Personalized Route Selection Methods in an Urban Computing Scenario

Matheus Brito [1], **Eduardo Cerqueira (Co-Advisor)**[1], **Denis Rosário (Advisor)** [1]

[1]Federal University of Pará (UFPA) - Belém, PA, Brazil

matheus.moraes.brito@itec.ufpa.br, {cerqueira, denis}@ufpa.br

Abstract. *As urban areas continue to expand, the infrastructural systems within these regions face multifaceted challenges that detrimentally affect inhabitants' health and quality of life. The advent of smart urban mobility technologies has introduced a persistent surveillance mechanism over the movement patterns of individuals and the ambient environmental conditions, including but not limited to the prevalence of crime, traffic accidents, and levels of air pollution. These technologies significantly contribute to the enhancement of urban transportation systems. In parallel, Location-Based Social Networks (LBSNs) leverage geolocation data derived from users to analyze travel behaviors and recommend alternative transportation options. This research introduces two innovative strategies aimed at selecting routes characterized by lower levels of pollution: the first strategy employs a multimodal transportation integration approach, and the second endorses route selection based on a comprehensive set of personalized criteria. The multimodal transport strategy offers journey options that are both cost-efficient and minimize environmental pollution. Upon assessing all potential routes, the personalized, multi-criteria-based approach demonstrates superior efficacy in route selection compared to methods that rely on a singular criterion within identical scenarios.*

1. Introduction

The movement from rural locales to metropolitan areas has precipitated a significant rise in urbanization, consolidating populations within expansive urban territories. This migration has created a culture centered on productivity, thereby quickening the rhythm of urban existence and underlining the imperative for each individual's engagement in the collective endeavor towards societal progress and the amelioration of living conditions [Wu et al. 2022]. Although adopting vertical expansion strategies has facilitated the provision of residential and commercial spaces, the imperative to modernize and enlarge the urban transportation framework to align with previous urban design initiatives persists. Many transportation alternatives have surfaced, transcending conventional, highway-focused models to accommodate a broad range of requirements enclosing the conveyance of individuals and merchandise for occupational and recreational purposes. Urban transit has emerged as a vital aspect of metropolitan life, maintaining its operations with minimal diminution during evening periods or festive seasons, highlighting the urgency for creative responses to out-of-date urban schemes.

Various transportation modes, including walking, biking, public transportation, and the use of personal vehicles characterize urban mobility. 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 made traffic data, public transport timetables, and ride-sharing services more accessible, 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.

In this paper, we introduce the contributions of a 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, and was also accepted and presented in a master thesis competition [Brito et al. 2024a]. 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 introduce 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 regarding economic, trip-related, and air quality features. iii) Present the multi-criteria route selection method application. iv) Compare the personalized profile selection with greedy simpler preferences, selecting balanced routes for each user profile.

2. Related Works

In contemporary route selection methodologies, strategies typically integrate data from social networks for human and mobility analysis, include hybrid routes across various transport modes, and consider air quality metrics, yet rarely in a unified solution. Additionally, multi-criteria route selection often fails to incorporate health, comfort, and security considerations, lacking customization to user preferences. This section highlights the distinctions between these state-of-the-art methods and our approach, emphasizing the comprehensiveness of our methodology.

This section introduces Table 1, summarizing key attributes of previous studies concerning the use of Location-Based Social Networks (LBSN) data, multi-modal routing, and mobility flow analysis. The table provides vital statistics for those choosing eco-friendlier transportation and urban managers focused on optimizing quality-of-life enhancements. It also links past research to the multi-criteria method across various issues, including air pollution and route ranking based on defined user preferences. The literature underscores the need to integrate additional factors and emerging technologies in route selection tailored to individual driver needs. Further details are available in Chapter 3 of the master thesis [Brito 2023].

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

In this section, we specify the two route selection methods, which find the best route among a set of possible routes, combining transport modes and considering different context information. This way, the route can be adapted to user preference. Figure 1 defines the steps described above. Our method differs from standard routing services because it

Table 1. Features comparison of related works from multi-modal and multi-criteria approaches

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**

acquires personalized user profiles to define the best route and consider different contexts in urban routes.

During the Criteria Definition step, the dataset comprises all contextual criteria in raw data form, which is subsequently normalized to prepare for the application of the selection method. In the Selection Method step, users specify an origin, destination, and routing preferences. The system then constructs the dataset, assigning contextual data to each route alternative derived from the city's open databases and routing service APIs. Finally, each route is assigned a cost, calculated as the aggregate expenses associated with traversing the route using a specified transport model, as detailed in the Method Evaluation step.

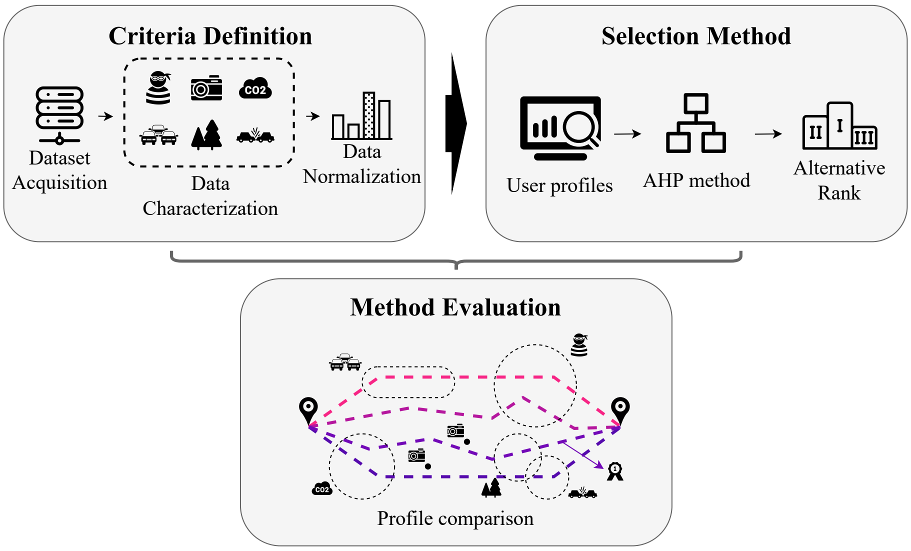


Figure 1. Methodology overview for route selection

The data acquisition stage involves gathering all contextual and physical data necessary for constructing the dataset. For example, each street segment contains an 8-tuple that includes metrics for crime, accidents, length, duration, pollution, natural scenery, attractions, and traffic conditions, detailed as follows: i) The crime metric reflects the area's criminality level based on historical crime data. ii) The accident metric assesses the risk of vehicle accidents along a particular route. iii) The length metric quantifies the route's total distance in meters, influencing fuel consumption and travel costs for internal combustion vehicles. iv) The duration metric estimates the time required to travel each route, a common factor in vehicular navigation systems that affects the driver's perception of the journey. v) The pollution metric evaluates air quality along the route, highlighting areas where air pollution poses a significant health risk. vi) The nature metric accounts for the presence of natural landscapes and green spaces, enhancing the aesthetic value of the route. vii) The attraction metric identifies tourist attractions along or near the route. viii) The traffic metric measures traffic density, which can increase driver stress and extend travel time. Subsequently, these contextual and physical metrics are integrated into the route alternatives, requiring normalization of each criterion from 0 to 1 to standardize the data.

The thesis aims to introduce route selection methodologies for urban environments that prioritize comfort, health, safety, and environmental sustainability. To achieve this objective, it is essential to address some research questions.

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

The answer to this question relies in the Multi-modal Route Selection Method in an Urban Computing Scenario proposal and evaluation, used to compare combined transportation modes and single options in performance metrics, such as economic, efficiency, and environmental results [Brito 2023][Chapter 4]. The performance analysis contains the benefits of a route to the user need, *i.e.*, the first thesis contribution (**Contribution #1**)

We implement a pre-processing technique to sift through geolocated social interactions from users, which contain anonymized temporal and geographic information. Subsequently, we identify mobility flow clusters within the urban context, capturing a substantial volume of travel records. We utilize these flow clusters rather than individual route records for simplicity in implementing the method. The execution of this method reveals 12 distinct mobility flows derived from the analyzed Twitter data, as illustrated in Figure 2. The primary concentrations of these flows are located in *"Jardim Itatinga"*, *"Olímpico em São Caetano do Sul"*, *"Jardim dos Perdizes"*, and *"Aclimação"*. Notably, only seven of these flows encompass the central four districts, considered for further user experience analysis as cited in [Rodrigues et al. 2019].

We generate transport mode alternatives from the identified origin-destination pairs by interchanging between hired-private vehicles (HPV) and public transport options such as buses. These hybrid alternatives typically feature a predominant use of one mode rather than the other. These transport possibilities are assessed based on several criteria: average travel time, distance traveled, trip cost, and pollutant gas emissions calculated for each mode. The comparative analysis of these alternative transport modes helps users make informed decisions about transport efficiency relative to economic costs. Additionally, the evaluation includes comparing pollutant emissions among the performance metrics, thus providing an environmentally considerate option for undertaking 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?***

The proposal and evaluation of the Multi-criteria Route Selection Method in an Urban Computing Scenario answer this question, as presented in [Brito 2023][Chapter 5]. The method considers contextual information and the user profile preference to select urban routes, *i.e.*, the second thesis contribution (**Contribution #2**). The route selection based on balanced profiles with contextual open data corroborates for faster, healthier, and more pleasant routes applied to an efficient urban scenario.

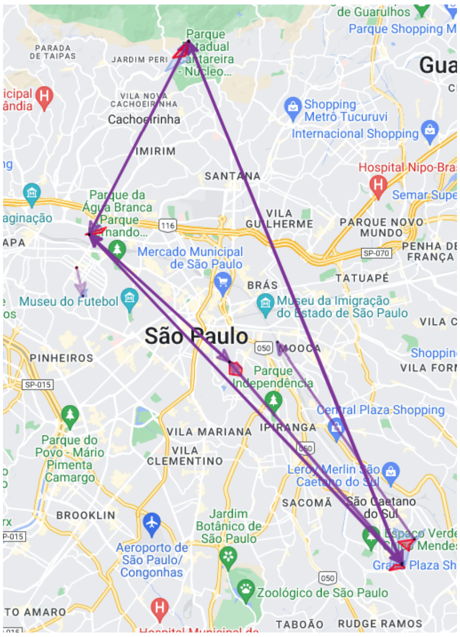


Figure 2. 12 main flows acquired by analysed Twitter Data

The multi-criteria method was employed to merge the set of contextual data for calculating the cost associated with each potential route. The Analytic Hierarchy Process (AHP) was selected to determine the relative importance of each contextual data point at runtime. AHP is advantageous as it incorporates qualitative and quantitative factors into the analysis, offering a structured approach to decision-making in scenarios involving multiple parameters. Accordingly, we attached the AHP methodology to establish the importance levels of each contextual data element.

Our multi-criteria route selection methodology incorporates four distinct user profiles: Worker, Green, Safe, and Tourist, which exemplify standard urban mobility patterns. Each profile is characterized by a unique set of priorities, influencing the construction of a dedicated comparison matrix for each user profile within the route selection service. Specifically, the Worker profile prioritizes Length, Duration, and Traffic to facilitate quicker commutes. Conversely, the Green profile places a higher value on Pollution and Nature, favoring eco-friendly and scenic routes. The Safe profile minimizes crime and accidents and enhances travel safety. Lastly, the Tourist profile emphasizes Attractions to enrich travel experiences.

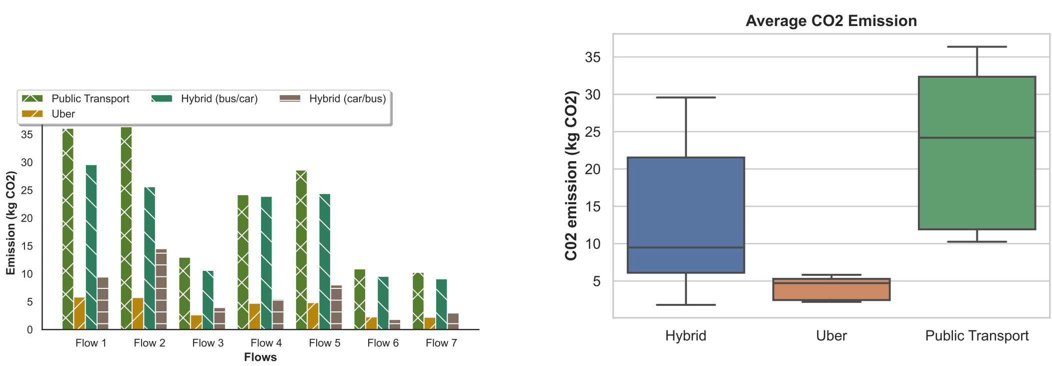
Based on the defined importance of each profile, the route selection methodology systematically ranks alternative routes by analyzing the alignment of criteria indices within each alternative tuple to the pre-assigned criteria weights. Ultimately, the method analyzes and ascertains the optimal route for all user profiles and greedy profiles under a comparative assessment. This profile comparison focuses on selection preferences, prioritizing a single feature with the highest importance, thereby enabling a targeted evaluation of route suitability according to distinct user preferences.

4. Results

This section delineates the principal outcomes of implementing the two methods under review. In the initial evaluation, user data was collected from São Paulo, Brazil, incorporating air pollution calculations to enhance the dataset. Subsequently, route possibilities were generated across varying distances using different modes of transport, facilitating a comparative analysis of the options. In the subsequent evaluation, we built the routes tuple in the London dataset to assess the effectiveness of the selection methods, incorporating a variety of factors to test the robustness and adaptability of the methodologies.

4.1. Multi-modal Analysis

Figure 3(a) depicts the emission values calculated for seven principal mobility flows derived from the distances traveled by different vehicle types along the routes. We converted these distances into fuel consumption estimates, which we incorporated into the overall emission calculations. The analysis provides a comparative perspective on the pollution levels emitted by various modes of transport across these key flows. The data indicates that bus routes produce significantly higher pollutant levels than those involving other forms of transport, with emissions approximately 85% greater than routes utilizing services like Uber, and even more so when compared to hybrid route alternatives. However, it is crucial to consider the higher carrying capacity of buses, which may justify these increased emissions per-passenger basis, in contrast to hired or private vehicles that typically accommodate no more than five passengers. In Figure 3(b), the average emissions for all routes analyzed are presented, highlighting the modes of transportation that contribute most significantly to pollution. Although bus travel sections exhibit notably high emissions, this comparison should also consider the larger number of passengers that public transport can accommodate relative to higher passenger vehicles (HPVs) and private cars.



(a) CO_2 emission in defined routes.

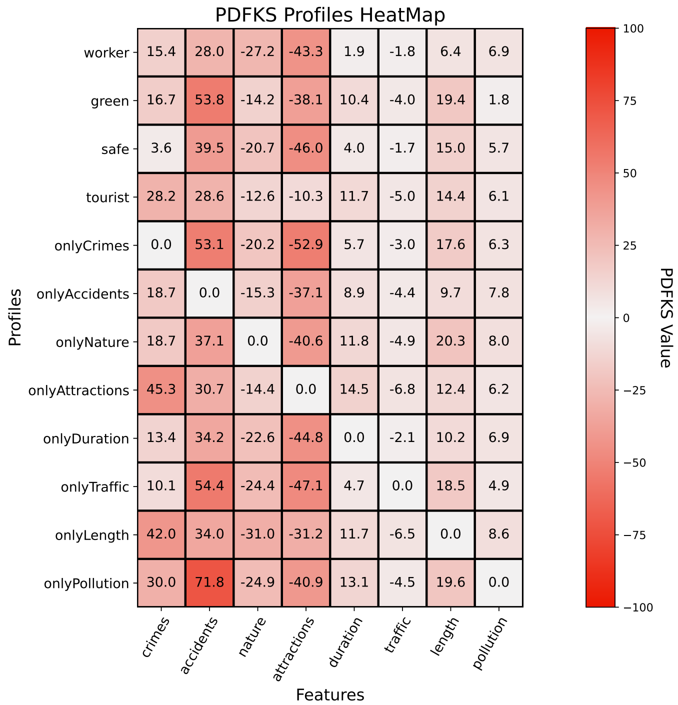
(b) Average CO_2 emission in defined routes.

Figure 3. CO_2 emission calculation results

4.2. Multi-criteria Evaluation

Figure 4 presents the percent deviation from a known standard (PDFKS) matrix, where the rows of the M matrix correspond to various selection profiles (p), encompassing four user profiles and eight greedy profiles. The columns of the matrix detail the trip features (f) under assessment. The values within the PDFKS matrix represent the optimal average value for each profile relative to a predetermined standard (std). For example, the initial index for the Safe profile shows a 3.6% enhancement over the standard in terms of crime rates, underscoring the profile's effectiveness in selecting routes with lower crime rates than others, particularly when compared to a crime-only profile. Additionally, the Safe profile demonstrates a 39.5% variance from the standard average for the accident feature, indicating its secondary importance in route selection. This variance does not suggest superior performance in accident avoidance but instead emphasizes the crime feature's precedence and the data's structuring. For less central attributes, such as the attraction feature, the Safe profile exhibits a -46% deviation, reflecting the reduced impact of this feature on its route selection process.

Contrariwise, the features relating to Nature, Attraction, and Traffic ratio within the PDFKS matrix exhibit negative percentage values, indicating the method's propensity to select routes with higher instances of nature and attractions and a higher traffic ratio, which typically suggests less congestion. This preference results in raw values falling below the established standard, leading to negative percentages. A lower raw value for these features indicates a more optimal route selection. In contrast, for all other features that show positive PDFKS values, the ideal selection strategy seeks to align features with percentages approaching 0%, which denotes a closer match to the desired standard. This approach highlights the method's capacity to optimize route selection by closely matching the most favorable conditions specified by the standard.



Profiles	crimes	accidents	nature	attractions	duration	traffic	length	pollution
worker	15.4	28.0	-27.2	-43.3	1.9	-1.8	6.4	6.9
green	16.7	53.8	-14.2	-38.1	10.4	-4.0	19.4	1.8
safe	3.6	39.5	-20.7	-46.0	4.0	-1.7	15.0	5.7
tourist	28.2	28.6	-12.6	-10.3	11.7	-5.0	14.4	6.1
onlyCrimes	0.0	53.1	-20.2	-52.9	5.7	-3.0	17.6	6.3
onlyAccidents	18.7	0.0	-15.3	-37.1	8.9	-4.4	9.7	7.8
onlyNature	18.7	37.1	0.0	-40.6	11.8	-4.9	20.3	8.0
onlyAttractions	45.3	30.7	-14.4	0.0	14.5	-6.8	12.4	6.2
onlyDuration	13.4	34.2	-22.6	-44.8	0.0	-2.1	10.2	6.9
onlyTraffic	10.1	54.4	-24.4	-47.1	4.7	0.0	18.5	4.9
onlyLength	42.0	34.0	-31.0	-31.2	11.7	-6.5	0.0	8.6
onlyPollution	30.0	71.8	-24.9	-40.9	13.1	-4.5	19.6	0.0

Figure 4. Methodology overview for route selection

The absolute sum technique is utilized across all 12 profiles to evaluate the user-defined profiles by aggregating all elements, irrespective of the sign of the values. The profile that registers the smallest absolute sum within the PDFKS metric is identified as the most effective selection method, reflecting its comprehensive performance across all routes, as depicted in Figure 5. It is noted that greedy profiles, tailored to optimize a single feature, align closely with the standard value (0%), indicative of optimal route selections for that particular feature. Nonetheless, these profiles tend to show larger discrepancies across other features. The profiles we have developed—Worker, Green, Safe, and Tourist—consider multiple features. Different colors within the graphical representation distinguish these profiles to clarify their relationships to specific features and facilitate comparative analysis of their performance across various scenarios.

The Green profile closely aligns with the standard for pollution and outperforms the onlyPollution profile in additional features, registering the second smallest deviation in the nature feature at -14.2%. This performance enhances its capacity to provide a more environmentally friendly routing experience. In contrast, the Safe profile surpasses the onlyCrimes and onlyTraffic profiles with deviations of 3.6% and -1.7%, respectively, with Crime being its primary concern. A higher traffic ratio, associated with slower and potentially riskier routes, allows the Safe profile to demonstrate the most favorable deviation concerning crime safety. The Worker profile excels in its primary areas of concern (onlyLength, onlyDuration, and onlyTraffic) with deviations of 6.4%, 1.9%, and -1.8%, respectively, outperforming standard navigation solutions in these metrics. Meanwhile, the Tourist profile offers superior route options compared to the onlyAttraction profile by deviating less from the ideal attraction value (-10.3%) and showing improved performance in the nature feature (-12.6%). These results show it is optimal for tourists seeking enriched travel experiences, highlighting its effectiveness in balancing aesthetic and environmental considerations in route selection.

Our remarks indicate that while greedy profiles are adept at optimizing their specific prioritized features, they exhibit considerable deviations across secondary features. Notably, the profile exclusively focused on accidents (onlyAccidents) exhibits the most favorable performance within the examined setting, as evidenced by its lowest absolute sum. This finding establishes it as the preferred choice, highlighting the effectiveness of employing an Analytic Hierarchy Process (AHP) profile that allocates balanced weights to each evaluative criterion. This balanced approach outperforms single-criterion-focused profiles and elucidates the superior performance of the onlyAccidents profile. Consequently, within datasets that encompass 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, providing a more holistic approach to feature prioritization and route selection.

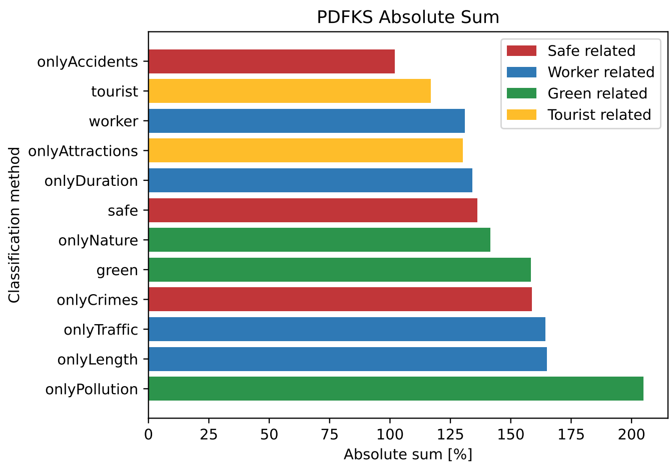


Figure 5. PDFKS absolute sum for each selection profile

5. Discussion

From constructing the method and evaluating its results, an interesting performance emerges when considering various transportation modes and contextual information. This method demonstrates a distinctive ability to effectively integrate multiple transportation preferences and environmental data.

Existing literature does not sufficiently address solutions that utilize contextual information from connected sensors to collect data on urban commutes tailored to users with diverse preferences. The selection method offers a straightforward yet robust approach to integrating profile weights with route weights, facilitating an effective selection process. This method achieves efficiency comparable to traditional routing services but distinguishes itself by accommodating a broader array of route alternatives and richer contextual information.

6. Conclusion and Thesis Impact

This master's thesis introduces two novel route selection methodologies aimed at enhancing urban mobility. The first method utilizes data from location-based social networks to facilitate multi-modal, pollution-aware routing. The second method employs an Analytic Hierarchy Process (AHP) to deliver personalized route options, incorporating a comprehensive assessment of eight distinct features. These methodologies contribute to the development of more cost-effective and healthier travel options, providing a robust framework for mobility planners to promote dynamic and sustainable urban environments. The thesis evaluates the potential of these methods to improve urban mobility by analyzing CO_2 emissions, waiting times, walking distances, cost estimates, and pollution levels for various modes of transport. It underscores the benefits of these advanced routing methods over traditional navigation systems by offering safer and more enjoyable travel experiences, with a particular emphasis on pollution awareness to enhance urban life quality. Table 2 summarizes the research papers published as a result of this master's thesis. Notably, the paper presented at the SBRC 2023 conference received an honorable mention, leading to an invitation to submit an extended version to the Elsevier ad hoc network journal. Additionally, the paper presented at the CoUrb 2022 also garnered an honorable mention award, further affirming the relevance and impact of this research in the field of urban mobility.

Table 2. Summary of Results Published

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

[1] Honorable mention award.

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