Personalized Route Selection Methods in an Urban Computing Scenario

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Abstract. *With population growth in urban areas, the more extensive city infrastructure faces several problems affecting the population's health and quality of life. In this context, smart urban mobility solutions perform a ubiquitous way of sensing the population mobility and the local mobility context, such as criminality, accidents, and air quality near the road infrastructure, complementing the city mobility. Likewise, Location-based Social Networks (LBSN) dispose of users' geolocated data, allowing the identification of mobility patterns and alternative modal transport recommendations. This work develops two pollution-aware route selection approaches, a multi-modal hybrid routes method and a multi-criteria personalized route selection method, for urban citizens' mobility flow improvement, attending to the urban mobility overload and deficiency. The hybrid multi-modal solution surpasses the single-modal, offering less expensive and less polluted trip options. Considering all calculated route possibilities, the multi-criteria personalized profile solution outperforms the single-criterion choice in the same context.*

1. Introduction

The migration from rural areas to urban centers has led to a dramatic increase in urbanization, bringing populations together in large cities. This shift has cultivated a productivity-driven culture, accelerating the pace of urban life and necessitating each individual's contribution to societal advancement and the enhancement of living standards [Wu et al. 2022]. While vertical development has been a boom for residential and commercial spaces, the challenge of updating and expanding urban transportation infrastructure to match the scale of past urban planning remains. Various transportation modes are emerging, evolving beyond the traditional highway-centric approaches to include diverse needs ranging from people and goods movement for both professional and leisure purposes. Urban transportation has become a critical component of city life, operating continuously with only slight reductions in activity during night or holidays, underscoring the need for innovative solutions in the face of outdated urban projects.

Various transportation methods characterize urban mobility, including walking, cycling, public transportation, and personal vehicles. The integration of these modes plays a crucial role in fostering economic development, enhancing social connections, and improving the overall well-being of the population [Zou et al. 2020]. The evolution of Information and Communication Technologies (ICT) has significantly influenced urban mobility by facilitating the deployment of new services and applications [Rodrigues et al. 2018a]. Advances in ICT have led to widespread access to mobile devices and the Internet, which has permitted road traffic data generation, making available public transport schedules and ride-sharing services, thereby simplifying urban travel planning. Furthermore, the proliferation of connected devices has enabled extensive data collection, advancing our understanding of human behavior and transportation systems through pervasive sensing technologies.

This paper presents the contributions in the master thesis [Brito 2023], which presents two route selection methods for urban areas as a solution for more comfortable, healthier, secure, and eco-friendly paths. We integrate a multi-modal routing method with a pollution calculation, combining public transportation with Hired-Private Vehicles (HPV) for economical, efficient, and eco-friendly trips. In addition, we present a personalized multi-criteria route selection with comfort, security, and air quality features to suggest better urban paths based on different user preferences. Thus, the work objectives include: i) Present the multi-modal route selection method with air pollution calculation. ii) Compare the hybrid routes with single-modal routes in terms of economic, trip-related, and air quality features. iii) Present the application of the multi-criteria route selection method. iv) Compare the personalized profile selection with greedy and more straightforward preferences, selecting balanced routes for each user profile.

2. Related Works

In state-of-the-art methods, route selection approaches consider social network data for human and mobility flow analysis, hybrid routes involving different transportation modes, and air quality measurement, but not the three elements in the same solution. Similarly, in the multi-criteria route selection literature, many works need to consider health, comfort, and security factors when offering urban routes without customizing the preference. We highlight the difference between state-of-art approaches to our methods and all related objectives attended.

Table 1 summarizes the main characteristics of previous works in terms of Location-based Social Networks (LBSN) data use, multi-modal routing, mobility flow analysis integration, providing statistics to be used by users who opt for less polluting modes of transport and by urban transport managers who can optimize values to improve the quality of life. Table 1 also shows the relation between previous works and the multi-criteria method on different issues, such as the multi-criteria approach, various criteria in the selection, including air pollution, and providing the best route ranking based on defined user profiles preference. The literature review indicates the need to integrate other factors in vehicle trip suggestions, using emerging technology to enhance the data acquisition step for route selection from each driver's necessities. Further details about the related works can be found in Chapter 3 of the master Thesis [Brito 2023].

Table 1. Multi-modal approach related works features comparison

Work	LBSN data usage	Multimodal routing	Mobility flow analysis	Air quality addition	Multi-criteria approach	User Profiles
[Ferreira et al. 2020]	**yes**	no	no	no	no	no
[Rodrigues et al. 2018b]	**yes**	**yes**	**yes**	no	no	no
[Rodrigues et al. 2018a]	**yes**	no	**yes**	no	no	no
[Zou et al. 2020]	no	no	no	**yes**	no	no
[Wu et al. 2022]	**yes**	no	**yes**	no	**yes**	no
[Sarraf and McGuire 2020]	no	no	**yes**	no	**yes**	no
[Kaivonen and Ngai 2020]	no	no	**yes**	**yes**	no	no
[Zhang et al. 2022]	no	no	**yes**	no	**yes**	no
[Solé et al. 2022]	no	no	**yes**	no	**yes**	**yes**
Multi-modal Method	**yes**	**yes**	**yes**	**yes**	no	no
Multi-criteria Method	no	no	**yes**	**yes**	**yes**	**yes**

3. Multi-modal and Multi-criteria Route Selection in an Urban Computing Scenario

The route selection service must find a set of possible route through different street segments in a different modal. In this way, the route selection service must consider as much contextual information as possible to provide an adequate route according to the user's preference. The standard routing services do not offer contextual route selection and present a discrete route suggestion based only on time, distance, and traffic constraints to return some urban routes. In this context, the user requests a route for a given origin-destination, also sharing the selection preference. Then, the cloud server contains the dataset construction and attributes the contextual information to each route alternative retrieved from the city's local open databases with modules of routing service API. Finally, each route has a cost, which is the sum of the cost of traversing it in a given transport model.

The data acquisition phase consists of retrieving all contextual and physical data for the dataset build. For instance, an 8-tuple could characterize each street segment to denote crime, accident, length, duration, pollution, nature, attraction, and traffic index, defined as follows: i) The **crime** feature is related to the criminality level considering crime event history in determined areas. ii) The **accident** index defines a danger level to vehicle accidents near a determined route. iii) The **length** index indicates the total route length, measured in meters, directly impacting the internal combustion engine vehicle consumption and travel financial cost. iv) The **duration** index defines an estimated duration for each route for alternative route tuple adding, which is a traditional parameter for a vehicular navigation system affecting driver trip perception. v) The **pollution** index allows us to measure the air quality level attribution for each alternative route, where air pollution constitutes a more significant threat to public health. vi) The **nature** index defines the natural landscapes and "green" areas along the route, which can affect the trip aesthetics. vii) The **attraction** index defines tourist attractions near routes. viii) The **traffic** index is one of the main factors that raise the driver's stress level and trip overall time. Afterward, we insert all contextual and physical feature values into the route alternatives, where each criterion's raw value must be normalized from 0 to 1.

The main objective of the thesis is to present route selection methods for urban areas, providing comfortable, healthier, secure, and eco-friendly paths. To achieve the main goal, we need to answer some research questions.

Research Question 1: ***How to select multi-modal routes considering the economic and efficiency performance between transportation modes?***

This question was answered in [Brito 2023][Chapter 4] by proposing and evaluating a Multi-modal Route Selection Method in an Urban Computing Scenario to compare combined transportation modes and single options in economic, efficiency, and environmental performance metrics, according to the user need, *i.e.*, the first thesis contribution (**Contribution #1**).

We apply a pre-processing method to filter the user's social geolocated interactions containing anonymous users' temporal and geographic records. Afterward, we retrieve mobility flow clusters among the urban scenario and resume a greater travel record amount. In order to ease the method implementation, we use the flow clusters acquired instead of individual route records.

From the origin-destination pairs, we can build transport mode alternatives permuting between HPV and public transportation, such as buses. The two-hybrid alternatives contain a larger section for one mode than the other. Regarding evaluating transport possibilities, they differ in the performance of average travel time, the average distance, trip price, and the calculation of pollutant gas emissions for each transport used. The results of comparing alternative transport modes support the user's choice regarding transport efficiency compared to the necessary economic cost. The amount of pollutants emitted is also compared among performance metrics, offering the environmental option for carrying out the trip.

Research Question 2: ***How to achieve a context-aware multi-criteria route selection method based on economic, security, and health features for urban mobility environment?***

This question was answered in [Brito 2023][Chapter 5] by proposing and evaluating a Multi-criteria Route Selection Method in an Urban Computing Scenario to select urban routes considering contextual information according to user profiles, *i.e.*, the second thesis contribution (**Contribution #2**), which is the efficient urban scenario contextual open data to select routes based on balanced profiles for faster, healthier, or pleasant routes.

We apply the multi-criteria method to combine the set of contextual data in order to compute the cost for each possible route. We chose the Analytic Hierarchy Process (AHP) method to adjust the degree of importance for each contextual data at runtime since AHP provides qualitative and quantitative factors for the analysis to provide a structured technique for decision-making of problems with multiple parameters involved. In this sense, we followed the AHP methodology to define the degree of importance of each contextual data.

We consider four distinct user profiles for our multi-criteria route selection methodology: Worker, Green, Safe, and Tourist, representing standard urban mobility patterns. Each profile has a unique set of priorities reflected in their respective importance, and thus, the route selection service constructs a comparison matrix for each user profile. In this way, Workers prioritize Length, Duration, and Traffic for quicker commutes; the Green profile values Pollution and Nature for eco-friendly and scenic routes; the Safe profile focuses on minimizing Crime and Accidents for safer travel; and the Tourist profile emphasizes Attractions for enriching travel experiences.

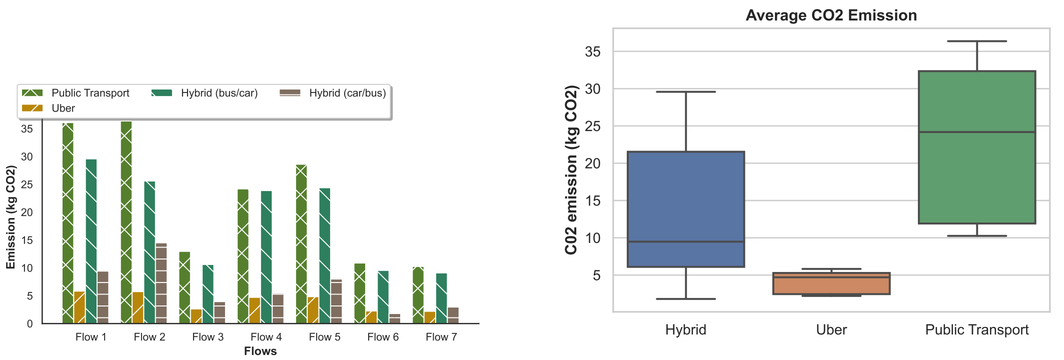
Based on the degree of importance for each profile, the route selection methodology establishes the ranking of alternative routes by examining how the criteria indices within each alternative tuple correspond to the assigned criteria weights. Finally, the method analyses the best result for all user and greedy profile routes under a profile comparison, corresponding to selection preference with higher priority for only one feature.

4. Evaluation

Regarding the results of the two methods, this section presents the main results obtained through implementing the described methods. In the first evaluation, we collected user data from São Paulo and integrated the air pollution calculation. We generate route possibilities using modes with different distances, making a comparative analysis. In the second evaluation, we use the London routes, designed for method evaluation, containing different factors.

4.1. Multi-modal Analysis

Figure 1(a) illustrates the emission values calculated for seven primary traffic flows derived from the distances traveled by different vehicle types along the routes. These distances were then translated into fuel consumption figures and factored into the overall emission calculations. This analysis of various routes highlights the differences in pollution levels emitted by different modes of transport within these critical flows. Bus routes emit significantly more pollutants than those involving other types of transport, showing an approximate 85% higher emission level than routes using services like Uber, and even more so compared to hybrid route alternatives. However, it is important to note the larger carrying capacity of buses, which can justify their higher emissions per-passenger basis compared to hired or private vehicles that typically accommodate no more than five passengers. In Figure 1(b), the average emissions for all analyzed routes are displayed, revealing the modes of transportation that contribute most to pollution across all routes examined. While notably high emissions mark sections of routes that include bus travel, the comparison must account for the number of passengers public transport can carry relative to HPV and private cars.



(a) CO_2 emission in defined routes.

(b) Average CO_2 emission in defined routes.

Figure 1. CO_2 emission calculation results

4.2. Multi-criteria Results

Figure 2 displays the PDFKS matrix, with the M matrix's rows corresponding to various selection profiles (p), including four user profiles and eight greedy profiles, and its columns detailing the trip features (f) under assessment. The metric value in the PDFKS matrix denotes the optimal average value for each profile relative to a predetermined standard (std). For instance, the initial index for the Safe profile indicates a 3.6% improvement over the standard average value in terms of crime, underscoring the efficacy of the Safe profile in selecting routes with lower crime rates compared to others, particularly after the only crime profile. Moreover, the Safe profile exhibits a 39.5% variance from the standard average for the accident feature, highlighting its secondary importance in route selection. This figure does not imply superior performance in accident avoidance but reflects the crime feature's precedence and the data organization. For attributes less central to its primary concern, such as the attraction feature, the Safe profile shows a -46% difference, indicating a lesser influence of this feature on its route selection process.

Conversely, the Nature, Attraction, and Traffic ratio features display negative PDFKS percentage values within the matrix, reflecting the method's preference for routes with greater instances of nature and attractions and a higher traffic ratio, which suggests less congestion. This preference leads to raw values falling below the established standard, hence the negative percentages. A lower raw value signifies a more optimal route choice for these features. In contrast, for all other features exhibiting positive PDFKS values, the ideal selection strategy aims for features with percentages approaching 0%, indicating a closer match to the desired standard.

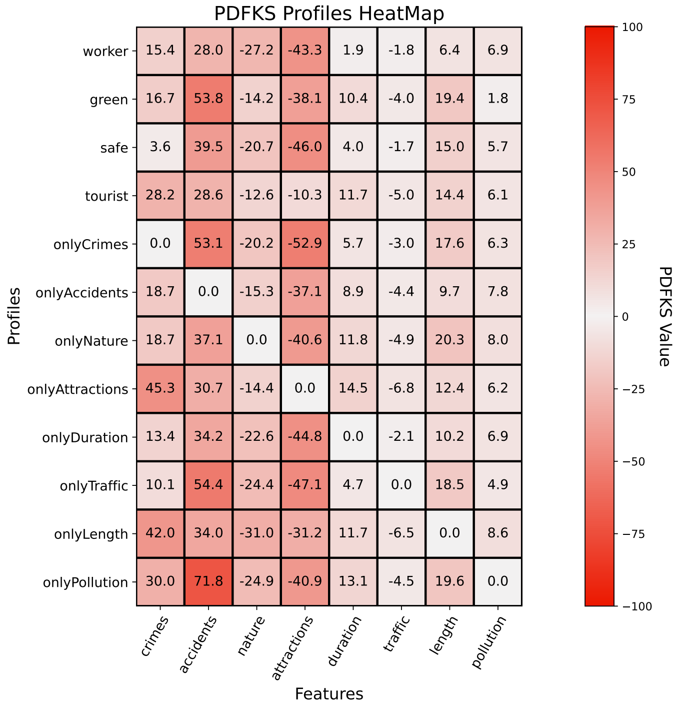


Figure 2. Methodology overview for route selection

The absolute sum technique is employed across all 12 profiles to evaluate the user-defined profiles by aggregating all elements, disregarding the sign of the values. The profile with the smallest absolute sum in the PDFKS metric is deemed the most effective selection method, considering the entirety of routes, as illustrated in Figure 3. Also, the figure shows that greedy profiles are optimized for a single feature and align closely with the standard value (0%), signifying optimal routes for that specific feature. However, these profiles often exhibit greater discrepancies across the remaining features. The profiles we have developed (Worker, Green, Safe, and Tourist) each consider multiple features. Different colors distinguish these profiles to illustrate their feature relationships and facilitate comparing their performance across various scenarios.

The Green profile achieves the nearest match to the standard for pollution and surpasses the onlyPollution profile in additional features, also showing the second smallest deviation in the nature feature (-14.2%), which facilitates a more environmentally friendly routing experience. The Safe profile exceeds the performance of onlyCrimes (3.6%) and onlyTraffic (-1.7%), with Crime as its primary concern; a higher traffic ratio is associated with slower and potentially riskier routes, thus showcasing the most favorable deviation in terms of crime safety. The Worker profile excels in its key areas of concern: onlyLength (6.4%), onlyDuration (1.9%), and onlyTraffic (-1.8%), outperforming standard navigation solutions in these respects. Meanwhile, the Tourist profile offers superior route options compared to onlyAttraction by deviating less from the ideal attraction value (-10.3%) and demonstrating improved performance in the nature feature (-12.6%), making it an optimal choice for tourists seeking enriched travel experiences.

Observations reveal that greedy profiles excel in optimizing their specific prioritized features but exhibit considerable deviations across secondary features. Notably, the profile focusing exclusively on accidents (onlyAccidents) demonstrates the most favorable performance, as indicated by its lowest absolute sum, thus establishing it as the preferred choice within the examined setting. This phenomenon underscores the effectiveness of employing an Analytic Hierarchy Process (AHP) profile that allocates balanced weights to each evaluative criterion, thereby outperforming single-criterion focused profiles and elucidating the superior performance of the onlyAccidents profile. Consequently, within datasets encompassing a wide range of environmental contexts, a strategically designed profile that evenly distributes emphasis on a select group of features can surpass the efficacy of profiles that adopt a singularly focused or 'greedy' optimization strategy.

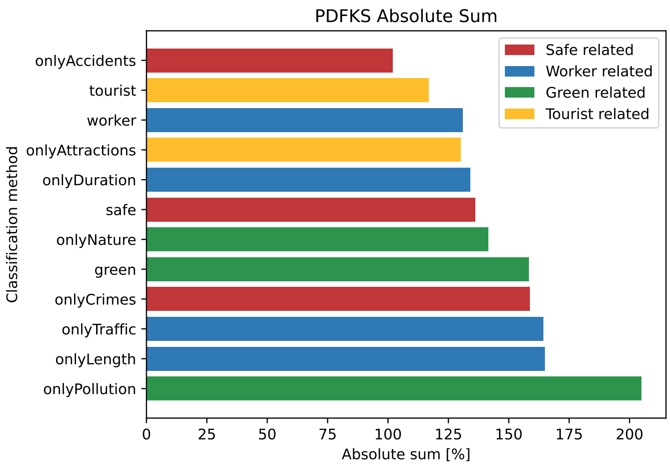


Figure 3. PDFKS absolute sum for each selection profile

5. Conclusion and Thesis Impact

This master's thesis introduces two innovative route selection methods to enhance urban mobility. The first method leverages data from location-based social networks to facilitate multi-modal, pollution-aware routing, while the second employs an AHP approach to provide personalized route options, considering eight different features. These methods contribute to more cost-effective and healthier travel options, offering a framework for mobility planners to foster dynamic and sustainable urban environments. The thesis demonstrates the potential of these methods to improve urban mobility by evaluating CO_2 emissions, waiting times, walking distances, cost estimates, and pollution emissions for various modes of transport. It highlights the advantages over traditional navigation systems by offering safer and more enjoyable travel experiences, emphasizing pollution awareness to enhance the quality of urban life. Table 2 summarizes the papers published due to this Master's thesis.

Table 2. Summary of Results Published

Works	**Qualis**	**Local**	Impact Factor	h5-index	**Situation**
[Brito et al. 2022]	B4	CoUrb (SBRC)[1]	-	-	Published
[Brito et al. 2023]	A4	SBRC[1]	-	8	Published
[Brito et al. 2024]	A1	Ad Hoc Networks	4.8	59	Accepted

[1] Honorable mention award.

It is important to highlight that the paper presented at SBRC 2023 received the honorable mention award, and as a result, we received an invitation to submit an extended version to Elsevier's ad hoc network. In addition, we also received the honorable mention award for the paper presented at CoUrb 2022.

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