AN OPERATIONAL PLANNING FRAMEWORK FOR ELECTRIC VEHICLE INTEGRATION IN ROAD FREIGHT TRANSPORTATION: A LITERATURE-BASED APPROACH

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ABSTRACT

Road freight transportation remains highly dependent on fossil fuels, exposing freight systems to fuel price volatility, supply disruptions, and energy security risks. Electric vehicles offer a potential pathway to reduce this dependence while also supporting emission reduction objectives. However, their integration into freight systems is not determined by vehicle availability alone, as operational feasibility depends on the interaction between vehicle capability, freight service requirements, charging conditions, economic viability, policy and market readiness, and real-world operating conditions. This study develops a literature-based factor-to-operational-parameter framework for electric vehicle integration in road freight transportation. A structured scoping synthesis of recent road freight electrification literature was conducted, focusing on studies related to electric freight vehicles, logistics system electrification, electric vehicle routing, charging infrastructure, energy consumption, total cost of ownership, and adoption barriers. The extracted factors were classified according to their primary role in the integration decision and mapped to the operational planning parameters they affect. The synthesis identifies six planning dimensions: vehicle and technology, freight operation, charging and energy, economic, policy, market and institutional, and route and operating condition factors. These dimensions jointly influence technical feasibility, operational suitability, charging requirements, financial viability, deployment readiness, and operational robustness. The proposed framework provides a structured basis for future feasibility assessment, route selection, charging planning, fleet transition modelling, and policy discussion in electric road freight systems.

Keywords: electric freight vehicles, fleet transition, freight electrification, operational planning, road freight transport

1. INTRODUCTION

Road freight transportation is an essential economic activity in any country. But its heavy dependence on petroleum fuels exposes freight systems to fuel price volatility, supply disruptions, and energy security risks. Electric vehicles (EVs) provide a pathway to reduce this dependence by shifting part of freight energy demand from fossil fuels to electricity, while also supporting emission reduction objectives when cleaner electricity generation is available.

However, electric road freight integration is more complex than replacing a diesel vehicle with an electric alternative. Freight vehicles must satisfy payload, route distance, delivery frequency, time window, utilization, and service reliability requirements, while electric vehicles introduce constraints related to battery capacity, usable range, charging time, charging infrastructure, and real-world energy consumption. Existing studies examine adoption, routing, charging, energy use, and ownership cost separately. This study addresses this fragmentation by developing a literature-based factor-to-operational-parameter framework that links key electrification factors to the planning parameters required for electric road freight integration.

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2. LITERATURE REVIEW

Recent review studies confirm that electric road freight research is growing but fragmented. Alarcón et al. (2023) reviewed electric mobility in sustainable cities and road freight logistics and classified the field into economic and competitive aspects, city logistics, environmental sustainability, vehicle fleet operations, and infrastructure and technology. Gillström et al. (2024) reviewed electrification of logistics systems and identified transport operation, charging, cost, stakeholder involvement, and sustainability as major categories. These studies show that freight electrification affects not only vehicle technology but also logistics planning, infrastructure, cost structures, and implementation conditions.

Operational modelling studies provide a second perspective. Xiao et al. (2021) showed that electric vehicle routing requires EV-specific considerations, including nonlinear charging, nonlinear energy consumption, dynamic driving range, charging station visits, payload, speed, travel time, and battery capacity. Fiori and Marzano (2018) modelled energy consumption of electric freight vehicles using real-world pickup and delivery data, showing the importance of vehicle characteristics, speed, roadway grade, on-board weight, and operating conditions. Economic studies also show that adoption cannot be assessed through purchase price alone. Gil Ribeiro and Silveira (2024) demonstrated that financial incentives can substantially affect the total cost of ownership and cost competitiveness of electric light commercial vehicles.

As a summary, the literature shows that electric road freight integration depends on several interacting factors. However, limited synthesis has connected those factors to the operational parameters used in planning and feasibility assessment. This paper therefore focuses on the relationship between factors and planning parameters, rather than only listing barriers or themes.

3. METHOD

A structured scoping literature synthesis was conducted to identify and organise the factors influencing electric vehicle integration in road freight transportation. The review focused on recent academic studies related to electric freight vehicles, logistics system electrification, electric vehicle routing, freight energy consumption, charging infrastructure, total cost of ownership, and policy or adoption barriers.

The literature was identified through searches in ScienceDirect and Google Scholar. Search terms were developed using combinations of keywords such as “electric freight vehicles”, “electric trucks”, “road freight electrification”, “logistics electrification”, “electric vehicle routing”, “charging infrastructure”, “freight energy consumption”, “total cost of ownership”, “fleet transition”, and “adoption barriers”. Studies were included when they focused on electric freight vehicles, electric road freight systems, logistics electrification, charging planning, EV routing, freight energy consumption, ownership cost, or adoption and implementation barriers. Studies were excluded when they focused only on passenger electric vehicles, general electric mobility without freight relevance, or technical battery and powertrain issues without operational planning implications.

The synthesis followed three stages. First, recent review papers were used to identify the broad structure of the field and recurring themes. Second, selected primary studies were examined to identify how individual factors affect operational planning decisions, particularly in relation to range, payload, routing, charging, energy use, cost, and deployment readiness. Third, the extracted factors were classified according to their primary role in the integration decision and mapped to the planning parameters they affect.

The classification was interpretive rather than purely keyword based. Factors were grouped according to their main function in freight electrification, while interdependencies were retained through the factor-to-parameter mapping. This approach was selected because the objective of the study was not to quantify the frequency of themes in the literature, but to develop a planning-oriented framework that links electrification factors to operational decision parameters.

4. RESULTS AND DISCUSSION

The study produced six connected factor groups, as shown in Table 1. These groups represent the main planning dimensions of electric road freight integration and should be interpreted as interdependent rather than isolated categories. For example, payload affects not only vehicle carrying capability but also energy demand and range reliability, while charging time affects both energy planning and fleet availability.

Table 1. Operational Planning Framework for Electric Road Freight Integration

Factor group	Main factors	Operational planning parameters affected	Integration decision supported
Vehicle and technology	battery capacity, usable range, energy consumption, payload, cargo volume, vehicle class	range feasibility, load compatibility, vehicle task matching	selecting suitable electric vehicle types
Freight operation	route length, stop pattern, duty cycle, time windows, delivery frequency, utilisation	route compatibility, schedule feasibility, fleet availability	assessing operational suitability
Charging and energy	charger location, charging power, charging duration, charger availability, grid access, tariff	charging downtime, charging frequency, energy cost, infrastructure requirement	selecting charging strategy
Economic	purchase cost, battery cost, maintenance, fuel and electricity costs, ownership period, residual value, incentives	lifecycle cost, payback period, investment feasibility	assessing financial viability
Policy, market, and institutional	regulation, incentives, vehicle availability, service support, financing, stakeholder coordination	implementation readiness, adoption risk, institutional feasibility	assessing deployment readiness
Route and operating conditions	traffic, speed profile, road condition, weather, roadway grade, route variability	energy demand, range reliability, buffer requirement, operational robustness	adjusting assumptions for real-world use

The framework suggests a sequential planning logic in which vehicle capability is evaluated against freight service requirements, followed by charging feasibility, economic viability, deployment readiness, and route operating conditions. Its practical value can be illustrated through Sri Lankan raw milk collection, where light-duty freight vehicles collect perishable milk from farmers and deliver it to collection centres while satisfying route, payload, range, and time-window constraints. In such cases, feasibility should not be judged only by average route distance or manufacturer-stated range, because collection points, charging options, road grade, speed variation, and route variability can affect energy use and schedule reliability.

This type of application also shows why the factor groups should be considered together rather than independently. A route that appears suitable based on distance alone may become unsuitable when payload accumulation, collection delays, limited charging access, road gradient, or return-trip energy requirements are considered. Therefore, the framework supports an initial screening process that can reduce unsuitable route-vehicle combinations before more data-intensive modelling is conducted.

The main contribution of the framework is its translation of literature-derived factors into planning parameters that help identify which routes, vehicle classes, and charging arrangements are suitable under specific freight operating conditions before detailed optimisation or fleet transition modelling.

5. CONCLUSION

This study developed a literature-based operational planning framework for electric vehicle integration in road freight transportation. The framework organises fragmented literature into six interdependent planning dimensions and maps them to operational parameters affecting technical feasibility, operational suitability, charging requirements, financial viability, deployment readiness and real-world robustness. Its main contribution is the translation of literature-derived factors into a planning-oriented structure that supports feasibility assessment, route selection, charging planning and fleet transition modelling. Future research can apply the framework to empirical case studies, including route-level and fleet-level assessment of electric freight integration under Sri Lankan operating conditions.

6. REFERENCES

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