University of Pardubice
Faculty of Transport Engineering

Multi-Criteria Decision-Making Methods in Last-Mile Delivery

DOCTORAL THESIS STATEMENTS

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1 STATE OF THE ART

City Logistics involves organizing and managing the movement of goods within urban environments in a way that eases traffic pressures, lowers environmental and energy impacts, and still supports efficient business operations and reliable delivery services (Rodrigue et al., 2017).

On the other side, **Last-Mile Delivery (LMD)** can be defined as the last step of the entire delivery process, where the shipments are delivered to the final customer's address using one of the most suitable delivery modes (electric vehicle, drone, cargo bike, autonomous delivery robot and others) in the exact urban area.

Electric Vehicle (EV) is a vehicle in which some or all the driving energy is supplied through electricity from a battery (Richardson, 2013).

Drone or Unmanned Aerial Behicle (UAV), is an aircraft that operates without a human pilot on board (Laghari and Nayak, 2023). It can be controlled remotely or fly autonomously using onboard sensors, software, and communication systems.

Autonomous Delivery Robot (ADR) is a pedestrian-sized autonomous machine designed for final-leg logistics. It carries packages directly to customers and makes navigational decisions by combining onboard sensors, artificial intelligence, and mapping capabilities (Chen et al., 2021).

Cargo bike is a modified bicycle with a cargo box, enabling it to transport various goods and loads (Dybdalen and Ryeng, 2021).

E-cargo bike is a cargo-carrying bicycle equipped with an electric motor to assist the rider, especially when transporting heavier loads (Carracedo and Mostofi, 2022).

Decision-making in daily life and business is often influenced by many criteria, making it difficult to identify the best option. To address this, researchers have developed various MCDM methods that evaluate alternatives across multiple qualitative and quantitative parameters (Seydel, 2006). Real-world decisions are typically complex, interrelated, and cannot be reduced to a single criterion (Zavadskas & Turskis, 2010). Many criteria conflict with one another, are hard to quantify, and require expert judgment, which can strongly influence final rankings. Since the 1980s, the MCDM field has grown significantly and continues to advance.

Regarding the last-mile delivery problems, the scientific literature reveals four main problems: 1) **Vehicle Routing Problems (VRP) 2) Location evaluation problems, 3) Last mile delivery mode selection problem and 4) Pick-up and delivery problems**. The dissertation addresses the group of problems related to the pick-up and last-mile delivery. Since the assessing the LMD is a multidisciplinary problem and various criteria need to be included, this is a typical problem suitable for MCDM methods.

Based on the comprehensive assessment of the current state of the field, the following points for improvement have been identified, and the conclusion has been reached:

a) The **LMD is a typical MCDM problem** since numerous criteria are involved, such as economic, environmental, technical, and social.
b) Most papers from the literature deal with the **LMD mode evaluation and selection problems, vehicle routing problems, location selection problems, and pick-up and delivery problems**.
c) Among many challenges, the **pick-up and last-mile delivery issues**, especially in urban areas **have been seen as a potential area for improvement.**
d) **A lack of comprehensive method** that combines the criteria that are essential for the last-mile delivery into a robust decision-making framework.
e) Although there are many **MCDM** methods used in the **LMD**, the **new approach and fresh perspective is always a necessity to broaden and strengthen the existing knowledge.**

By analysing the structure of the **MCDM** methods it can be concluded that all these methods are mostly based on similar principles of decision-making. The existing **MCDM** methods are strong and trustable. However, there is always a space for the improvement. Based on the analysis, the author of this dissertation tries to approach to the **MCDM** field from a different perspective.

Therefore, there is a lack of comprehensive method that addresses these limitations:

1) **Complexity in Problem Structuring**
2) **One Normalization Technique Utilization**
3) **No possibility of changing the normalization technique**
4) **Sensitivity testing in terms of robustness**

2 RESEARCH OBJECTIVES

Based on the analysis of the current state of the issue under consideration, the main objective of the dissertation is defined (Figure 1):

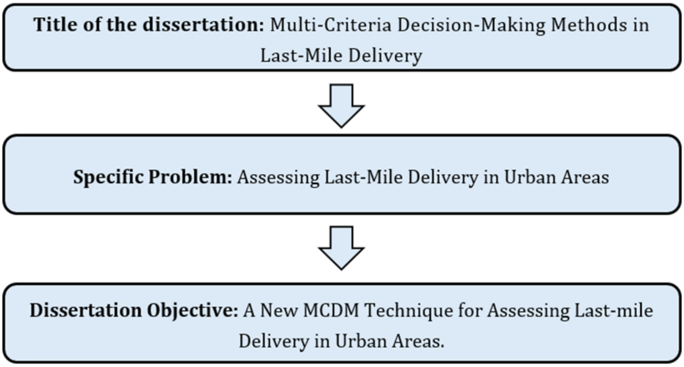

Figure 1. Dissertation Objective

Solving the mentioned problem can significantly assist the postal network operators improve the delivery process in urban areas. In addition, it will contribute to better organization of future last-mile delivery activities in urban areas.

To fulfil the dissertation objective, it is necessary to:

1) Analyse the current state of last-mile delivery.

2) Assess the opportunity for improvement in LMD.

3) Propose a new MCDM technique for assessing the LMD in urban areas.

4) Implement and verify the developed MCDM technique in a real-life case study.

3 RESEARCH METHODOLOGY

This dissertation is organized according to a logical and methodical research framework designed to ensure systematic development, verification, and presentation of a novel **MCDM** technique for assessing LMD in urban areas. The methodological steps are presented in Figure 2.

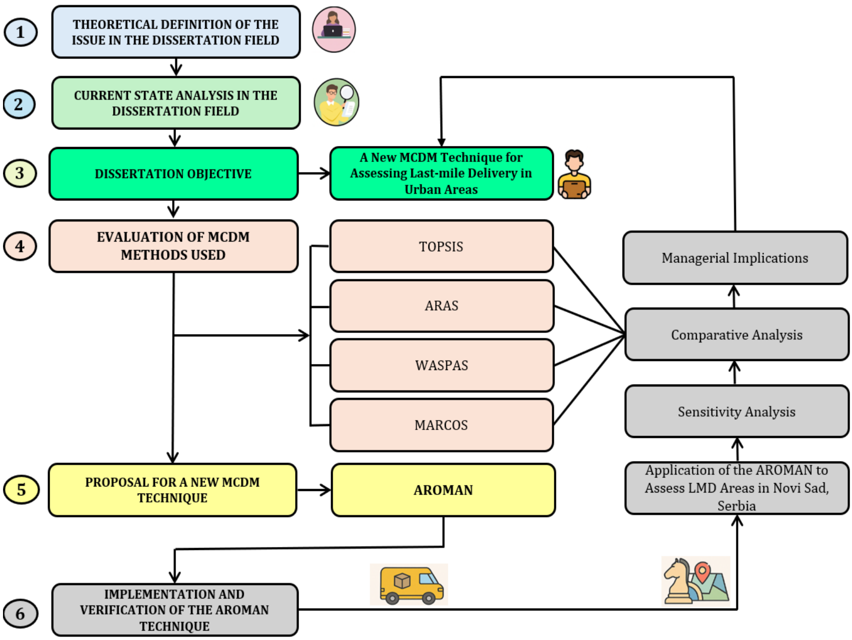

Figure 2. Methodological Structure

Step 1 theoretically defines the area being addressed such as basic terms and concepts of city logistics and last-mile delivery, last-mile delivery modes, theoretical background of multi-criteria decision-making theory and existing MCDM methods. Its role is to provide conceptual clarity, outline the scope of the research area, and prepare a theoretical base upon which the dissertation's further developments rest

Step 2 analyses the MCDM methods and their usage to various problems related to LMD. The analysis highlights shortcomings, and opportunities for innovation—thereby establishing the necessity for the research. This step is essential for motivating the development of a new MCDM technique tailored to the complexities of urban LMD assessment.

The main objective of the dissertation "**A new MCDM technique for Assessing Last-Mile Delivery in Urban Areas**" is defined in **Step 3**. This step represents the central part of the dissertation.

Step 4 is the evaluation of the MCDM methods used. The dissertation presents an in-depth examination of general research methods and several widely used **MCDM** methods, including TOPSIS, ARAS, WASPAS, and MARCOS. These methods are applied to the LMD assessment problem to establish comparative benchmarks. This step ensures that the research does not operate in isolation but instead positions the new technique within the broader landscape of MCDM methodologies.

Based on the findings from the application of existing methods, the dissertation introduces the **AROMAN** method as a novel MCDM technique. This is presented in **Step 5.** This methodological step is the most essential to the dissertation's contribution and presents the conceptual development, mathematical formulation, and theoretical justification of the **AROMAN** approach. The proposal is grounded in the limitations identified in existing methods and is designed to more accurately capture the complexities of evaluating urban LMD scenarios. The new method is developed rigorously to ensure methodological robustness and practical relevance.

Step 6 of the methodological structure is the implementation and Verification of the New AROMAN MCDM technique. Once the AROMAN technique is formulated, it is implemented to a real-world case study. In addition, its verification is done by applying a sensitivity analysis, and the comparative analyses. Finally, this step suggests managerial implications. It will be explained more in detail in the next chapter.

4 ACHIEVED RESULTS

The achieved results follow the logical sequence of the dissertation. **The initial analysis identified a key research gap: the necessity for new MCDM method to solve the group of problems (Last-Mile Delivery Area Assessment) related to Pick-Up and LMD.**

Twelve delivery areas (DAs) in Novi Sad, Serbia, were assessed and compared based on the following criteria: *Number of planned parcels per day (C1), Number of collected parcels from the customer's address per day (C2), Number of delivered parcels per day (C3), Number of failed deliveries (C4), Number of kilometres driven per day by a deliveryman (C5), and Number of stops for pick-up and delivery (C6).*

The AROMAN method ranked the delivery areas as follows (Figure 3): *DA8 > DA4 > DA3 > DA9> DA1 > DA12 > DA2 > DA5 > DA7 > DA11 > DA6 > DA10.* The best ranked delivery area is the delivery *DA8* (Novi Sad - Limani), followed by *DA4, DA3, DA9*, etc. The worst-ranked delivery area is the *DA10* (Petrovaradin-Sremski Karlovci).

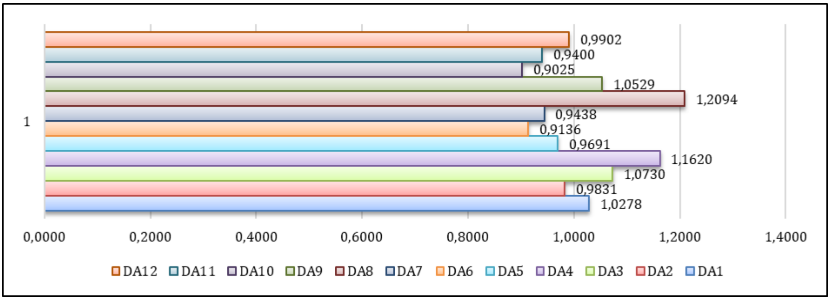

Figure 3. Rank of the Delivery Areas By AROMAN

To test the robustness of the proposed AROMAN method, the **sensitivity analysis (SA)** is performed. The author tested the variations of the coefficient degree λ in the final ranking. The results are shown in Figure 4.

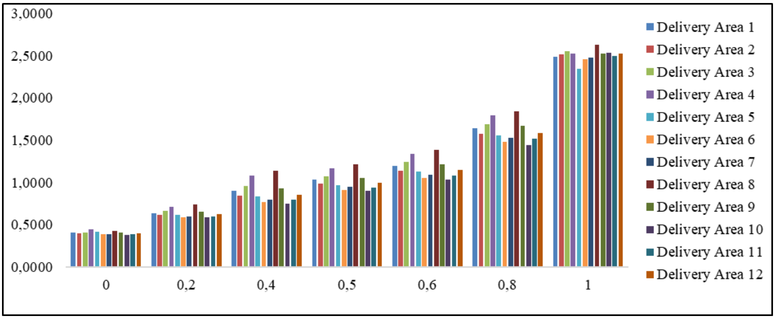

Figure 4. Sensitivity Analysis

A comparative analysis (**CA)** is performed to check the results that are obtained by the AROMAN method. The same study is performed by some other existing state-of-the-art MCDM methods such as ARAS, TOPSIS, MARCOS, and WASPAS. The results are presented in Figure 5.

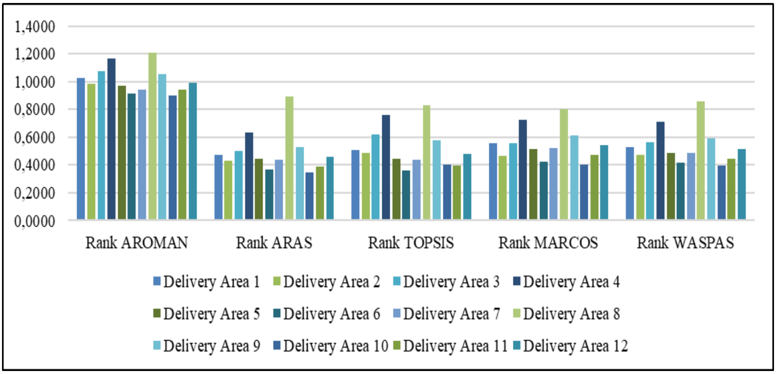

Figure 5. Comparative Analysis

5 AUTHOR'S CONTRIBUTIONS

The dissertation provides both the theoretical and practical contributions as well as future research directions.

5.1 Theoretical Contributions

The theoretical contributions are *a) Normalization-Adaptive Framework for MCDM; b) An Original Final Ranking Equation; c) Broader Theoretical Implications and d) Citations from recognized world-class researchers working in this area.*

5.2 Practical Contributions

The practical contributions are *a) The New Method Validation in a Real Operational Setting; b) Broad Applicability and Flexible Integration Across Diverse Decision Problems; c) Flexibility and Ease of Use and d) The New Method is Used by Other Research Teams in the World.*

5.3 Future Directions

Future directions of the AROMAN method could be:

1) To extend it within the fuzzy environment and apply to various contexts.

2) To test the methodology coupling different combinations of the normalization techniques besides linear and vector.

3) To compare the methodology with the future techniques based on two normalization procedures.

4) To combine the AROMAN method with Geographic Information Systems (GIS) to create a spatially enhanced decision-making model.

REFERENCES

Rodrigue, Jean-Paul, Laetitia Dablanc, A. Conway, G. Giuliano, J. S. Lee, and T. O'Brien, (2017). 1.1-What is City Logistics? In City Logistics: Concepts, Policy and Practice. Routledge.

SEYDEL, J. (2006). Data envelopment analysis for decision support. Industrial Management & Data Systems, 106(1), 81-95. http://doi.org/10.1108/02635570610641004

ZAVADSKAS, E. K., & TURSKIS, Z. (2010). A new Additive Ratio Assessment (ARAS) method in multicriteria decision-making, Technological and Economic Development of Economy, 16(2), 159-172, https://doi.org/10.3846/tede.2010.10

RICHARDSON, D. B. (2013). Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. Renewable and Sustainable Energy Reviews, 19, 247-254. https://doi.org/10.1016/j.rser.2012.11.042

LAGHARI, A. A., & NAYAK, S. K. (2023). Unmanned aerial vehicles: A review. Heliyon, 9(1), e12560. https://doi.org/10.1016/j.heliyon.2022.e12560

CHEN, C., DEMIR, E., HUANG, Y., & QIU, R. (2021). The adoption of self-driving delivery robots in last-mile logistics. Transportation Research Part E: Logistics and Transportation Review, 146. https://doi.org/10.1016/j.tre.2020.102214

DYBDALEN, ÅDNE, EIRIN OLAUSSEN RYENG. (2021). Understanding how to ensure efficient operation of cargo bikes on winter roads. Research in Transportation Business & Management, (), –. http://doi.org/10.1016/j.rtbm.2021.100652

CARRACEDO, D., & MOSTOFI, H. (2022). Electric cargo bikes in urban areas: A new mobility option for private transportation. Transportation Research Interdisciplinary Perspectives, 16, 100705. https://doi.org/10.1016/j.trip.2022.100705

6 AUTHORS PUBLICATIONS

1. **BOŠKOVIĆ**, **Sara**, RADONJIC, Vesna, RALEVIĆ, Predrag, DOBRODOLAC, Momčilo & JOVČIĆ, Stefan. Selection of Mobile Network Operator Using the CRITIC-ARAS Method. International Journal for Traffic and Transport Engineering (IJTTE), 2021, vol. 11(1), pp. 17-29, doi: https://doi.org/10.7708/ijtte.2021.11(1).02
2. **BOŠKOVIĆ, Sara**, ŠVADLENKA, Libor, JOVČIĆ, Stefan, DOBRODOLAC, Momčilo, SIMIĆ, Vladimir, & BAČANIN, Nebojša. An Alternative Ranking Order Method Accounting for Two-Step Normalization (AROMAN)—A Case Study of the Electric Vehicle Selection Problem. IEEE Access, 2023, vol. 11, pp. 39496-39507, Q2, doi: https://doi.org/10.1109/ACCESS.2023.3265818
3. **BOŠKOVIĆ, Sara**, ŠVADLENKA, Libor, JOVČIĆ, Stefan, DOBRODOLAC, Momčilo, SIMIĆ, Vladimir, & BAČANIN, Nebojša. A New FullEX Decision-Making Technique for Criteria Importance Assessment: An Application to the Sustainable Last-Mile Delivery Courier Selection. IEEE Access, 2023, vol. 11, pp.137426-137436, Q2, doi: https://doi.org/10.1109/ACCESS.2023.3339580
4. **BOŠKOVIĆ, Sara**, JOVČIĆ, Stefan, SIMIĆ, Vladimir, ŠVADLENKA, Libor, DOBRODOLAC, Momčilo & BAČANIN, Nebojša. A New Criteria Importance Assessment (CIMAS) Method In Multi-Criteria Group Decision-Making: Criteria Evaluation For Supplier Selection. FACTA UNIVERSITATIS (Series: Mechanical Engineering), 2023, Q2, link:

https://casopisi.junis.ni.ac.rs/index.php/FUMechEng/article/view/ 12018

5. **BOŠKOVIĆ, Sara,** ŠVADLENKA, Libor, DOBRODOLAC, Momčilo, JOVČIĆ, Stefan, & ZANNE, Marina. An Extended AROMAN Method for Cargo Bike Delivery Concept Selection. Decision Making Advances, 2023, vol. 1(1), pp. 1-9, doi: https://doi.org/10.31181/v120231
6. ŠVADLENKA, Libor, **BOŠKOVIĆ, Sara,** JOVČIĆ, Stefan, SIMIĆ, Vladimir, KUMAR, Shashank & ZANNE, Marina. Third-Party Logistics Provider Selection for Sustainable Last-Mile Delivery: A Case Study of E-Shop in Belgrade. Journal of Urban Development and Management, 2023, vol. 2(1), pp. 1-13, doi: https://doi.org/10.56578/judm020101
7. ČUBRANIĆ-DOBRODOLAC, Marjana, JOVČIĆ, Stefan, **BOŠKOVIĆ, Sara** & BABIĆ, Darko. A Decision-Making Model for Professional Drivers Selection: A Hybridized Fuzzy-AROMAN-Fuller Approach. Mathematics, 2023, Q3, vol. 11(13), doi: https://doi.org/10.3390/math11132831
8. DOBRODOLAC, Momčilo, **BOŠKOVIĆ, Sara,** JOVČIĆ, Stefan, & LAZAREVIĆ, Dragan. Sustainable Delivery Model Selection Using AROMAN Approach. Decision Making Advances, 2023, vol. 2(1), pp: 73-82, doi: https://doi.org/10.31181/dma21202429
9. **BOŠKOVIĆ, Sara,** ŠVADLENKA, Libor, JOVČIĆ, Stefan, SIMIĆ, Vladimir, DOBRODOLAC, Momčilo, ELOMIYA, Akram. Sustainable Propulsion Technology Selection in Penultimate Mile Delivery using the FullEX-AROMAN

Method. SocioEconomic Planning Sciences, 2024, vol. 95, pp. 102013, Q2, doi: https://doi.org/10.1016/j.seps.2024.102013

10. NINOVIĆ, Milena, DOBRODOLAC, Momčilo, **BOŠKOVIĆ, Sara,** DUPLJANIN, Đorđije, LAZAREVIĆ, Dragan, & DUMNIĆ, Slaviša. An Extended FullEX Method: An Application to the Selection of Online Orders Distribution Modes Based on the Shared Economy. Journal of Theoretical and Applied Electronic Commerce Research, 2025, 20(3), 207. doi: https://doi.org/10.3390/jtaer 20030207
11. DOBRODOLAC, Momčilo, **BOŠKOVIĆ, Sara**, JOVČIĆ, Stefan, & LAZAREVIĆ, Dragan. Izbor održivog modela dostave korišćenjem AROMAN višekriterijumske analize. Simpozijum o novim tehnologijama u poštanskom i telekomunikacionom saobraćaju, 2023, pp. 99, link: https://ebooks.sf.bg.ac.rs/index.php/1/catalog/book/22
12. **BOŠKOVIĆ, Sara,** ČUBRANIĆ-DOBRODOLAC, Marjana, ZANNE, Marina, ŠVADLENKA, Libor & JOVČIĆ, Stefan. Logistician Selection Problem in the Maritime Sector Using the Multi-Criteria Decision-Making Methods. 21st International Conference on Transport Science (ICTS 2024), 2024, vol. 83, pp. 335-342. doi: https://doi.org/10.1016/j.trpro.2025.02.044
13. **BOŠKOVIĆ, Sara,** ŠVADLENKA, Libor, DOBRODOLAC, Momčilo, JOVČIĆ, Stefan, CHATTERJEE, Prasenjit, & BAUER, Libor (2025). Hydrogen Refuelling Station Selection Using the AROMAN Method: A Case Study in the Pardubice

Region. Transportation Research Procedia, 2025, vol. 91, pp. 99-106. https://doi.org/10.1016/j.trpro.2025.10.014

ABSTRACT

This dissertation examines the Last-Mile Delivery (LMD) problem through a Multi-Criteria Decision-Making (MCDM) approach and introduces a new method for more reliable LMD assessment. It evaluates the limits of current methods and develops a structured decision-support framework, using benchmark techniques to inform a novel model with adaptive normalization and a new final-ranking procedure. The method is tested in a real LMD setting in Novi Sad, Serbia, where twelve delivery areas are assessed using criteria such as parcel flows, failed deliveries, distance, and number of stops, showing strong robustness, practical value, and managerial relevance.