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Toward Sustainable Urban Mobility: A Multidimensional Ontology-Based Framework for Assessment and Consensus Decision-Making Using DS-AHP

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Abstract: Urban mobility is a critical aspect of sustainable urban development, with significant environmental, social, and economic implications. Assessing the sustainability of urban mobility systems in order to create more carbon neutral, liveable, healthier, and sustainable cities and neighborhoods for the future requires a multidimensional approach that integrates diverse factors. However, the lack of a unified assessment framework poses challenges in comparing and evaluating different urban mobility projects. This article proposes an ontology for assessing the sustainability of urban mobility systems. This ontology is based on a multidimensional approach that integrates knowledge from experts in transportation engineering, urban planning, environmental science, and social sciences to incorporate existing sustainability indicators and frameworks, as well as domain-specific knowledge. A consensus approach based on Dempster–Shäfer (DS) and Analytic Hierarchy Process (AHP) methods is proposed to account for uncertainties and to allow for the consideration of preferences and ill judgment. Through a case study in Romania, the authors demonstrated the applicability of the proposal to provide a comprehensive and flexible framework for assessing urban mobility sustainability. The proposed ontology provides a valuable tool for policymakers, urban planners, and transportation engineers to make informed decisions towards sustainable urban mobility, and the sensitivity analysis is carried out to demonstrate the robustness of the proposed framework. It has potential for iterative validation and feedback from domain experts, and can serve as a foundation for future research.

Keywords: urban mobility; sustainability; ontology; group decision-making; consensus; uncertainty; Analytic Hierarchy Process (AHP)

1. Introduction

For an extended period, urban mobility has been perceived as the ease of travel from origin to destination within urban areas [1]. However, with advancements in technology, the definition of urban mobility is evolving to accommodate new behaviors in

the utilization of mobility services and the increasing number of stakeholders involved. According to projections from the United Nations report on urbanization prospects, it is anticipated that 66% of the world's population will reside in urban areas by 2050, consequently doubling the demand for passenger movement [2]. This surge in urbanization poses a significant challenge for governments in facilitating mobility for both goods and people, necessitating a multidisciplinary approach in line with sustainability and climate change recommendations.

Over the years, the concept of mobility has broadened in scope with the evolution of metropolises, placing city dwellers and new technologies at the forefront of urban organization. A holistic approach to the concept of mobility, encompassing physical, social, and economic insights, has been articulated in "Mobility and urban form—theoretical issues" by [3]. This definition emphasizes a behavioral understanding of mobility, serving as a foundational premise for advocating for the role of mobility policies in shaping mobility supply to (re)model mobility behavior in a sustainable manner, necessitating a holistic and systematic approach to urban mobility planning.

Information and communication technologies are recognized by [4] as pivotal in fostering sustainable development in mobility. Similarly, Ref. [5] contend that assessing the sustainability of an urban mobility system entails considering a comprehensive set of parameters reflecting its dimensions. In this regard, sustainable urban mobility indicators as highlighted by [6] play a crucial role. Indicators are generally defined as quantitative or qualitative measurements designed to identify significant trends, highlight problems, monitor progress over time towards specific vision objectives, contribute to priority setting, and simplify complex information for both experts and the public [7].

To integrate sustainability requirements into the selection of urban mobility policies, decision-makers, considered experts in the field, must express their preferences using a decision support method [8]. While several approaches to selecting sustainable urban mobility systems exist in the literature [9–11], there remains a lack of common agreement or standards guiding mobility authorities in decision-making processes. Even when such indicators exist, they often suffer from redundancy, incompleteness, heterogeneity, inconsistency, or errors, leading to inappropriate and unsustainable decision-making. Moreover, this scenario often compels experts to express judgments despite lacking sufficient relevant foundations. To address these shortcomings in the planning and implementation of sustainable urban mobility systems, this paper sets out two primary objectives:

- Firstly, to propose a sustainable urban mobility ontology as a powerful tool for representing and sharing knowledge in computer sciences, resolving issues of data consistency, redundancy, and interoperability through a knowledge engineering methodology employing a holistic view of the system;
- Secondly, to define a framework for assessing the sustainability of urban mobility from a decision-making perspective, considering consensus and subjectivity in group decision-making.

The main objective is to enable decision-makers from various urban mobility-related fields to reach a consensus-based method that utilizes DS-AHP on their judgments and preferences regarding the sustainability of target policies, facilitating the selection of the most appropriate policy for a given mobility system. To validate the proposal, a realistic case study in Romania is presented, involving the selection of the best mobility policy from several alternatives for deploying eco-friendly mobility solutions that meet user requirements. The case study demonstrates the effectiveness and efficiency of the proposed approach in facilitating informed and objective decision-making in sustainable urban mobility. The authors state that the proposed ontology and sustainability assessment method are scalable, providing a significant contribution to the field of group decision-making in urban mobility. This improves the effectiveness and efficiency of decision-making processes in this field and has important implications for urban planners, policy-makers, and researchers aiming to promote sustainable mobility solutions in urban areas.

The rest of the paper is structured as follows: Section 2 presents a comprehensive literature review on sustainable urban mobility decision-making, focusing on the challenges encountered by decision-makers in this domain. Section 3 introduces the proposed approach, including the development of the sustainability ontology and DS-AHP method, and provides a detailed explanation of how it works. In Section 3.2, a realistic case study in Romania to validate the proposed approach's effectiveness and efficiency is described, and the sensitivity analysis is carried out to demonstrate the robustness of the proposed system. Finally, the concluding section offers a summary of the proposal and highlights potential directions for future research.

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