been successfully implemented in a mobile application, once the above data have been entered and the user preferences defined (previously saved by the system), the relevant calculations are performed internally according to the diagram provided in Figure 1 and as described in Section 4. Most traveling modes are available in the chosen area. For the input data entered, the travel planner has identified five variants. All of them have been illustrated in Figure 2. These variants comprise traveling by single transport modes, i.e., using a bike sharing service (\( W_1 \), Figure 2a), an electric car sharing service (\( W_2 \), Figure 2b), as well as by several transport modes in a single travel, i.e., by collective transport without changing (\( W_3 \), Figure 2c), by collective transport and bike sharing (\( W_4 \), Figure 2d), as well as by collective transport and car sharing (\( W_5 \), Figure 2e). Selected travel parameters for the five variants are summarized in Table 4.

\[ K_{k,i} = \frac{\sum_{i=1}^{p} K_{SUB}}{p}, \quad [-] \] (6)
Figure 2. Travel variants for the example discussed—different routes and transport modes: (a) \(W_1\)—travel by using a bike sharing service, (b) \(W_2\)—travel by using an electric car sharing service, (c) \(W_3\)—travel by using collective transport without changing, (d) \(W_4\)—travel by using collective transport and bike sharing, (e) \(W_5\)—travel by using collective transport and car sharing.

Table 4. Characteristics of the five travel variants identified using the planner.

| Variants | Description |
|----------|-------------|
| \(W_1\) | Using the bike sharing system which, in the area in question, requires docking stations to be used (walking to the nearest dock and returning the bicycle to the dock closest to the travel destination). Traveling partially on foot. |
| \(W_2\) | Using the electric car sharing system. To complete the travel, one must first walk to the nearest parked vehicle available under the given service. Necessity of finding a free parking place close to the travel destination. |
| \(W_3\) | Mixed-mode traveling using collective transport modes. In the case in question—using two different tram services. Traveling based on the current timetable, including walking and waiting at stops. |
| \(W_4\) | Mixed-mode traveling, first by a shared bicycle, and then using a tram. Traveling based on the current timetable, including walking, waiting at stops, and necessary bicycle docking. |
| \(W_5\) | Mixed-mode traveling—using a bus to reach a shared electric car parked as close as possible, and continuing by the sharing service mode. Traveling based on the current timetable, including walking, waiting at stops, and finding a free parking place close to the travel destination. |

\(W_1\)—travel by using a bike sharing service, \(W_2\)—travel by using an electric car sharing service, \(W_3\)—travel by using collective transport without changing, \(W_4\)—travel by using collective transport and bike sharing, \(W_5\)—travel by using collective transport and car sharing.

Depending on the parameters of individual travels and the user preferences, a set of values of the global criteria has been established under individual variants (Table 5) as well as a set of weights to be assigned to these criteria (Table 6). Using Equation (7), the value of the utility function has been estimated for each variant (Table 7). Their ranking
in a descending order implies the result that is to be suggested to the user as the optimal solution considering the first user preferences:

\[ W_5 > W_4 > W_3 > W_2 > W_1 \]

**Table 5.** Global criteria values for the travel variants identified.

| Variants | \( K_{loc} \) | \( K_D \) | \( K_T \) | \( K_F \) | \( K_Q \) | \( K_L \) |
|----------|---------------|-------------|-------------|-------------|-------------|-------------|
| \( W_1 \) | 0.688 | 1.000 | 0.667 | 0.500 | 0.969 | 0.833 |
| \( W_2 \) | 0.750 | 1.000 | 0.792 | 0.317 | 0.938 | 0.833 |
| \( W_3 \) | 1.000 | 1.000 | 0.917 | 0.445 | 0.813 | 0.792 |
| \( W_4 \) | 0.714 | 1.000 | 0.854 | 0.444 | 0.897 | 0.720 |
| \( W_5 \) | 0.750 | 1.000 | 0.917 | 0.250 | 0.857 | 0.815 |

\( W_1 \)—travel by using a bike sharing service, \( W_2 \)—travel by using an electric car sharing service, \( W_3 \)—travel by using collective transport without changing, \( W_4 \)—travel by using collective transport and bike sharing, \( W_5 \)—travel by using collective transport and car sharing. \( K_{loc} \)—global criterion related to location, \( K_D \)—global criterion related to demographics, \( K_T \)—global criterion related to traveling, \( K_F \)—global criterion related to economy, \( K_Q \)—global criterion related to quality, \( K_L \)—global criterion related to lifestyle.

**Table 6.** Weights of the global criteria as per two users’ preferences.

| No. of User | Weights | \( K_{loc} \) | \( K_D \) | \( K_T \) | \( K_F \) | \( K_Q \) | \( K_L \) |
|-------------|---------|---------------|-------------|-------------|-------------|-------------|-------------|
| I           | Weights | 0.181818      | 0.004253    | 0.277157    | 0.160553    | 0.170654    | 0.205564    |
| II          | Weights | 0.139988      | 0.003708    | 0.174289    | 0.232695    | 0.213226    | 0.236094    |

\( K_{loc} \)—global criterion related to location, \( K_D \)—global criterion related to demographics, \( K_T \)—global criterion related to traveling, \( K_F \)—global criterion related to economy, \( K_Q \)—global criterion related to quality, \( K_L \)—global criterion related to lifestyle.

**Table 7.** Values of the utility function for the variants in question.

| No. of User | Variants | \( W_1 \) | \( W_2 \) | \( W_3 \) | \( W_4 \) | \( W_5 \) |
|-------------|----------|-----------|-----------|-----------|-----------|-----------|
| I           | \( U_c \) | 0.73093   | 0.74218   | 0.81293   | 0.74327   | 0.74864   |
| II          | \( U_c \) | 0.735798  | 0.717028  | 0.767106  | 0.717162  | 0.701834  |

\( W_1 \)—travel by using a bike sharing service, \( W_2 \)—travel by using an electric car sharing service, \( W_3 \)—travel by using collective transport without changing, \( W_4 \)—travel by using collective transport and bike sharing, \( W_5 \)—travel by using collective transport and car sharing, \( U_c \)—utility function.

What should also be noted is that changing the preferences to the system defaults or to ones which result from another set of user habits may cause a different final result to be returned by the algorithm. Sample weights resulting from the levels of importance defined by second user have been also provided in Table 6. Assuming identical travel parameters, the results obtained (Table 7, second row) imply variant \( W_3 \) to be the best, while the variant \( W_1 \) is indicated as the second best.

The proposed method makes it possible to take individual preferences of a specific traveler into account. Given its operating principle, the dedicated application enabling this method to be utilized in practice requires that a user-customized settings tab is used, allowing the proposed method to define individual parameters specified in Appendix A and their level of importance on the first use or whenever one changes their preferences. Once the user settings have been saved, further use of the application will be limited to defining the origin and destination points as well as the date and time of the travel planned (with an hour’s tolerance in terms of the time of departure or possibly the time at which the travel should end at the destination).

Bearing in mind the potential unwillingness of users to define their own preferences, the application should offer default levels of importance of individual sub-criteria. What the authors propose in this respect is a configuration which favors ways of traveling that
reduce the negative environmental impact of transport and foster integration of the available transport modes in the travel chain. When using the application, a user connects to the service’s central database, which means that no computations are performed directly on the user’s device. The result offered to the user is a suggested way to complete the given travel according to their preferences, with the application taking all the available urban sharing services into account. So, the application also requires a server service enabling data related to the use of external data sources to be stored. This pertains to weather forecasts, travel costs per transport modes, safety statistics, etc. In this respect, the existing open data sources can be used (depending on the area). The method also requires a link between the application and an external travel planning tool. The possible solutions are being established in this manner, representing a set of travels by the transport modes discussed in the article, including an option of changing them while traveling. What has been proposed in the article is that an existing multimodal travel planner, i.e., ETPPlanner, should be used to this end. The planner itself has already been verified and put into practical use when solving other decision-making problems (Sierpiński et al. [79]). However, it is also possible that another travel planning tool is used. This requires a capacity to store a set of routes enabling the sub-criteria values to be determined for individual variants, and then a possibility of uploading the final solution (the best of the ranking obtained) to the travel planner as geo-information.

This method can also be adapted to a specific area by adjusting the values of the parameters specified in Appendix A to the local specifics.

6. Conclusions

The literature review implies that solutions supporting the integration of urban shared mobility services are actually scarce. A relevant incentive for the traveling population may be provided by taking their individual traveling preferences into consideration. Addressing this problem in a comprehensive manner may help in changing the modal split of transport and promoting certain organizational solutions (e.g., bike sharing and car sharing) enabling the flexibility of traveling to be increased.

The main findings of the article include a number of classified and grouped travel describing parameters: location (four parameters), demographics (two parameters), traveling (six parameters), economy (four parameters), quality (eight parameters), lifestyle (six parameters) and related preferences of the traveling population. In this way, six global criteria have been identified, and multi-criteria decision-making methods have been proposed as the means to obtain a solution that would meet the user’s expectations best. Proposed method focuses on different modes of traveling other than the individual use of a private passenger car. This particularly includes traveling by sharing services and public transport. Equally important is the data availability, which is precisely why the method proposed by the authors is based on using open data sources, a travel planning tool, as well as levels of importance for individual criteria according to the traveling population. Preferences of the traveling population, taken into consideration as the levels of importance, affect the result returned by the computational algorithm (as proved using the example in Section 5), while at the same time, they increase the flexibility of the method proposed.

Under further research, the authors are planning to conduct calculations using other multi-criteria methods, including ones which are based on the outranking relationship, in order to perform a comparative analysis of the mutual dependences between the preferences (level of important of criteria) and the method assumed. Next, the relevant algorithm should be implemented into a user friendly application. On account of the fact that the values of some of the parameters have been derived from a literature review, the authors are also planning to perform a case study in practice, addressing a specific urban area, in order to verify these values.
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### Appendix A

**Table A1.** Impact of the parameters classified on the choice of the mode of transport from the user’s perspective—bike sharing and car sharing services.

| Parameter | Bike Sharing | Car Sharing | Scooters | Travel Sharing Services | Public Transport |
|-----------|--------------|-------------|----------|------------------------|------------------|
| **Loc1**  |              |             |          |                        |                  |
| Percentage share of bicycle paths in the route planned: | 100%—1 | 80%—0.75 | 60%—0.50 | 40%—0.25 | Less than 40%—0 |
| There is a highly developed road and street network in the city. There are no infrastructural problems. | 1 | | | | |
| Percentage share of bicycle paths in the route planned (depending on the municipal policy): | 100%—1 | 80%—0.75 | 60%—0.50 | 40%—0.25 | Less than 40%—0 |
| There is a highly developed road and street network in the city. There are no infrastructural problems. | 1 | | | | |
| **Loc2**  |              |             |          |                        |                  |
| Inclination of the route planned (Broach et al. [80]): | 0%—1 | 1–2%—0.75 | 2–4%—0.50 | 4–6%—0.25 | More than 6%—0 |
| No effect of terrain inclination on the use of motor vehicles. | 1 | | | | |
| No effect of terrain inclination on the use of electric scooters. | | | | | |
| **Loc3**  |              |             |          |                        |                  |
| Bicycle can be left anywhere—1 Must be docked—0 | | | | | |
| Parking space guaranteed at a publicly accessible place—1 | | | | | |
| Large number of parking spaces near the destination—0.50 | | | | | |
| Small number of parking spaces near the destination—0 | | | | | |
| Scooter can be left anywhere—1 Must be returned to a dedicated zone—0 | | | | | |
| **Loc4**  |              |             |          |                        |                  |
| For human-powered bicycles, depending on distance in kilometers: | | | | | |
| 48 and more—0 | 40–48—0.2 | 32–40—0.4 | 24–32—0.6 | 16–24—0.8 | 0–16—1 |
| For conventionally propelled vehicles—1 For electric vehicles, on account of long charging time (for maximum range of ca. 350 km) (Schlüter et al. [82]): | SOC above 80%—1 | SOC of 60–80%—0.75 | SOC of 40–60%—0.50 | SOC of 20–40%—0.25 | SOC below 20%—0 |
| For electric vehicles, on account of long charging time (for maximum range of ca. 40 km) (Schellong et al. [13]): | SOC above 80%—1 | SOC of 60–80%—0.75 | SOC of 40–60%—0.50 | SOC of 20–40%—0.25 | SOC below 20%—0 |
| For electric vehicles—0 For traditional engine vehicles—0.50 No need to charge/refuel—1 | | | | | |
| No impact: factor out of passenger’s consideration—1 | | | | | |
For electric vehicles, on account of long charging time (for maximum range of ca. 150 km)

| SOC | Below 20%—0 | 20–40%—0.25 | 40–60%—0.50 | 60–80%—0.75 | Above 80%—1 |
|-----|-------------|-------------|-------------|-------------|-------------|
| SOC | 0–20—0.50 | 21–30—1 | 31–40—0.75 | 40–60—0.25 | More than 60—0 |
| SOC | 0–20—0.75 | 21–30—1 | 31–40—0.75 | 40–60—0.50 | More than 60—0 |
| SOC | 0–20—0.75 | 21–30—1 | 31–40—0.75 | 40–60—0.50 | More than 60—0 |

Age (Böcker et al. [83]):
- 0–20—0.50
- 21–30—1
- 31–40—0.75
- 40–60—0.25
- More than 60—0

Age (Kim et al. [84]):
- 0–20—0
- 21–30—1
- 31–40—0.75
- 40–60—0.25
- More than 60—0

Age (Degele et al. [85]):
- 0–20—0.75
- 21–30—1
- 31–40—0.75
- 40–60—0.50
- More than 60—0

Frequency of use by gender (Langford et al. [81]):
- Men—1
- Women—0.75

Frequency of use by gender (Kim et al. [84]):
- Men—1
- Women—0.25

Frequency of use by gender (Ciociola et al. [86]):
- Men—1
- Women—0.50

Time (min)(Du et al. [87]):
- <5—1
- 5–10—1
- 10–20—0.75
- 20–30—0.50
- 30>—0

Time (min)(Martin et al. [88]):
- <10—0.75
- 10–20—1
- 20–30—0.50
- 30–40—0
- 40>—0.25

Time (min)(Schellong et al. [13]):
- 0.5–1
- 1–2—1
- 2–3—0.50
- 3–4—0.25
- More than 4—0

Walking distance from bicycle or dock (min) (Kim et al. [64]):
- 0–2—1
- 2–4—0.75
- 4–8—0.50
- 8–10—0.25
- 10 and more—0

Walking distance from car (min) (Ferrero et al. [28]):
- 0–3—1
- 3–6—0.75
- 6–9—0.50
- 9–12—0.25
- 12 and more—0

Walking distance from scooter or scooter parking zone (min) (Ferrero et al. [28]):
- 0–1—1
- 1–2—0.75
- 2–3—0.50
- 3–4—0.25
- 4 and more—0

Walking distance from stop to destination (min) (Soczówka et al. [92]):
- 0–5—1
- 5–10—0.75
- 10–15—0.50
- 15–20—0.25
- More than 20—0
| $T_i$ | Walking distance from dock to destination (min) (Kim et al. [64]): | Walking distance from parking (min) (Ferrero et al. [28]): | Walking distance from vehicle leaving place to destination (min) (Schellong et al. [13]): | Walking distance from stop to destination (min) (Soczówska et al. [92]): |
|------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| 0–2 | 0–3 | 0–1 | 0–5 | Assuming that the vehicle can be left at any generally accessible parking area—1 |
| 2–4 | 0–75 | 1–2–0.75 | 5–10–0.75 |
| 4–8 | 0–50 | 2–3–0.50 | 10–15–0.50 |
| 8–10 | 0–25 | 3–4–0.25 | 15–20–0.25 |
| 10 and more | 0 | 4 and more | 20 and more—0 |

| $T_s$ | Travel planned well in advanced and vehicle booked—1 (Schellong et al. [96]): | Travel planned well in advanced and vehicle booked—1 (Schellong et al. [96]): | Travel planned well in advanced and vehicle booked—1 (Schellong et al. [96]): | Travel planned slightly in advance—1 (Schellong et al. [96]): |
|------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Spontaneous travel—0 | Spontaneous travel—0 | Spontaneous travel—0 | Spontaneous travel—0 | Unplanned travel—0 |
| Light-weight shopping—1 | Shopping—1 | No cargo—1 | Shopping—1 | No cargo—1 |
| Other—0 | Large shopping—0.75 | Rucksack—0.75 | Large shopping—0.75 | Rucksack—0.75 |
| Cargo bicycle available—1 | Large size cargo—0 | Other—0 | Large size cargo—0 | Other—0 |

| $E_i$ | Data from service provider (miscellaneous depending on services and country): | Data from service provider (miscellaneous depending on services and country): | Data from service provider (miscellaneous depending on services and country): | Data from service provider (miscellaneous depending on services and country): |
|------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Data from service provider (miscellaneous depending on services and country): | Data from service provider (miscellaneous depending on services and country): | Data from service provider (miscellaneous depending on services and country): | Data from service provider (miscellaneous depending on services and country): |
| None—1 | Having discounts—1 | Having discounts—1 | Having discounts—1 |
| No discounts—0 | No discounts—0 | No discounts—0 | No discounts—0 |

| $E_t$ | Depending on number of people: | Depending on number of people: | Depending on number of people: | Depending on number of people: |
|------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Sunny weather with good temperatures—1 | Sunny weather with good temperatures—1 | Sunny weather with low temperatures—0.75 | Sunny weather with low temperatures—0.75 |
| Sunny weather with low temperatures—0.75 | Sunny weather with low temperatures—0.75 | No weather impact on use—1 | No weather impact on use—1 |
| Windsy weather—0.50 | Windsy weather—0.50 | Sunny weather with low temperatures—0.75 | Sunny weather with low temperatures—0.75 |
| Sunny weather with low temperatures—0.75 | No weather impact on use—1 | No weather impact on use—1 | No weather impact on use—1 |

| $Q_i$ | (Xu et al. [91]) | No weather impact on use—1 | (Zoepf et al. [93]) | (Zoepf et al. [93]) |
|------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| No weather impact on use—1 | No weather impact on use—1 | No weather impact on use—1 | No weather impact on use—1 | No weather impact on use—1 |
| Sunny weather with good temperatures—1 | Sunny weather with good temperatures—1 | Sunny weather with low temperatures—0.75 | Sunny weather with low temperatures—0.75 |
| Sunny weather with low temperatures—0.75 | Sunny weather with low temperatures—0.75 | No weather impact on use—1 | No weather impact on use—1 |
| Windsy weather—0.50 | Windsy weather—0.50 | Sunny weather with low temperatures—0.75 | Sunny weather with low temperatures—0.75 |
| Sunny weather with low temperatures—0.75 | No weather impact on use—1 | No weather impact on use—1 | No weather impact on use—1 |
| Q4 | Bicycles provide high flexibility; congestion has no significant impact on traveling—1 |
|----|------------------------------------------------------------------------------------------------|
| Q5 | High traffic volume—0, Medium traffic volume—0.50, Low traffic volume—1                     |
| Q6 | High traffic volume—0, Medium traffic volume—0.50, Low traffic volume—1                     |
| Q7 | Bicycles provide high flexibility; congestion has no significant impact on traveling—1       |
| Q8 | High traffic volume—0, Medium traffic volume—0.50, Low traffic volume—1                     |

### Table 1: Transportation Modes

| Q4 | High willingness to change transport modes to reach the next destination—1 |
|----|---------------------------------------------------------------------------|
| Q5 | Unwillingness to change transport modes—0                                  |
| Q6 | High willingness to change transport modes to reach the next destination—1 |
| Q7 | Unwillingness to change transport modes—0                                  |
| Q8 | High willingness to change transport modes to reach the next destination—1 |
| Q9 | Unwillingness to change transport modes—0                                  |

### Table 2: Number of Robberies/Thefts

| Q4 | Number of robberies/thefts above average for the area of analysis or fatalities—0.25 |
|----|-------------------------------------------------------------------------------------|
| Q5 | Number of robberies/thefts around average value (±5%) for the analyzed area—0.50    |
| Q6 | Number of robberies/thefts below the average for the analyzed area—0.75            |
| Q7 | No robbery/theft and casualties—1                                                  |

### Table 3: Number of Collisions

| Q4 | Number of collisions above the average for the area of analysis or fatalities—0.25 |
|----|-------------------------------------------------------------------------------------|
| Q5 | Number of collisions around (±5%) the mean value for the analysis area—0.50        |
| Q6 | Number of collisions below the average for the analyzed area—0.75                  |
| Q7 | No collisions and no casualties—1                                                  |

### Table 4: Time (min)

| Q4 | 0–2—1                                                                 |
|----|------------------------------------------------------------------------|
| Q5 | 2–4—0.75                                                              |
| Q6 | 4–6—0.50                                                              |
| Q7 | 6–8—0.25                                                              |
| Q8 | 8 and more—0                                                           |

### Table 5: Risk Factors

| Q4 | Risk factor—1 |
|----|---------------|
| Q5 | Risk factor—0 |
| Q6 | Risk factor—1 |
| Q7 | Risk factor—0 |
| Q8 | Risk factor—1 |
| Q8 | Mobile application for paying is available—1 | Payment by mobile application—1 | Mobile application for paying is available—1 | Payment by mobile application—1 | Payment by mobile application—1 | Payment by mobile application—1 |
|----|---------------------------------------------|---------------------------------|---------------------------------------------|---------------------------------|---------------------------------|---------------------------------|
|    | Mobile application for paying is available—1 | Payment by mobile application—1 | Mobile application for paying is available—1 | Payment by mobile application—1 | Payment by mobile application—1 | Payment by mobile application—1 |
| L1 | Conventional bicycle—1                       | Conventional car—0              | Electric stand-up scooter—1                  | Electric vehicle travel sharing—1 | Electric vehicle travel sharing—1 | Electric vehicle travel sharing—1 |
|    | Electric bicycle—0.75                        | Electric car—1                  | Electric car—1                               | Electric car—1                  | Electric car—1                  | Electric car—1                  |
|    | (Xu et al. [91])                             |                                 |                                             |                                 |                                 |                                 |
|    | Car owned—0                                 | Car owned—0                    | Car not owned—1                             | Car not owned—1                 | Car not owned—1                 | Car not owned—1                 |
|    | Car owned—0.50                              | Car owned—0.50                 | Car not owned—1                             | Car not owned—1                 | Car not owned—1                 | Car not owned—1                 |
|    | Car not owned—1                             | Car not owned—1                |                                             |                                 |                                 |                                 |
|    | 2 and more—0                                | 2 and more—0                   |                                             |                                 |                                 |                                 |
| L2 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 |
|    | No information—0                            | No information—0               | No information—0                            | No information—0                | No information—0                | No information—0                |
|    | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 |
|    | No information—0                            | No information—0               | No information—0                            | No information—0                | No information—0                | No information—0                |
|    | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 | Application with information on available vehicles and booking feature—1 |
|    | No information—0                            | No information—0               | No information—0                            | No information—0                | No information—0                | No information—0                |
| L3 | No impact—1                                 | No impact—1                    | No impact—1                                 | No impact—1                     | No impact—1                     | No impact—1                     |
| L4 | Improving fitness—1                         | Improving fitness—0.50         | Improving fitness—0                         | No impact                       | No impact                       | No impact                       |

**Loc1—existing infrastructure, Loc2—terrain topography, Loc3—parking availability, Loc4—available driving range, D1—age, D2—gender, T1—travel time, T2—distance, T3—travel start point, T4—travel end point, T5—travel planning, T6—size of cargo, E1—travel cost per 1 km, E2—parking costs, E3—discounts held, E4—travel cost sharing, Q1—weather, Q2—road congestion, Q3—road safety, Q4—personal safety, Q5—waiting time, Q6—congestion (pedestrian traffic), Q7—payment forms, L1—eco-friendliness, L2—car ownership, L3—bicycle ownership, L4—information, L5—driving license, L6—user health.**
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