ROADS - A Unified Network-Based Framework for Road System Indicators

Keywords: Road networks, Infrastructure resilience, Network analysis, Mobility, Clusters

Extended Abstract

Road transport systems are critical elements when it comes to urban and regional infrastructure, yet their performance and resilience are often assessed using heterogeneous and non-comparable indicators. We propose a unified network-based framework, that is designed to capture structural, functional, and resilience-related properties of road networks through a consistent set of graph-theoretic measures.

Our approach models investigates road systems used internationally, such as CEEQUAL / BREEAM Infrastructure – sustainability assessment and rating methodology for civil engineering and infrastructure projects, Greenroads – international rating system originally developed at the University of Washington for sustainable roadway projects, INVEST (Infrastructure Voluntary Evaluation Sustainability Tool), I-LAST (Illinois – Livable and Sustainable Transportation), GreenLITES (Green Leadership In Transportation and Environmental Sustainability), GreenPave, SUNRA (Sustainability – National Road Administrations) – European ERA-NET framework, iRAP (International Road Assessment Programme) – Star Rating. We also included in our analysis documents like: the European Green Deal and Sustainable and Smart Mobility Strategy. The methodology builds a knowledge base from conceptual frameworks, technical codes, strategies, legislation, and reference models, which is then processed using an AI language model to semantically analyze and pre-identify macro-objectives. These objectives are refined through network analysis (connectivity, centrality, modularity, and robustness indicators), literature review, and the Delphi Fuzzy method, leading to validated macro-objectives and their associated indicators. We demonstrate the framework's application using different case studies of a regional road network (i.e. Spain road system), analyzing dynamic scenarios. The results confirm that AI-driven analysis accelerates the identification of sustainability objectives and ensures broader coverage of heterogeneous documents. Nevertheless, the interpretability of outputs requires careful expert validation. By applying the Delphi Fuzzy method, experts contribute to refining objectives, weighting indicators, and reducing ambiguity in the mapping process. This hybrid approach – combining machine learning with participatory methods – strengthens robustness and legitimacy. Furthermore, the integration of network analysis with fuzzy logic highlights systemic relationships between macro-objectives, facilitating the detection of synergies and potential conflicts in policy implementation. This research demonstrates the feasibility of combining AI semantic analysis, Fuzzy Cognitive Maps, and Delphi expert validation to build a structured framework for sustainability assessment in transportation and infrastructure projects. The methodology not only accelerates knowledge integration but also enhances transparency, adaptability, and reliability in defining macro-objectives and indicators. Future work should expand the knowledge base, validate the model across case studies, and test scalability at different governance levels (EU, national, and regional). The approach holds potential for becoming a decision-support tool for policymakers and infrastructure managers aiming to align strategies with sustainable development goals.

References:

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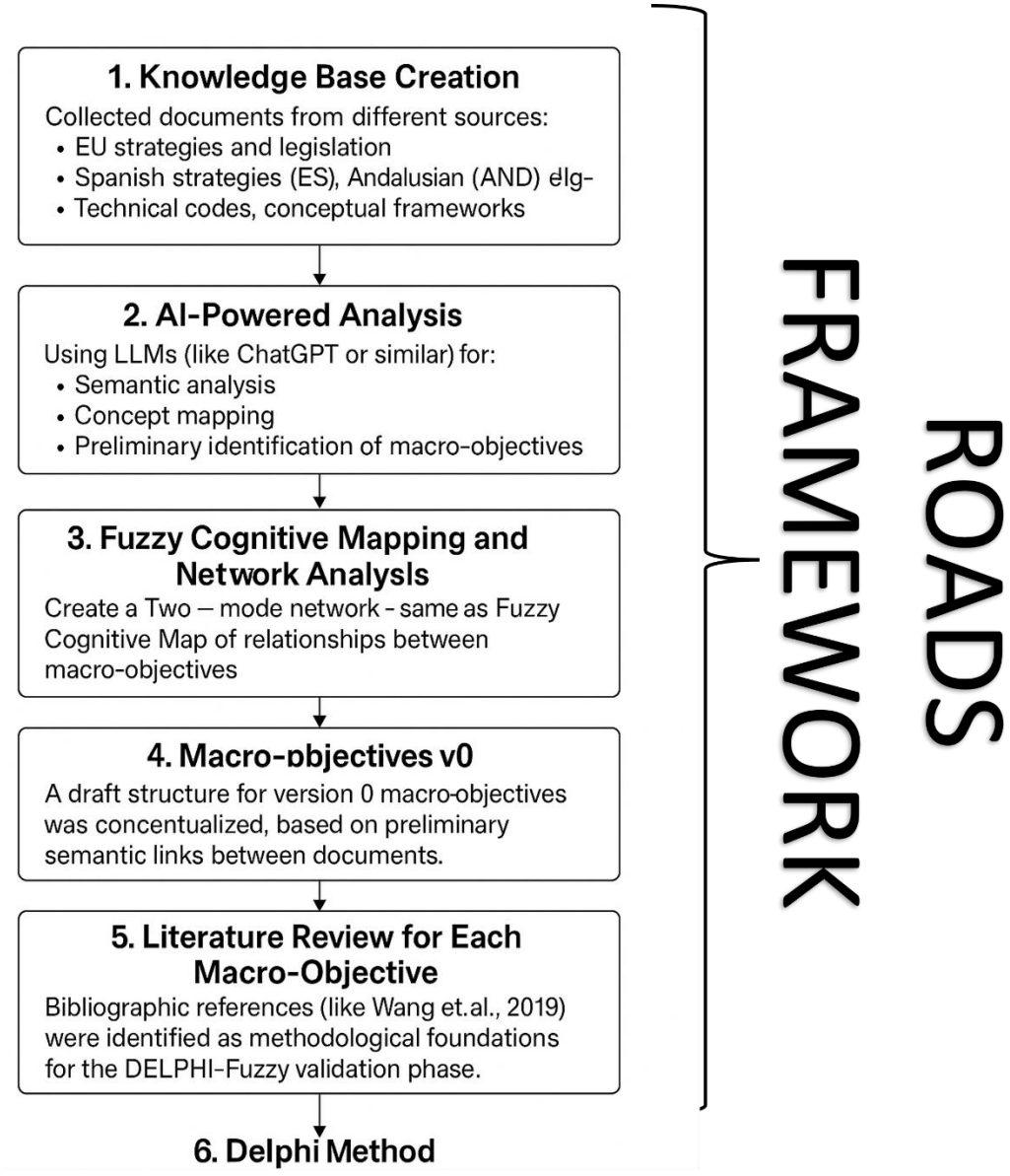

Figure 1. Logical process for knowledge integration, AI semantic & network analysis, and Delphi-Fuzzy validation of macro-objectives