APPLICATIONS OF ELECTRIC TRUCKS IN TRANSPORT LOGISTICS

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Abstract: This paper examines the advantages of deploying electric trucks in transport logistics, with emphasis on environmental, economic, and social implications. It also aims to strengthen the algorithmic basis for mathematical and economic modelling of logistics networks in the context of digitalization and advanced transport technologies.

Keywords: Mathematical model, electric truck, transport logistics

Introduction

Efficient transport networks are fundamental to the movement of people and goods and therefore to economic and social development. In many parts of the world, however, traffic congestion has intensified because of increased motorization, urban growth, population expansion, and changing settlement patterns. These pressures undermine social welfare and economic performance by increasing travel time, fuel consumption, and air pollution, while simultaneously reducing the effective use of transport infrastructure. For this reason, transport regulation and infrastructure management remain essential societal responsibilities. Rather than relying solely on the construction of new road systems, recent advances in electronics, communications, control systems, computing, and sensor technologies make it possible to develop more effective policies for using the existing network more efficiently. Such technologies support more accurate traffic data collection, better control interventions, and a reduction in the uncertainty that characterizes contemporary transport systems.

The successful implementation of intelligent transport systems requires an understanding of traffic dynamics at both local and system levels, including disturbances such as shock-wave formation and propagation, congestion onset, and related nonlinear effects. It is equally important to understand how users interact with the transport system. Because transport systems are highly complex and dynamic, simplified mathematical representations are often inadequate. More advanced modelling approaches are needed to capture causality, coupling, feedback effects, and the sometimes chaotic behavior of transport phenomena. Such models support both the design and the management of modern transport systems.

The driving range of an electric vehicle is not a fixed value; instead, it varies according to operating conditions and driving cycles. For that reason, manufacturers and researchers need models that estimate range on the basis of representative traffic and driving cycles. In the source manuscript, vehicle power reserve is assessed by means of a mathematical model incorporating four driving cycles, the forces acting on the vehicle, the lengths of the cycles, and resistive

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forces during motion, while accounting for electric-motor efficiency in order to estimate overall energy consumption.

Literature review

Logistics and transportation are central to the functioning of the global economy and to wider social and economic development. Because the sector contributes substantially to regional GDP and has expanded steadily under globalization and the growth of international trade, operations research and computer science have studied logistics systems for decades with the aim of increasing efficiency. One of the most established research themes in this area is the modelling and optimization of vehicle tours, commonly referred to as the Vehicle Routing Problem (VRP) [1]. The basic capacitated version of the VRP addresses customer demand under vehicle capacity limits, while time-window formulations extend the problem by assigning service intervals to depots and customers. More realistic variants, often described as rich VRPs [2] or multi-attribute VRPs [3], incorporate additional operational constraints and attributes.

Much of the classical VRP literature assumes fleets composed exclusively of internal combustion engine vehicles, yet this assumption no longer reflects current transport realities. Road transport consumes a major share of oil use in Europe and the United States and contributes substantially to transport-related carbon emissions. One response is to include emissions costs directly in routing objectives [4,5]. Another is to adopt alternative propulsion technologies, including electric and plug-in hybrid vehicles, though these require models that explicitly address their technological characteristics. Cities increasingly promote EV technologies to improve urban air quality, and adoption has been encouraged by corporate decarbonization goals, volatility in petroleum costs, public subsidies, and improvements in alternative-energy technologies [6]. At the same time, deficiencies remain, especially in battery energy density, charging duration, and charging-station availability. Although long range and acquisition cost historically limited EV adoption, technological progress and rising fuel prices continue to improve competitiveness [6].

Transport externalities also remain central to the debate. Air pollution, noise, congestion, infrastructure wear, visual intrusion, and accidents all impose costs that are not always incorporated into transport planning. Because transport consumes more than one quarter of global energy, these externalities must be considered if long-term sustainability is to be achieved [7]. Research has focused particularly on air and noise pollution, yet the valuation of transport externalities remains unsettled, especially in Europe [8]. Electrified mobility introduces its own strategic questions, including how many charging stations are required, where they should be located, and what capacity they should provide [9]. Vehicle range must likewise be considered in route design [10]. Moreover, if electricity generation continues to rely heavily on carbon-intensive primary energy sources, the environmental benefit of e-mobility may be limited in the medium term unless charging is increasingly supplied by renewables [11,12]. For that reason, sustainable freight electrification must be approached within a broader energy-system perspective.

The literature also addresses policy evaluation and operational deployment. One study proposes a framework for assessing policy options that support EV use in urban freight transport [13]. Taefi compares EV-based distribution with alternative strategies using a multi-criteria approach and concludes that electric medium-duty freight vehicles become financially attractive only at higher annual mileages, when lower operating costs offset battery replacement expenditures [14]. Deflorio and Castello model traffic impacts associated with electric medium-sized vans in freight distribution [15]. Cagliano and colleagues analyze the diffusion of low-impact commercial vehicles in urban contexts while taking key operational factors into account [16]. Tan et al. examine a remote-driving platform as a possible response to last-mile transport problems [17].

Characteristics of an Electric Vehicle

A driving cycle is a sequence of speed–time observations used to evaluate vehicle performance under standardized conditions. Pure battery electric vehicles rely on a single energy-source system. In operation, the traction battery supplies electrical energy through a power distribution unit to the motor control unit, which converts high-voltage direct current into alternating current for the traction motor. The motor transforms electrical energy into mechanical energy and transmits it to the wheels through a reduction gear. When regenerative braking is enabled, part of the vehicle's kinetic energy is transferred back through the drivetrain to the motor, which then acts as a generator and returns electrical energy to the battery.

To model vehicle range across different motion cycles, the source text first computes acceleration for each segment of the cycle. Acceleration is expressed as the derivative of vehicle speed with respect to time:

$$a = \frac{dV(t)}{dt}$$

The dynamic force is then calculated as

$$F_d = (1 + \gamma)ma$$

where γ denotes the coefficient accounting for the inertia of rotating parts, given in the source as $\gamma = 0.1$. Total resistance is defined as the sum of rolling resistance and aerodynamic resistance:

$$F = F_r + F_a$$

Aerodynamic resistance increases with speed and frontal area and is expressed as

$$F_a = SkV^2$$

where S is frontal area and k is the streamlining coefficient:

$$k = 0.5C_x\rho_{air}$$

Using $\rho_{air} = 1.225\ \mathrm{kg/m^3}$ and $C_x = 0.35$, the source obtains $k \approx 0.21$. The frontal area is calculated from the empirical relation

$$S = 0.9hb = 0.9 \times 1.705 \times 1.585 = 2.43\ \mathrm{m^2}$$

The rolling-force component is written as

$$F_r = mgf_r$$

where m is vehicle mass, $g = 9.81\ \mathrm{m/s^2}$, and $f_r = 0.015$ for asphalt-concrete pavement. Three operating cases are distinguished in the source text: traction, coast-down, and braking mode:

$$F_r = F_d + F_c \quad \text{(traction)}$$
$$F_r = F_c \quad \text{(coast-down)}$$
$$F_r = F_d - F_c \quad \text{(braking)}$$

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Mechanical power is defined as the product of wheel force and instantaneous speed:

$$P_{mech} = F_k V$$

Energy consumption in traction mode is the time integral of traction power:

$$E_c = \int_0^t P_t\,(t)\,dt$$

where the source expresses traction electrical power as a function of mechanical power and drivetrain efficiencies. In braking mode, the electrical energy returned to the battery is

$$E_g = \int_0^t P_b\,(t)\,dt$$

with braking electrical power depending on the same efficiency chain, but in the reverse direction. The manuscript further explains that mechanical braking power may be derived from the change in kinetic energy over the braking interval.

The battery energy state is described by a piecewise relation that subtracts consumed energy in traction mode and adds regenerated energy in braking mode, while accounting for average battery efficiency $\eta_{acum} = 97\%$:

$$E_f = \begin{cases} E_0 - \dfrac{E_{cons}}{\eta_{acum}} \\ E_0 + E_{gen}\eta_{acum} \end{cases}$$

For comparative purposes, the specific energy consumption is defined per unit distance as

$$E_{spec} = \frac{E_f}{3600\,l}$$

in $\mathrm{Wh/km}$, where $1/3600$ converts joules into watt-hours. The state of charge is then expressed as the remaining battery energy relative to full capacity:

$$SoC = \frac{E_f}{E_0} \times 100\%$$

Finally, the vehicle range estimate is obtained from the proportionality relation

$$\frac{l}{l_c} = \frac{E}{E_c}$$

which yields

$$l = \frac{E}{E_c} l_c$$

where l_c and E_c denote the distance and energy consumption associated with one motion cycle, and E is total traction-battery capacity.

Electric trucks and transport logistics

The source manuscript presents electric trucks as a major shift in contemporary transport logistics and identifies several categories of benefit.

- Electric trucks reduce direct tailpipe emissions and therefore lower local emissions of nitrogen oxides, carbon dioxide, and particulate matter. Their environmental profile becomes still more favorable when the electricity used for charging is generated from renewable sources.
- They may offer economic benefits through lower fuel and maintenance costs over their operational life, while government incentives, toll reductions, access privileges for low-emission zones, and related policy measures can mitigate high upfront acquisition costs.
- Electric drivetrains are more energy-efficient than internal combustion technologies, which means that a larger share of stored energy is converted into useful motion.
- Electrification supports regulatory compliance in jurisdictions with increasingly strict emissions standards and may help operators' future-proof their fleets against later restrictions on diesel vehicles.
- Electric trucks reduce operational noise, which is especially valuable in dense urban and residential settings and may expand the feasibility of night-time distribution.
- Ongoing improvements in battery performance, charging speed, and renewable-energy integration strengthen the technological viability of electric trucks while also supporting corporate sustainability image and stakeholder relations.

In that sense, the transition toward electric freight transport can contribute simultaneously to environmental, economic, and reputational goals.

Table 1. Electric Truck Market Development in Czechia and Slovakia at the Turn of 2025 and 2026.

Topic	Czechia	Slovakia
Electric trucks in operation, end of 2025	**184** BEV trucks in categories N2/N3	**77** BEV trucks in categories N2/N3
New electric truck registrations in 2025	**136** new BEV trucks	Smaller market; confirmed stock reached **77** vehicles by year-end
Electric trucks in operation, Q1 2026	**233** BEV trucks in categories N2/N3	Exact total not specified in the earlier data
Q1 2026 market share	**1.4%** of new truck registrations	**0.4%** of new truck registrations
Typical use cases	Urban logistics, municipal services, regional distribution, depot-based fleets	Early fleet deployment, pilots, urban/regional logistics
Market maturity	Early commercial scaling	Pilot / early adoption phase
Main growth drivers	Purchase subsidies, depot charging support, first public heavy-truck charging sites	More available truck models, planned high-power charging infrastructure
Main barriers	Still limited heavy-duty public charging network	Low adoption, weaker purchase support, limited high-power truck charging

Table 1 compares the development, market uptake, typical applications, maturity, growth drivers, and key barriers of battery-electric trucks in Czechia and Slovakia. It covers vehicles in the N2 and N3 categories at the end of 2025 and during the first quarter of 2026. Data for 2026 refer only to Q1 and should not be interpreted as full-year results.

Conclusion

This paper offers a simplified mathematical account of the benefits associated with integrating electric trucks into transport logistics. It argues that the adoption of electric vehicles in road distribution, especially in urban environments, is promising but still far from fully realized. At the same time, broader deployment raises strategic and operational problems, including the design of charging or battery-swapping networks, decisions about the size and composition of mixed fleets, route-feasibility constraints associated with heterogeneous vehicle ranges, time-window limitations driven by charging requirements, and supply-chain-wide economic effects. The source concludes that new optimization and hybrid optimization–simulation methods, especially those capable of handling uncertainty and dynamic scenarios, are essential if logistics systems are to transition effectively toward more sustainable energy sources.

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