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LOGISTICS MODELLING OF ELECTROMOBILITY-BASED PARCEL DISTRIBUTION IN URBAN ENVIRONMENT

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Various industries increasingly adopt sustainable and eco-friendly technologies to distribute finished goods in today's globalized world. In Miskolc, electromobility and logistics play a crucial role in ensuring the efficient supply of these products. This study introduces a novel optimization model for sustainable urban parcel delivery that integrates electromobility and green logistics. The model applies a genetic algorithm to optimize resource allocation and delivery routes, offering control over electric vehicle usage and responsiveness to varying customer demands and cost constraints for the infrastructural characteristics of a disadvantaged Miskolc region. Using this method, the research demonstrates improved sustainability, cost-effectiveness, and flexibility in urban logistics—particularly in response to the challenges posed by the rise of e-commerce. The findings contribute to the advancement of eco-friendly and efficient distribution systems.

Keywords: supply chain, logistics, electromobility, parcel distribution, general modelling

HIGHLIGHTS

- Integrated EV-based model achieves significant urban delivery cost reductions via spatial clustering and cost analysis.
- Holistic framework unifies vehicle choice, route planning, and clustering for sustainable urban parcel distribution.
- The model demonstrates practical relevance in Miskolc, where EV infrastructure is still developing.
- Promotes sustainable urban logistics by combining operational cost control with ecological responsibility, in line with EU goals.

1 Introduction

The diversity of supply chain processes in logistics requires modern methods and strategies, especially in the fields of electromobility and parcel distribution. These approaches not only address current challenges but also help define future logistics concepts.

There are many different challenges in logistics, which are managed according to the 7R rule. This principle states that customer orders must be fulfilled with the right product, in the right quantity, of the right quality, at the right place, at the right time, at the right cost, and for the right customer. Third-party logistics (3PL) and fourth-party logistics (4PL) providers cover the entire supply network, including the key areas of procurement, inventory management, manufacturing, distribution, and reverse processes [1].

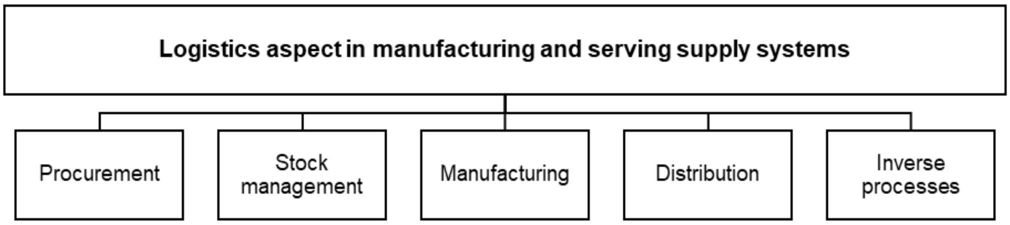

Fig. 1. Interpreting a logistics aspect in manufacturing and serving systems

As Fig. 1. shows, the supply chain can be interpreted as a system of multiple market participants in which individual supply conditions have a significant impact on companies' manufacturing and service processes. Logistics has undergone significant changes over recent decades, driven by the implementation of new global transport technologies [2].

In today's market, various sectors of manufacturing and service industries are developing more efficient and environmentally responsible solutions for the distribution of finished products. Electromobility and logistics play a crucial role in the supply of these products in cities like Miskolc. The growth of e-commerce has introduced new objectives for designing urban delivery solutions for logistics and delivery companies.

The identified research challenges underscore the necessity of comprehensively understanding and advancing last-mile delivery processes within modern urban logistics systems, in response to the rapidly evolving demands of contemporary supply chains.

Due to the large amount of research on the related topics, the most relevant literature must be summarized to better understand the operation of these delivery systems before elaborating on model and optimization solution concepts. The complexity of supply chain systems is related to a hyperconnected global supply chain network, which requires up-to-date methods and smart solutions to define the optimal system parameters for the efficient operation of the processes.

The second objective of this paper is to develop a general operational cost-based model for electromobility and finished product delivery. This paper is organized as follows: Section 2 presents a literature review, which summarizes the research results related to electromobility and logistics in the delivery of finished goods and their supply chain operation. Section 3 describes the general modelling of electromobility and logistics in parcel distribution between different districts (clusters) of Miskolc city, focusing on the operational cost of delivery. Section 4 presents a case study on the applicability of the model. Conclusions and future research directions are discussed in Section 5.

1.1 Literature review

Electromobility and logistics have emerged as a key research focus on sustainable urban delivery systems. In recent years, numerous scientific studies have explored the integration of electric vehicles (EVs) into last-mile logistics, with an emphasis on improving efficiency, reducing emissions, and enhancing cost-effectiveness. These systems require smart and up-to-date methods to understand how the Electric Vehicle (EV) solutions integrate into delivery processes, especially infrastructural characteristics of a disadvantaged Miskolc region.

The systematic literature review is based on SLR-PDSA-based testing protocol, which helps to increase the visibility and quality of the literature review, identify problem gaps, and eliminate irrelevant and inappropriate research efforts [3,4].

Research conducted in European countries highlights the potential of electromobility to transform delivery systems by lowering operational costs and supporting environmentally sustainable solutions. Several studies analyze the design, manufacturing, and operational integration of electric vehicles, which form the technological foundation for urban logistics systems [5,6]. These findings contribute to a better understanding of EV applications and their environmental impact [7,8,9].

In addition, it is important to explore battery cycle life [10], increase battery capacity to meet performance requirements, and continuously improve operating conditions in order to reduce capacity degradation and losses [11]. These aspects are directly linked to the economic and technical feasibility of EV-based delivery operations. As charging infrastructure plays a decisive role in system viability, recent research proposes strategic planning frameworks for optimal charger placement along delivery routes [12,13,14,15], including the use of location optimization models to support logistics decision-making [16].

Additionally, behavioral analyses have been addressed to examine social vehicle parameters, including the numbers of vehicles in households, the types of vehicles, to describe the traffic behavior patterns and usage trends for future transport design approaches [17].

From a methodological standpoint, the literature provides a robust set of optimization models, heuristics, and simulation techniques aimed at solving complex logistics problems [4]. Simulation-based techniques have proven particularly useful in evaluating EV charging strategies, thermal behavior, and system-wide performance under real-world conditions [18]. Thermal simulations forecast the average coolant battery temperature and the battery level [19]. The quasi-dynamic simulation shows both the most robust aspects and the weakest bottlenecks of the vehicle-grid systems [20]. These models inform operational decision-making by identifying bottlenecks and evaluating cost-related parameters.

Mathematics support to design complex supply chain mathematical models by improving the transparency of calculations and facilitating deeper understanding and effective problem-solving. These models are applied in multi-objective optimization problems to balance conflicting goals such as cost, time, and energy consumption [21]. The Electric Vehicle Smart Charging Reservation algorithm has been shown to improve battery efficiency and optimize charging intervals [22]. Furthermore, genetic algorithms support the implementation of intelligent vehicle-to-grid (V2G) strategies and electric vehicle (EV) charging management, contributing to extended battery life and the overall stability and health of the system [23].

Fig. 2. provides a summary of the systematic literature review findings, offering a clear overview of the most relevant keywords and research topics. Despite the literature, many research gaps remain. Most of the studies focus on vehicle technology, battery management, or charging infrastructure, with limited attention to integrated, cost-based transport models tailored to disadvantaged urban regions. Furthermore, few studies consider real urban segmentation (for example, district-level delivery clusters) in their modelling framework. The available studies also fail to provide a coherent approach that directly links economic performance to modelling the operational costs of urban-level delivery systems.

From a policy perspective, EU directives have focused on reducing CO2 emissions through different strategic concepts and sustainability guidelines, e.g. for Japan, the target is set for 2030, and for the United States, up to 2050 [24]. This is essential for enabling the adoption of EVs in standard operating environments, especially in low-density urban regions [25].

These relevant articles were published within the last five years. This finding highlights the scientific potential of electromobility and logistics in finished product delivery systems and their developments. Most of the studies and articles address decision-making support for urban delivery logistics processes [26].

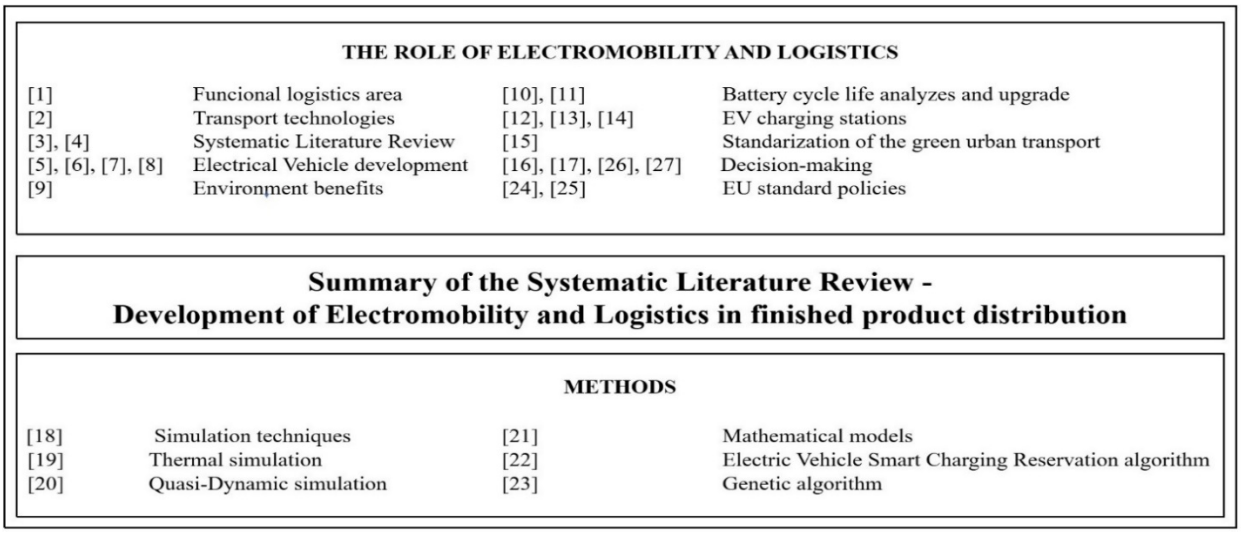

Fig. 2. Summary of the systematic literature review findings

In summary, while previous research provides valuable insights into EV technologies, battery systems, and charging infrastructure, there is limited focus on integrated, cost-oriented delivery logistics models tailored to disadvantaged urban areas. Few studies address spatial clustering or link operational costs directly to delivery system design.

This paper aims to address these gaps by proposing a generalized operational cost-based model for electromobility-integrated parcel distribution, focusing on urban areas such as Miskolc. The model includes delivery clustering and applies a genetic algorithm to optimize delivery efficiency and vehicle utilization under region-specific constraints.

2 Materials and methods

2.1 Modelling of electromobility and logistics in parcel distribution

The general protocol for traditional parcel handling processes in urban logistics can be structured into the following key stages:

- Request: Receive the delivery request status before the delivery provider picks up the package.
- Pick-up load tour: Status update for picking up the package that is en route to the Logistic center.
- Logistics center: Receiving the incoming parcel and processing it at the local operations center.
- Miskolc Operations Centre: Local delivery center that assigns packages to the corresponding delivery clusters and vehicles for each tour.
- Delivery load tour: Delivery courier transports the package to the recipients.
- Required address: The destination location of the customer, the final delivery address of the products.

The parcel delivery operations are structured according to service clusters, which correspond to the administrative districts of Miskolc, Hungary. As the Fig. 3. represent, these clusters are the followings: Avas, Belváros, Berekalja, Bulgárföld, Csabai kapu, Diósgyőr, Dél-Kilián, Egyetemváros, Görömböly, Hejőcsaba, Kilián-dél, Kilián-észak, Martin-Kertváros, Miskolctapolca, Pereces, Selyemrét, Szirma, Szondi telep, Tetemvár, Újdiósgyőr, Vargahegy, and Vasgyár (C1–C22).

The analysis focuses on the parcel delivery processes of the Miskolc Operations Center, which is responsible for processing customer requests (delivery points) and allocating the appropriate delivery resources (attributes) for each route. This center serves as a critical node for synchronizing urban delivery flows, resource planning, and electromobility integration within the city-wide distribution framework.

The central concept involves a delivery operations center that is connected to all participants within the delivery supply chain network. This center is responsible for fulfilling end-user demand by utilizing requested attributes and allocated resources, while leveraging the benefits of electric vehicles (EVs).

The problem is addressed by the delivery provider, where the requested finished products are delivered through a specified operations center, as a distribution hub. This approach is based on the principle of just-in-sequence supply design methods.

The underlying demand includes the following assumptions: identifying the best vehicle routes to meet customer demand using electric vehicles (EVs), achieving lower operating costs, especially in urban environments, through policies to support emission reductions, and announcing possible government funding incentives for EVs.

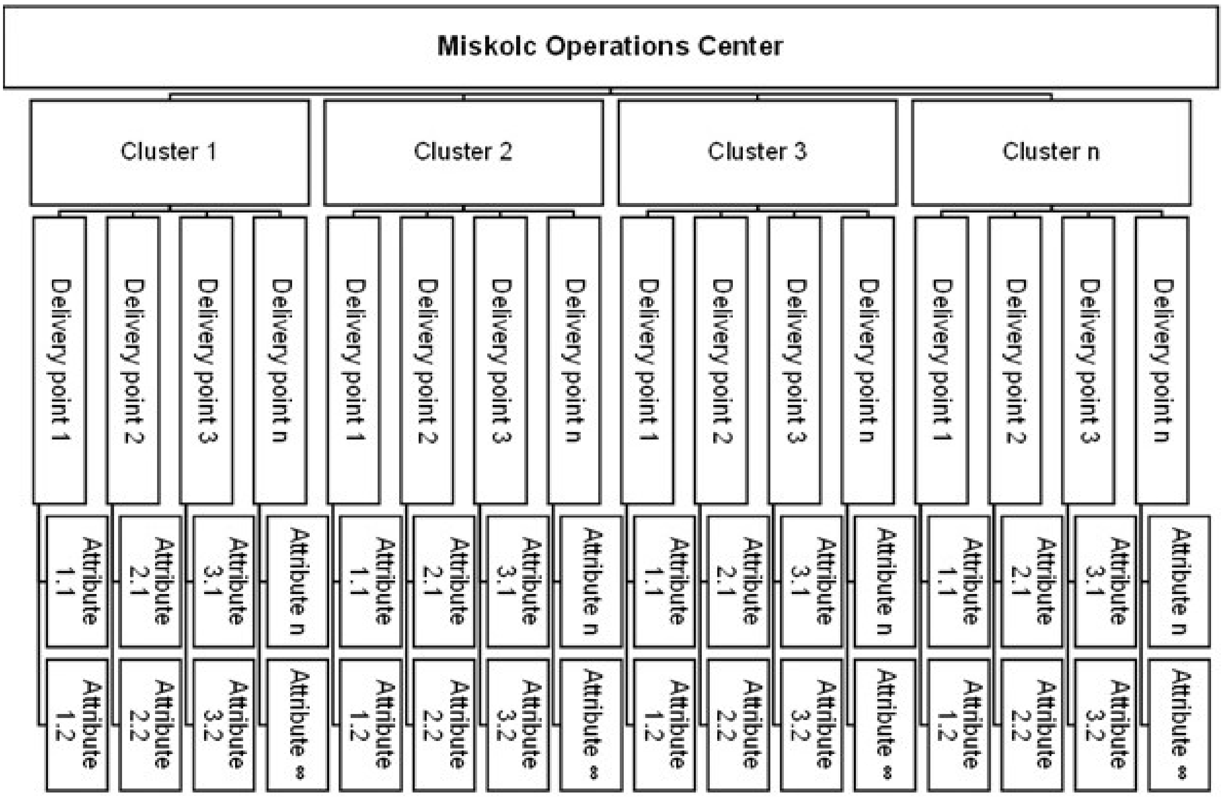

Fig. 3. Hierarchy model of the Miskolc package delivery processes

Based on these considerations, the following supply chain attributes, considered as operation costs (OP) components, are defined for the delivery service processes using traditional and electric vehicles (EVs) in Miskolc:

- Supply Chain Material Flow Costs
  - Package delivery supply costs
    - Specific vehicle cost
      - Traditional
      - EV
    - Specific costs of each driver line
      - Insurance
      - HR
      - Unexpected fares (parking, entry passes)
    - Specific costs of the vehicle infrastructure facilities
      - Refueling stations for traditional vehicles
        - installation,
        - operation,
        - waiting time
        - gas prices.
      - Charging stations for electric vehicles
        - installation,
        - operation,
        - waiting time,
        - electricity prices.
  - Miskolc Operations Center costs:
      - Handling service costs,
      - Standard smart solutions costs,
      - Cross-transporting costs,
      - Vehicle route planning costs,
      - Customer data processes.

- Natural usage costs [27]
    - Emission rates costs,
    - The network cost of electricity for the delivery courier,
    - Specific cost of unscheduled natural resources for delivery courier.

The natural usage costs are defined as the natural resources used:

$$C^{NUC} = C^{E} + C^{N} + C^{US} \tag{1}$$

where:

- C^{E} is the specific cost of emission rates,
- C^{N} is the network cost of electricity for the delivery courier,
- C^{US} is the specific cost of unscheduled natural resources for delivery courier.

The costs of all delivery services are defined as the *operation center's* supply chain specific costs:

$$C^{OC} = C^{VEH} + C^{LIN} + C^{INF} + C^{HAN} + C^{CTP} + C^{VRP} + C^{CRM} + C^{ADD} \tag{2}$$

where:

- C^{VEH} is the cost of vehicles, based on the different types of vehicles,
- C^{LIN} is the cost of driver line,
- C^{INF} is the cost of related vehicle infrastructure facilities,
- C^{HAN} is the cost of handling services,
- C^{CTP} is the cost of cross-transportation, including internal and external logistics at each service tier,
- C^{VRP} is the specific cost of vehicle route planning,
- C^{CRM} is the specific cost of customer relationship management,
- C^{ADD} is the specific cost of clusters, the nearest clusters are considered in the delivery selection process.

The objective function aims to minimize the cost difference in parcel delivery operations, specifically comparing traditional delivery scheduling with a just-in-sequence approach:

$$C = \sum_{n=1}^{j} \sum_{m=1}^{i} C^{NUC}.x_{nm} + \sum_{n=1}^{j} \sum_{m=1}^{i} C^{OC}.x_{nm} \rightarrow min. \tag{3}$$

where:

- x_{nm} is an assignment matrix of each delivery point (DP) and associated cluster in each delivery sequences,
- n=1...j and m=1...i,
- There is a direct supply connection between each tier.

2.2 Numerical analysis

This section presents the general model for final product delivery processes. The model incorporates elements of the objective function that enhances the efficiency of supply chain operations. It was implemented using Microsoft Excel with custom-developed macros, allowing for automated data handling and operational cost calculations. To solve the complex vehicle routing problem associated with parcel distribution across urban clusters, a genetic algorithm (GA) was applied.

The proposed framework enables the determination of optimal vehicle routes for each service cluster. It is based on the customer demand and destination locations, utilizing electric vehicles (EVs). The main operations center is located at Kandó Kálmán Square, with GPS coordinates: latitude 48.101295, longitude 20.810399.

Table 1. Available delivery routes for each cluster from the operation center

Miskolc clusters	Destination points	GPS x	GPS y	Route [km]	TR Cost [€]	EV Cost [€]
C1	DP1	48.099405	20.775629	5.6	1.568	1.12
C4	DP2	48.101381	20.715821	8.0	2.24	1.6
C20	DP3	48.099970	20.731582	6.4	1.792	1.28
.	.	.	.	.	.	.
C6	DP50	48.097954	20.689436	10.8	3.024	2.16

The scenario compares delivery service processes using traditional and electric vehicles (EVs) in Miskolc. Table 1. represents the parameters of the available cluster addresses. The total costs are calculated for EV and traditional delivery for 50 destinations. The total delivery cost using traditional vehicles is 152.63 €. The total delivery cost of EVs is 99.56 €, representing a 40% cost reduction in the supply chain solution.

The results of existing Miskolc delivery networks identify the potential synergies of innovative delivery solutions. The use of electromobility and logistics solutions in finished goods delivery systems allows networks to optimize decisions for the financial and environmental benefits of supply chains, while reducing unnecessary flows in delivery operations. The study evaluates a supply chain model that optimizes delivery efficiency.

To further support the results, an extended sensitivity analysis was carried out using the built-in Microsoft Excel Solver Sensitivity Report. The analysis examined the impact of cost parameter changes related to electric vehicle (EV) operations, ranging from –20% to +20% in 5% increments.

Table 2. Sensitivity analysis of EV delivery cost changes

EV Cost Factor [%]	Adjust EV Cost [€]	TR Cost [€]	Cost Reduction [%]	Cost Difference [%]
80	79.65	152.63	47.81	72.98
85	84.63	152.63	44.55	68.00
90	89.60	152.63	41.30	63.03
95	94.58	152.63	38.03	58.05
100	99.56	152.63	34.77	53.07
105	104.54	152.63	31.50	48.09
110	109.52	152.63	28.24	43.11
115	114.49	152.63	24.97	38.14
120	119.47	152.63	21.71	33.16

The results are summarized in Table 2. These show that even in the highest-cost scenario, the model still achieves a cost reduction of over 21% compared to traditional delivery. In absolute terms, this corresponds to a saving between €33.16 and €72.98, depending on the EV cost level.

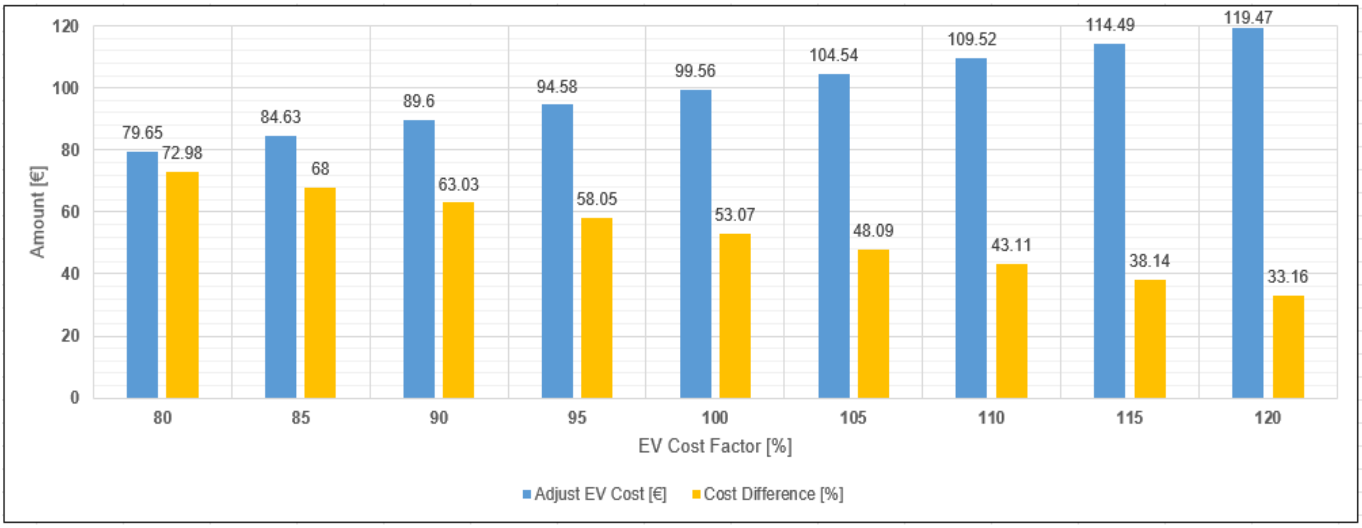

Fig. 4. Impact of EV cost changes on total delivery saving

Fig. 4. represents the effect of EV cost changes on the overall delivery cost savings. The diagram shows that even with increasing EV costs, the model maintains a significant cost advantage compared to traditional delivery.

3 *Results and discussion*

This study demonstrates that integrating electromobility into urban delivery systems creates substantial opportunities for optimizing both economic performance and environmental impact. The proposed supply chain model leverages innovative vehicle technologies to reduce unnecessary flows, improve delivery efficiency, and support sustainable logistics practices.

Compared to previous research, which often isolates vehicle efficiency or environmental outcomes, this study presents a more holistic approach by integrating vehicle type selection, spatial clustering, and cost-based modeling into a unified optimization framework. This approach aligns with the growing trend in logistics toward multi-criteria decision-making and data-driven operational design.

Earlier studies have addressed various aspects of electromobility. Research on EV design and operational integration can be found in [5–6], while environmental impacts and vehicle application studies are covered in [7–9]. Battery performance and degradation are discussed in [10–11], and recent efforts to optimize charging infrastructure and location planning are presented in [12–15]. For instance, [9] reports approximately 25% operational cost savings through EV-based route optimization. In contrast, our integrated approach achieves between 34% and 48% cost reduction under varying EV cost scenarios, illustrating the added value of combining spatial clustering with cost sensitivity analysis. However, these studies often overlook integrated, cost-based delivery models that reflect the realities of urban logistics.

For instance, [9] reports approximately 25% operational cost savings through EV-based route optimization. In contrast, our integrated approach achieves between 34% and 48% cost reduction under varying EV cost scenarios, illustrating the added value of combining spatial clustering with cost sensitivity analysis.

This paper addresses that gap by directly linking vehicle allocation and delivery clustering to operational cost optimization. The proposed solution offers a more comprehensive framework, particularly relevant for disadvantaged urban regions such as Miskolc.

There are several advantages and limitations associated with the study:

Advantages:

- Integrated modeling of electric vehicles (EVs) and urban delivery clusters tailored to real-world settings in Miskolc.
- Operational cost-based optimization that takes into account infrastructure and route dynamics.
- Inclusion of environmental performance indicators, supporting EU sustainability goals.
- Adaptable framework suitable for cities with varying levels of EV infrastructure maturity.

Limitations:

- The model assumes fixed infrastructure for charging and does not fully consider real-time network variability, such as traffic congestion or dynamic charging station availability.
- In practice, charging station availability, waiting times, and local traffic conditions can fluctuate dynamically, which may affect route optimization and operational costs.
- Energy consumption modeling is simplified and does not account for factors such as route elevation, vehicle load variability, or thermal behavior.
- The optimization process focuses on predefined clusters and does not yet support adaptive cluster reconfiguration based on demand fluctuations.

4 Conclusions

Overall, electric vehicles (EVs) prove to be more cost-effective in urban deliveries that prioritize emission reduction, urban delivery efficiency, and the utilization of government incentives. However, the analysis also indicates that conventional vehicles remain a viable option in scenarios where EV infrastructure is insufficient or initial setup costs are prohibitively high. These findings highlight the need for context-specific vehicle selection strategies in urban logistics planning:

- Delivery carriers fulfil the customer requests in delivery processes by managing economic and environmental impacts.
- Optimized scheduling of package delivery results in more competitive and economical delivery for urban city distribution.
- Important indicators are selected for optimization methods to determine the most efficient delivery approach.

Nevertheless, more attention and research are required to address the design aspects of complex logistics systems in electromobility by utilizing different algorithms to solve NP-hard delivery problems.

The proposed model shows practical value for Miskolc city, where urban delivery systems operate under infrastructure constraints and growing environmental demands. By aligning delivery route allocation, spatial clustering, and cost-based decision-making, the study supports efficient and sustainable logistics planning in regional urban settings. These results provide a useful foundation for adapting electromobility strategies to regional cities with limited EV infrastructure.

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7 Conflict of interest statement

There are no conflicts affecting the research.

8 Author contributions

The author confirms having solely conducted all phases of the research and manuscript preparation.

9 Availability statement

There is no dataset associated with the study or data is not shared.

10 Supplementary materials

There are no supplementary materials to include.

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