Transitioning to EV Fleets: Best Practices and a Decision Tool

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New U.S. regulatory targets aim for an electric vehicle (EV) market share of at least 50% by 2030, a shift mirrored by manufacturers phasing out internal combustion engine (ICE) vehicles. While public organizations are increasingly eager to transition, the pathway is complicated by cold-climate range uncertainties, infrastructure gaps in rural areas, and the technical hurdles of transitioning medium- and heavy-duty fleets for large agencies like MnDOT. This study presents a comprehensive framework to help agencies navigate fleet transition and secure available funding. The research began by assessing human factors and organizational readiness through survey of agencies and in-depth interviews with fleet managers to identify operational barriers and perceptions. Subsequent stages involved a detailed analysis of fleet composition and infrastructure capacity, gathering data on vehicle types, usage patterns, and parking facilities across various Minnesota agencies. These foundational data informed a 10-year life-cycle cost analysis, comparing EVs against traditional ICE vehicles across multiple classes. Finally, the project developed an optimization model, applied to Minneapolis trip data, to demonstrate a strategic plan for EV acquisition and charging infrastructure deployment that minimizes total cost while ensuring uninterrupted operation. The study's findings and strategic roadmap was disseminated via a statewide webinar to support Minnesota agencies in achieving a cost-effective transition.

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FINAL REPORT

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TABLE OF CONTENTS

Chapter 1: Introduction 1

1.1 Policies and Planning 1

1.2 Assessing Existing Fleet.. 2

1.3 Documenting Existing Vehicle Characteristics.. 2

1.4 Right-sizing Fleet Size 2

1.5 Finding Usage Pattern.. 3

1.6 Charging Infrastructure: Location, Installation, and Technology 3

1.6.1 Location 3

1.6.2 Installation.. 4

1.6.3 Technology 5

1.7 Human Factors.. 5

1.8 Fleet Managers' Skills 6

1.9 IT Implementations.. 6

1.10 Identifying the Government Incentives.. 7

Chapter 2: Investigation of the Human Factors Component of Transitioning to EV Fleets 8

2.1 Introduction 8

2.1.1 Consumer Trends & Attitudes.. 8

2.1.2 Electric Vehicles in Public Agencies.. 9

2.2 Survey & Interviews.. 10

2.3 Results.. 10

2.3.1 Human Factors Component of Transitioning to EV Fleet Evaluation Survey 11

2.3.2 Interviews.. 20

2.3.3 Conclusion 24

Chapter 3: Survey of Minnesota Agencies on Fleet Conversion Status and Needs..............................25

3.1 Introduction 25

3.2 Survey Results 26

3.2.1 Current Fleet Status Analysis 26

3.2.2 EV-Related Information and Future Planning 31

3.2.3 Additional Details 37

3.2.4 Conclusion 37

Chapter 4: Life cycle Cost Analysis of EV Fleet Conversion 39

4.1 Introduction 39

4.2 Life Cycle cost analysis 39

4.2.1 Life Cycle Cost Calculation 40

4.2.2 Comparing Life Cycle Costs Across Agencies 49

4.2.3 Conclusion 51

Chapter 5: Charging Infrastructure Planning 52

5.1 Introduction 52

5.2 Agency Fleet Driving Patterns 52

5.2.1 Fleet Usage Insights and Charging Station Location Candidates 55

5.3 Siting and Sizing Charging Infrastructure and EV Fleet 57

5.3.1 Fleet and Infrastructure Requirements 59

5.3.2 Charging Activity and Operational Impacts 60

5.3.3 Total Cost Evaluation 62

5.3.4 Sensitivity Analysis 63

5.3.5 Practical Guideline for Sizing & Siting Charging Infrastructure and EV Fleets 65

5.3.6 Conclusion 68

Chapter 6: Recommendations and Identification of Potential Funding Sources 69

6.1 Project Summary 69

6.2 Blueprint for EV Fleet Electrification 69

6.3 Human Factors Component 71

6.4 Funding Opportunities 72

Chapter 7: Conclusion 75

References 77

Appendix A: Human Factors survey questions

Appendix B: Fleet Conversion Status Survey Questions

Appendix C: Optimization Model

Appendix D: Tour Counts, Frequencies, and Minimum Required Fleet (All Fleet Groups)

List of Figures

Figure 2.1 Survey Responses on Sentiments Toward the Transition from Traditional Vehicles to Electric Vehicles 12

Figure 2.2 Perceived Benefits of Electric Vehicles Among Survey Respondents 13

Figure 2.3 Key Concerns About Electric Vehicles Among Respondents 14

Figure 2.4 Survey Responses on Sentiments Toward the Reliability of Electric vehicles Compared to Traditional Vehicles 15

Figure 2.5 Survey Responses on Concerns Regarding Safety of Electric Vehicles 16

Figure 2.6 Preferred Support and Training Resources for Transitioning to Electric Vehicles 17

Figure 2.7 Survey Responses on Employee Feedback Consideration for Transitioning to Electric Vehicles 18

Figure 2.8 Desired Features for Agency Electric Vehicles to Enhance Work Efficiency 19

Figure 3.1 Survey Responses on the Number of EVs in Agencies with EV Fleets 28

Figure 3.2 Relationship between Fleet Size and Average Trips per Day 29

Figure 3.3 Relationship between Fleet Size and Average Distance per Trip 29

Figure 3.4 Relationship between Average Trips per Day and Average Distance per Trip 30

Figure 3.5 Survey Responses on the Number of EVs in Agencies with EV Fleets 31

Figure 3.6 Charging Strategy and Timing for Electric Heavy/Medium-Duty Vehicles 33

Figure 3.7 Geographic Distribution of Fleet Locations by ZIP Code... 35

Figure 3.8 Clustering of Agency Fleet Locations 36

Figure 3.9 Public Charging Opportunities by Agency... 37

Figure 4.1 Comparison of 10-Year LCC between ICE and BEV technologies across various vehicle classes using fleet data from the City of Minneapolis. (a) heavy-duty vehicles (class 7-8), (b) medium duty vehicles (class 3-6), (c) passenger vehicles (light-duty). 42

Figure 4.2 Comparison of 10-year life-cycle costs (LCC) between ICE and BEV fleets across agencies using reported annual mileage. 50

Figure 4.3 Comparison of 10-year life-cycle costs between ICE and BEV technologies by vehicle class across agencies: (a) light duty; (b) medium duty ; (c) heavy duty. 51

Figure 5.1 Origin location of tours in the City of Minneapolis.. 53

Figure 5.2 Distribution of tour lengths by frequency (top) and by number of vehicles (bottom)............. 54

Figure 5.3 Clustered origin location of tours 56

Figure 5.4 Estimated tour metrics and minimum fleet requirement per time interval for Fleet Group 8. (a) tour frequency, (b) tour duration, (c) minimum required fleet. 57

Figure 5.5 Hourly charging activity at two selected charging stations across three transition phases. (a) Hiawatha Maintenance Facility, (b) Currie Maintenance Facility.. 61

Figure 5.6 Breakdown of cost components across electrification phases and routes.(a) Aggregated costs across all Fleet Groups for each electrification phase.(b) Daily operational costs per route after the completion of the fleet electrification process.. 62

Figure 5.7 Guideline steps for charger siting and EV fleet sizing 65

List of Tables

Table 3.1 Current Charging Strategies and Future Charging Plans of Agencies with EV Fleets................. 32

Table 3.2 Charger Technology and Satisfaction Levels by EV Fleet Size 33

Table 4.1 Maintenance cost per mile estimates derived from the DRVE User Guide (Atlas Public Policy, 2024; Burnham et al., 2021). 41

Table 4.2 Total saving and payback period for each vehicle class based on average annual mileage using fleet data and trip history from the City of Minneapolis. 43

Table 4.3 Payback period for each vehicle class based on 10th, 90th percentiles annual mileage of fleet in the same vehicle calss using fleet data and trip history from the City of Minneapolis. The last column reports the required annual mileage ($\boldsymbol{L}*$) needed to achieve payback within ten years. 47

Table 5.1 Fleet composition by duty class, fuel type, and tour length. 54

Table 5.2 Fleet group identification 56

Table 5.3 Parameter values 59

Table 5.4 Fleet electrification phases with associated EV counts, chargers, and budget allocations. 60

Table 5.5 Daily operation cost saving 64

Table 5.6 Number of (Heavy/Medium/Light) EVs 64

Table 5.7 Number of chargers (L1, L2, DCFC, MCS) 65

Table 6.1 Funding Opportunities for Fleet Electrification 73

Executive Summary

This research identifies the key factors, challenges, and strategic opportunities for public agencies in Minnesota transitioning to electric vehicle (EV) fleets. Through a mixed-methods approach, including employee surveys, fleet manager surveys, interviews, cost analysis, and the development of an optimization model, the study provides a comprehensive roadmap for electrification. The process began by assessing human factors and organizational readiness through surveys of agency employees and in-depth interviews with fleet managers to understand perceptions, concerns, and operational barriers. The next step involved a detailed analysis of fleet composition and infrastructure capacity, collecting specific data on vehicle types, usage patterns, and parking facilities from a wide range of agencies. This foundational data enabled a cost-benefit analysis, comparing the 10-year life-cycle costs of EVs with traditional internal combustion engine vehicles across different vehicle classes. Finally, the project developed and applied an optimization model using collected trip data from the city of Minneapolis to create a phased plan for charging infrastructure deployment that minimizes total cost and operational disruption. This mixed-methods approach provides a data-driven foundation for the following key findings:

- **Mixed readiness and significant barriers**: Agency sentiment toward EV adoption is neutral, with major concerns centering on limited vehicle range, insufficient charging infrastructure, high upfront costs, and specialized maintenance needs. Reliability in cold weather and battery safety are also prominent concerns, particularly for rural agencies.
- **Cost analysis reveals varied opportunities**: A 10-year life-cycle cost analysis shows that light-duty EVs have already reached cost parity with internal combustion engine (ICE) vehicles, making them a strong starting point. Heavy-duty EVs also show a favorable cost profile due to lower operating expenses, despite high initial prices. However, medium-duty vehicles remain the most difficult to electrify cost effectively.
- **Infrastructure and collaboration are critical**: While 57% of agencies have sufficient parking for chargers, installation costs and power availability are hurdles. Depot charging is the preferred strategy, but opportunities exist for inter-agency collaboration to share public charging infrastructure, reducing costs and accelerating adoption.
- **Phased optimization is key to budget limitation**: A phased optimization model helps overcome budget and technological challenges by strategically planning charger placement and fleet expansion. This approach ensures a cost-effective transition while minimizing operational expenses in the long run.

The analysis yields several critical strategic insights for a successful fleet electrification. Agencies should begin by prioritizing light-duty vehicles, such as sedans and SUVs, where the financial case is strongest and life-cycle costs are already competitive with traditional vehicles. Implementation is best achieved through a phased and flexible approach, which allows for managed capital expenditure, organizational learning, and the adaptation of infrastructure plans to eliminate early inefficiencies like deadheading. Simultaneously, planning must account for diverse charging needs, incorporating a mix of Level 2 and DC Fast Chargers and exploring opportunities for shared public infrastructure to meet operational demands.

Furthermore, practical execution necessitates rigorous attention to building-related requirements, including electrical capacity upgrades, conduit installation, fire safety ventilation, ADA-compliant physical layouts, and smart load management systems to ensure facility readiness. To be executable, adoption mandates, especially for heavy-duty vehicles, must be backed by robust financial support, realistic long-term planning, and sufficient incentives.

Chapter 1: Introduction

Organizations are well-positioned to be early adopters of electric vehicles (EVs) due to their ability to purchase in large quantities, extensive vehicle use, centralized refueling stations, and streamlined decision-making processes (Nesbitt and Sperling, 2001). Organizations normally employ fleet managers who are knowledgeable about the long-term costs associated with vehicle ownership. These professionals have a deeper understanding of these costs compared to private individuals. While many organizations are eager to transition to EV fleets, the pathway is far from straightforward. Real-world challenges add layers of complexity to this transition. For instance, uneven development of charging infrastructure is a significant issue, particularly in rural areas (Jossi, 2023). The Minnesota Department of Transportation (MnDOT) has also noted that the agency, which predominantly operates medium- and heavy-duty fleets, faces the challenge of limited EV options. Furthermore, the reduced range of EVs in cold weather conditions presents an additional concern. According to the literature, the below sub-sections explain the factors that must be considered to ensure a successful transition.

1.1 Policies and Planning

Early involvement of key decision-makers significantly enhances the planning process for transitioning to electric fleets. A study by the Rocky Mountain Institute highlighted the importance of reviewing current policies and involving key decision-makers early in the planning process (Gahlaut and Shapiro, 2023). In line with this, McKinsey & Company (2022) emphasized that forward-looking companies are developing comprehensive decarbonization plans focusing on diagnostics, strategy development, testing, and execution before making critical technology and infrastructure investments.

- **Diagnostics**: Involves a detailed assessment of current operations, fleet size, vehicle requirements, and routes.
- **Strategy Development:** Requires a holistic plan to achieve future goals, prioritizing vehicles and technologies while balancing economic and environmental objectives.
- **Testing and Piloting:** Should be conducted on a small scale to identify and address potential issues.
- **Execution:** Involves detailed planning for sourcing, construction, and partnerships to support the transition.

By integrating these comprehensive planning steps with the early involvement of key stakeholders, agencies can better manage the transition to electric fleets, ensuring robust infrastructure and operational efficiency.

Collaboration within and between departments is essential for success. The green transportation program at Washington State University recommends that agencies create cross-departmental teams including fleet operators, facility managers, energy managers, planning teams, finance, and parking managers (Tousignant et al., 2021). This collaborative approach ensures that all aspects of the transition are considered and managed effectively.

1.2 Assessing Existing Fleet

Conducting a thorough assessment of an existing fleet is key to identifying optimal opportunities and timing for electrifying vehicles. According to the results of studies by the Rocky Mountain Institute, this type of technical analysis can guide decision-makers in the electrification process (Gahlaut and Shapiro, 2023). Daniels and Nelder (2021) conducted a survey of managers overseeing large fleets (over 50 vehicles) in their report on preparing fleet managers for the coming wave of electrified vehicles. The findings revealed that the primary concern among these managers is the lack of available vehicle models that meet their specific fleet needs. Additionally, fleet managers indicated that the most significant factor influencing their decision to electrify is ensuring no disruption to their current operational model. Therefore, a detailed understanding of current fleet operations and requirements is essential for a smooth transition to electrified vehicles.

1.3 Documenting Existing Vehicle Characteristics

To effectively plan for the electrification of a vehicle fleet, it is essential to document several crucial variables, such as the vehicle model, age, mileage, parking location, and other pertinent characteristics. According to a study by Washington State University, this documentation should include a detailed inventory featuring Vehicle Identification Numbers (VINs), annual odometer readings, daily mileage averages and peaks, duty cycles, and dwell times (Tousignant et al., 2021). Such comprehensive data collection allows fleet managers to make informed decisions regarding which vehicles are best suited for electrification and helps in planning the necessary infrastructure.

Atlas Public Policy provides a tool known as DRIVE (Dashboard for Rapid Vehicle Electrification) that is designed to assist decision-makers in comparing their current fleet of conventional vehicles with electric alternatives. The DRIVE dashboard requires detailed input, including a VIN for each vehicle in the fleet, annual vehicle miles traveled, and the projected years of use. This information is used to calculate the total cost of ownership. Furthermore, it is essential to map the location where each vehicle is domiciled to accurately determine the necessary charging infrastructure for the fleet (Atlas Public Policy, 2024).

1.4 Right-sizing Fleet Size

Optimizing an agency's prospective EV fleet by right-sizing is essential. This involves removing or reallocating redundant or seldom-used vehicles, which can be consolidated or shared among various departments or employees, resulting in cost savings and reducing the total number of new EVs required. Two reports (Gahlaut and Shapiro, 2023; Tousignant et al., 2021) emphasized the importance of right-sizing the fleet for agencies. To facilitate this right-sizing, the study conducted at Washington State University recommended addressing specific questions such as how often drivers need all-wheel drive, go off-road, or require a range exceeding 100 miles per day. Additionally, the report suggested assembling a cross-functional team and setting clear goals and responsibilities, from fleet operators to finance groups, to expedite the process.

1.5 Finding Usage Pattern

Agencies should also consider their vehicles' typical usage patterns when transitioning to electric fleets. According to the U.S. Government Accountability Office report, in 2021, federal vehicles had an average annual mileage of around 6,000 miles, equivalent to less than 25 miles a day if used regularly. Based on such use, experts suggest that plug-in hybrids may be ideal for daily runs of under 40 miles, while full-battery electric vehicles could be suitable for daily use below 200 miles, assuming overnight charging is available (U.S. Government Accountability Office, 2022). These considerations are vital in accurately gauging power needs and specifying charging infrastructure. Factors affecting EV power consumption, as noted in (Gahlaut and Shapiro, 2023) reference, include the time of day, total mileage covered, battery temperature, climatic conditions (heating or air conditioning), driving routes, topographical variations, and idle times. Specific formulas, such as the following equation, can offer agencies a nuanced understanding of the anticipated power demands accompanying electrification.

Power for an EV = (Energy consumption * Max daily mileage)/ Dwell time

Building on the initial analysis, accurate power demand estimation is essential for fostering productive collaborations between local agencies and selected electric utilities.

1.6 Charging Infrastructure: Location, Installation, and Technology

Effective planning and implementation of EV charging infrastructure are vital for the successful transition to electric fleets. This section covers key considerations for the location, installation, and technology of charging infrastructure, with insights from various studies and reports.

1.6.1 Location

Determining the location for charging infrastructure is a pivotal phase in the journey to fleet electrification. A research project by the Genesee Finger Lakes Regional Planning Council has tried to outline the hurdles and prospects involved in initiating fleet electrification (Genesee Finger Lakes Regional Planning Council, 2022). They conveyed that a pivotal phase in this journey is to determine the location for charging infrastructure. According to their study, some agencies prefer to select a site at a fleet depot, or they want to distribute charging stations throughout their organization’s property, or even an employee's residence. This decision is intertwined with whether the charging predominantly occurs overnight or during work hours (Genesee Finger Lakes Regional Planning Council, 2022). In other words, they may require knowing if employees take their work vehicles home and need to charge them there or if the vehicles are left at a fleet site or other agency site to charge overnight. According to research by Nesbitt and Sperling (1998), based on extensive one-on-one interviews with operators and a comprehensive two-part survey involving more than 2700 California respondents, 24% of fleet operations do not maintain on-site central refueling due to space limitations. Additionally, numerous fleets permit employees to take vehicles home overnight due to restricted availability of parking space.

Moreover, the study by Tousignant et al. (2021) recommends agencies collaborate with other companies to establish a charging station network that offers free or discounted charging at multiple locations. Daniels and Nelder (2021) underscores the importance of setting up charging infrastructure before acquiring EVs. This strategy helps prevent challenges related to inadequate charging capabilities as the fleet expands.

1.6.2 Installation

Many organizations have only a limited number of Level 2 chargers and have yet to fully address the significant challenges involved in transitioning a substantial portion of their fleets to EVs. Incrementally adding EVs and chargers each year can be the most expensive method for developing a fleet's charging infrastructure. This piecemeal approach can hinder future optimization efforts, as continuous investment in infrastructure must be recouped over subsequent years. Daniels and Nelder (2021) also highlights the importance of a long-term strategy for building charging infrastructure to minimize total costs. Effective techniques for reducing overall charging expenses include managing utility costs by optimizing the charging load, maintaining an appropriate charger-to-vehicle ratio, centralizing high-power chargers in one location, and preparing charging sites for future expansion by installing necessary utility infrastructure during the initial construction phase. Planning for charging infrastructure is especially complex for fleets with heavy-duty trucks due to their substantial power requirements. Organizations must conduct thorough and long-term planning to ensure the infrastructure can efficiently support these operational demands. A report from Carnegie Mellon University, sponsored by the U.S. Department of Energy, highlights that energy and demand management systems can help fleet operators control the cost of charging units. These systems are designed to regulate charging schedules, capitalizing on low electricity rates while avoiding peak pricing periods by starting vehicle charging only at specified times (Smith and Castellano, 2015).

As noted by Driivz (2022), the increasing demand for EV charging, combined with existing electrical grid loads, means fleet managers cannot always assume the necessary power will be available when needed. There are capacity limits to the number of vehicles that can charge at a given location simultaneously, especially considering the substantial energy required to charge larger vehicles. Energy and demand management systems enable fleet and facility managers to understand and plan for the actual energy available to meet EV charging demands successfully. This involves analyzing energy requirement patterns, maximizing local energy sources, such as battery storage and renewables, and ensuring fleet EVs can complete their assigned tasks. Fleet drivers expect a seamless charging experience and fully charged vehicles whenever needed. Confidence and peace of mind for EV fleet managers come from ensuring that charging schedules align with operational needs rather than disrupting them. A robust software solution for EV smart charging and energy management is essential for achieving these outcomes, optimizing fleet utilization, and enhancing driver satisfaction. The right EV Fleet Management platform will enable fleet managers to save time, reduce costs, and maintain fleet operations efficiently while providing the flexibility and scalability required as the fleet grows.

During the installation phase of EV charging infrastructure, several factors must be considered. According to Smith (2015), the type of foundation can significantly impact costs. Pedestal-mounted charging stations can often be directly anchored onto existing solid surfaces like sidewalks. However, in some cases, a concrete foundation may be necessary, with costs varying based on local factors such as the freeze depth of groundwater. To protect the equipment, property owners may install safety features like bollards or wheel stops, with estimated costs ranging from approximately $200 to $800 for bollards and $100 to $200 for wheel stops.

1.6.3 Technology

The following introduces EV Charger Types (Levels 1-4):

- **Level 1 Chargers:** Typically provide charging through standard 120-volt AC outlets, delivering 2-5 miles of range per hour of charging. These are often used for residential purposes.
- **Level 2 Chargers:** Use 240-volt AC outlets and can deliver 10-20 miles of range per hour of charging. Commonly used in workplaces and public charging stations.
- **Level 3 Chargers (DC Fast Chargers):** Provide rapid charging through direct current, delivering 60-100 miles of range in 20-30 minutes. Suitable for commercial and public charging stations.
- **Level 4 Chargers (Ultra-Fast Chargers):** An emerging technology, offering even faster charging capabilities, though not yet widely adopted.

Workplace settings typically use Level 1 or Level 2 chargers, either as single or dual-port units. Employers may provide Level 1 charging via simple electrical outlets or install more permanent Level 1 charging stations. The choice between networked and non-networked units depends on agency preferences. Networked units offer internet connectivity, often through wired or wireless means, enabling real-time remote monitoring via a central server. Non-networked units are simpler and cheaper but lack remote monitoring and management capabilities. Maintaining a stable charging environment is crucial, as noted by Driivz (2022). EV chargers occasionally encounter technical difficulties, disrupting the charging experience and potentially interrupting business operations for fleets on tight schedules. Drivers expect to locate an available charger and complete the charging session seamlessly at various points along their route, at work, or at the depot. A stable charging environment is essential, and fleet managers need tools to continuously monitor and control the chargers. These tools should enable real-time issue identification and resolution, ideally through automated systems that proactively address problems. Without such automation, managers may need to hire field technicians, leading to increased costs and longer wait times for solutions. Prolonged charger downtime can result in inconsistency and unreliability for drivers. Implementing an effective EV charging infrastructure requires thorough planning and consideration of these factors to ensure a reliable and cost-effective solution.

1.7 Human Factors

The human element plays a critical role in the transition to electric vehicles, as emphasized in the County of Santa Clara's Office of Sustainability report. Drivers unfamiliar with EVs may face behavioral challenges, including range anxiety and other concerns, which can hinder seamless integration. To address these issues, fleet managers should implement driver orientation programs, workshops, or training sessions that cover vehicle features, charging protocols, and optimal driving habits to enhance EV performance and safety (Santa Clara County, 2018).

Training programs focused on energy-efficient driving techniques can extend the operational lifespan of EVs and reduce fuel consumption in conventional vehicles. For complex or heavy-duty vehicles, additional training may be necessary to address the unique operational characteristics of EVs compared to traditional diesel vehicles. It is also crucial to assess whether technical staff have the requisite knowledge and skills for EV repair and maintenance or if additional training is required. Furthermore, evaluating a fleet's maintenance facilities is essential to determine if any upgrades, such as stronger lifts for heavy-duty EVs, are needed to support the transition to electric vehicles (Office of State and Community Energy Programs, 2024). By addressing these human factors, fleet managers can ensure a smoother transition to EVs, fostering acceptance and effective utilization of new technology among drivers and maintenance staff.

1.8 Fleet Managers' Skills

Bridging the skills gap is essential for a smooth transition to fleet electrification. Accenture (2023) examined data from 450 senior fleet management decision-makers across various regions, including North America, Europe, and Asia, highlighting a significant skills gap in the transition to fleet electrification. Traditional internal combustion engine (ICE) fleet managers often lack expertise in critical areas such as energy procurement and the use of advanced tools like Virtual Power Plants, energy storage systems, and load balancing techniques.

The analysis revealed that only 49% of the current workforce possesses the necessary skills for effective electrification, with 10% of organizations yet to assess their skills gaps. This lack of skills often leads to decision-making based on psychological factors such as attitudes, lifestyle, risk perception, and corporate culture, rather than thorough life-cycle cost analysis. Many fleet managers rely on past experiences and brand loyalty, rather than being fully aware of life-cycle costs (Lane and Potter, 2007; Nesbitt and Sperling, 1998). Addressing these skill shortages is essential for successful fleet electrification. By equipping fleet managers with modern energy management knowledge and tools, organizations can optimize their operations and make more informed, cost-effective decisions.

1.9 IT Implementations

Successful fleet electrification necessitates significant IT upgrades and implementations within organizations. Accenture (2023) emphasizes that the early involvement of IT executives in strategic planning is crucial for efficient electric transportation. Digital platforms are essential for managing vehicles and facilities, and the integration of vehicle telematics data, such as battery status and consumption efficiency, can enhance operations and reduce costs. EVs generate valuable charging data, which assists IT departments in planning and integration efforts. In addition, implementing smart charging solutions, bidirectional charging, and participating in Virtual Power Plants (VPPs) can further optimize fleet electrification. These advanced technologies enable better management of energy use, support grid stability, and maximize the benefits of electrified fleets.

1.10 Identifying the Government Incentives

Government incentives are a major driver in the adoption of electric vehicles by organizations. Sierzchula's (2014) study of 14 organizations in the US and the Netherlands, which adopted EVs between 2010 and 2013, identified key factors influencing their purchasing decisions. Fleet managers most frequently cited four main reasons for purchasing EVs: experimenting with new technologies, reducing environmental impact, enhancing their organization's public image, and benefiting from government grants. Financial considerations played a significant role, with eight out of the 14 organizations relying on government grants to mitigate the uncertainties associated with adopting new technology and the high costs of EVs. These grants facilitated objectives like technology testing and emission reduction rather than serving as the primary motivation for purchasing EVs. This raises questions about whether many fleet managers would have chosen to adopt EVs without the financial incentives provided by public policies.

The incentives for fleet electrification extend beyond purchase discounts. Javed et al. (2024) highlights British Columbia's Go Electric Fleets program, which provides various support measures for fleet vehicle electrification. These include personalized advisory services for up to 40 hours, professional development through training sessions and webinars, and coverage of 33% of electrical installation costs, capped at $20,000. Additionally, bulk purchasing programs support small agencies lacking specific government interventions. Sourcewell collaborates with original equipment manufacturers (OEMs) and dealerships to offer quantity-based discounts on EVs to its members. The Climate Mayors EV Purchasing Collaborative, launched in 2017 by Los Angeles and 30 other US cities, leverages collective purchasing power to meet the increasing demand for EVs and charging infrastructure in municipal fleets. These initiatives demonstrate the importance of financial incentives and support programs in facilitating the transition to electric vehicles, particularly for organizations navigating the high costs and uncertainties of adopting new technologies.

Given the background, this project addresses the critical needs of public agencies in managing the transition to an electric vehicle (EV) fleet, focusing on the human and infrastructural factors essential for a smooth and fiscally responsible process. The research methodology involved two primary components: first, an analysis of human factors through a survey of Minnesota agency employees and stakeholder interviews was conducted; and second, an assessment of current fleet characteristics, agency capacities, and operational challenges was completed. Utilizing collected fleet data, we developed a comprehensive model that pairs ten-year life-cycle cost estimates plus an optimized charging infrastructure assessment. Finally, we designed and tested the designed optimization model on Minneapolis trip data to illustrate practical charging strategies. This integrated approach identifies the most economical pathways to electrification based on each agency's unique operational profile, providing policymakers and fleet managers with actionable insights for strategic planning.

Chapter 2: Investigation of the Human Factors Component of Transitioning to EV Fleets

2.1 Introduction

With the ever-changing climate and the necessity for sustainable systems, electric vehicles have been increasingly popular amongst the public as a way to reduce emissions. Emissions from standard gas vehicles have played a large role in the negative impact transportation has had on the environment. The solution to this problem, specifically in the form of sustainable transportation via car, is seen as fully electric vehicles and plug-in hybrid vehicles (PHEVs). One of the largest adopters of electric vehicles is public agencies that utilize agency-owned vehicles that are used for work purposes (Sierzchula, 2014).

While the switch from gasoline to electric vehicles seems like a promising solution, there are a few psychological apprehensions and potential drawbacks associated with this transition that must be overcome. This ranges from the impact on infrastructure, new technology development, and especially, range limitations (Farhar et al., 2016). The following subsections review and discuss various psychological and physical advantages and disadvantages associated with electric vehicle adoption, both as a public consumer, and from the perspective of public agencies.

2.1.1 Consumer Trends & Attitudes

Several studies have focused on the adoption of electric vehicles by consumers and fleets, specifically examining plug-in electric vehicles (PEVs), battery electric vehicles (BEVs), and electric vehicles in general. The jump from standard gasoline vehicles to PHEVs or EVs as a whole has been met with both enthusiasm and apprehension. The primary reason individuals do not consistently use technology is a lack of trust in it (Zmud & Sener, 2017). A significant barrier to the adoption of electric vehicles is a lack of trust in their safety and reliability, driven by cognitive biases like fear of loss and the overestimation of risks such as crashes (Mahdavian et al., 2021). Some studies also suggest gender roles where men are more inclined than women to acquire electric vehicles. This gender-specific trend is evident in men's adoption of vehicles, greater willingness to invest in new technologies, and stronger confidence in the safety of autonomous vehicles (Kyriakidis et al., 2015; Schoettle & Sivak, 2014). Also, individuals with better technological familiarity are more likely to adopt electric vehicles easily (Mahdavian et al., 2021). Specifically, one of the largest considerations when purchasing an electric vehicle is the all-electric range (AER), otherwise known as the distance that the vehicle can go using solely the battery (Farhar et al., 2016). In order to preserve or maintain a charge on an electric vehicle, it must be charged at a charging station for an extended period of time (≥3 hours). This is similar to bringing a standard gasoline vehicle to a gas station and filling up the gas tank, which normally takes less than ten minutes. This phenomenon has caused anxiety among consumers, out of fear of running out of battery, a concept which has been deemed “range anxiety” (Berkeley et al., 2017; Rainieri et al., 2023).

Range anxiety stems from the consumer concern of charging management. Comparatively speaking, currently, public electric vehicle charging stations are much scarcer than gas stations for standard gasoline cars. A field study conducted at the University of Colorado at Boulder studied human adaptation over time with plug-in electric vehicles, and the human factors that impact electric range management. Participants were given plug-in electric vehicles as well as at-home charging stations and were randomly assigned a “managed” electric range or an “unmanaged” electric range. Over the course of nine weeks, participants presumed a normal day-to-day life with their electric vehicle, and questionnaires were distributed to gauge the attitudes around the adoption of their electric vehicle. The study concluded that 90% of participants expressed a generally positive attitude towards driving the vehicle, that they either loved or liked their electric vehicle. Specifically, with a charging station at home, consumers found electric vehicles to be practical and environmentally friendly (Farhar et al., 2016). An online survey was conducted with fleet managers via a five-month research project in Italy to collect empirical data on the factors influencing the adoption of electric vehicles in corporate fleets. The study highlighted a lack of awareness regarding the technical characteristics of these vehicles, with 59% of managers scoring low to medium in the area (Di Foggia, 2021).

Alternatively, there have been various incentives that influence consumer behavior. A common example of this is new electric vehicle purchasers receiving a monetary tax incentive. Another example is workplace promotion. Specifically, one company conducted a workplace study which observed the impact of company incentives on employee purchase behavior. The incentive from the workplace greatly increased the number of electric vehicle purchases (Decrinis et al., 2023). With both financial and workforce incentives, electric vehicle apprehension is met with great positive reinforcement.

2.1.2 Electric Vehicles in Public Agencies

Public agencies already have a strong relationship with the automotive industry, given their frequent usage and purchases. These public agencies often have a large fleet of vehicles that are used by employees for work-related purposes. This factor makes public agencies target consumers to companies that produce electric vehicles. Further, these vehicles can assist agencies in achieving their sustainability goals. The following paragraph expands on EV adoption and operation, exploring driver experiences, operational challenges, and safety considerations.

An analysis of agency behavior was conducted, specifically through fleet manager interviews, to find how these agencies were adopting electric vehicle fleet management a decade ago (Sierzchula, 2014). An electric taxi pilot initiative was deployed in New York City with fast-charge stations instead of battery-swapping stations. The BEV pilot was evaluated based on interviews with fleet operators, drivers, crash and summons data, and trip analysis. Drivers and industry partners were interviewed to discuss other operational issues including charging and battery range, maintenance, passenger comfort, and ease of adaption (New York City Pilot Project, 2013). The result revealed no safety concerns were reported regarding vehicle acceleration or motor power. Drivers found the transition to using electric vehicles smooth, despite differences in acceleration compared to internal combustion engine vehicles. They attributed this to the sensitive touch of the gas and brake pedals, which enhanced safety and responsiveness. They also highlighted thorough training on vehicle safety features and optimal use of braking and acceleration techniques provided by their employers before using the vehicles.

After observing and analyzing fourteen different organizations that adopted electric vehicle fleets, as well as interviewing their fleet managers, public agencies were strongly in-favor of the electric vehicle adoption. These public agencies found that they enjoyed the advanced technologies, operational capabilities, and the positive environmental impact. Most public agencies were also in favor of expanding their electric vehicle fleets, with the exception being some not wanting to expand their fleet due to costs. Overall, public agencies have a mostly positive attitude towards the adoption of electric vehicles for their company fleets.

In today's environment, there is a dire need for a solution to the rise in CO2 emissions produced from transportation. One of the most promising solutions is the adoption of electric vehicles. From a consumer perspective, there are both advantages and disadvantages to be considered. Specifically, there is the psychological concern of range anxiety and battery range management. Alternatively, there are benefits such as financial and potentially employment incentives. From an agency integration perspective, electric vehicles, when adopted on a fleet scale, have a positive impact on their users. Public agencies have found that the capabilities of EVs, both technologically and operationally, are a good fit for their frequent vehicle usage needs (Sierzchula, 2014). Conclusively, electric vehicle integration is associated with positive attitudes when managed properly.

2.2 Survey & Interviews

This chapter employs a qualitative approach to explore the human factors involved in transitioning to electric vehicle (EV) fleets. Surveys and interviews (see **Appendix 1** for survey details). were conducted with agency employees who either currently use or are planning to use EVs for various purposes. The aim was to gain a deeper understanding of the human factors influencing EV adoption among employees managing agency vehicles. The interactive online survey was conducted via Qualtrics platform and distributed by email, which provided detailed insights into employees' professional perspectives on EVs. It examined common attitudes towards EV adoption, concerns related to their use, and expectations regarding performance, convenience, and benefits. The results revealed significant gaps and contradictions in existing research, helping to build a comprehensive narrative of the human factors affecting EV adoption. Following the survey, a series of 15-minute online interviews were conducted with five key stakeholders responsible for managing or using agency fleets. These interviews offered more nuanced responses and additional insights through open-ended questions, further elucidating the specific concerns and professional perspectives unique to the user group.

2.3 Results

The results section of this report is divided into two key parts: an analysis of the survey findings on the human factors involved in transitioning to an EV fleet and a summary of key insights from stakeholder interviews. The first part delves into professionals' perspectives on the human factors influencing the shift to EV fleets within Minnesota state agencies. The second part summarizes the interviews with professionals who specifically use agency vehicles, offering deeper insights into their experiences and concerns regarding the adoption of EVs.

2.3.1 Human Factors Component of Transitioning to EV Fleet Evaluation Survey

This subsection presents the findings from a survey designed to gather the professional opinions of employees who use agency vehicles across the state on the human factor components involved in transitioning to EV fleets. The survey, distributed to various agencies throughout Minnesota, garnered responses from 86 participants representing a diverse array of agencies across 37 counties and 27 cities within Minnesota.

2.3.1.1 General Information

The survey gathered responses from 86 employees across multiple agencies in Minnesota. Among the participants, 21% were fleet managers, 7% were field staff, 21% were operations managers, and 4% were mechanics. The remaining 47% included engineers, directors of public works departments, supervisors, maintenance directors, and other key roles. More than half of the respondents have been for more than 6 years in their current role. Additionally, over half of the respondents use the agency vehicle daily, while only 2% have never used it. In terms of gender, 87% of the respondents are male, and only 10% are female.

2.3.1.2 Adoption and Understanding of EVs

Among the 31 respondents who responded their agency operates an EV, some were from the same agencies, so the responses were aggregated to represent 21 distinct agencies. These 21 agencies in Minnesota reported that 1-10% of their vehicle fleets consist of EVs. Most EVs in these agencies (1-10% of EVs comprise their fleet) are passenger cars and light commercial vehicles, with only a few heavy and specialized trucks, such as those for construction and emergency services. The survey on sentiments toward the transition to EVs, collected from all 86 respondents, indicates that the majority hold neutral views about the transition from traditional vehicles to electric vehicles as shown in **Figure 2.1**. Specifically, 33% have neutral feelings, while 9% and 16% are very positive and somewhat positive, respectively. On the other hand, 29% and 13% are somewhat negative and very negative toward the transition.

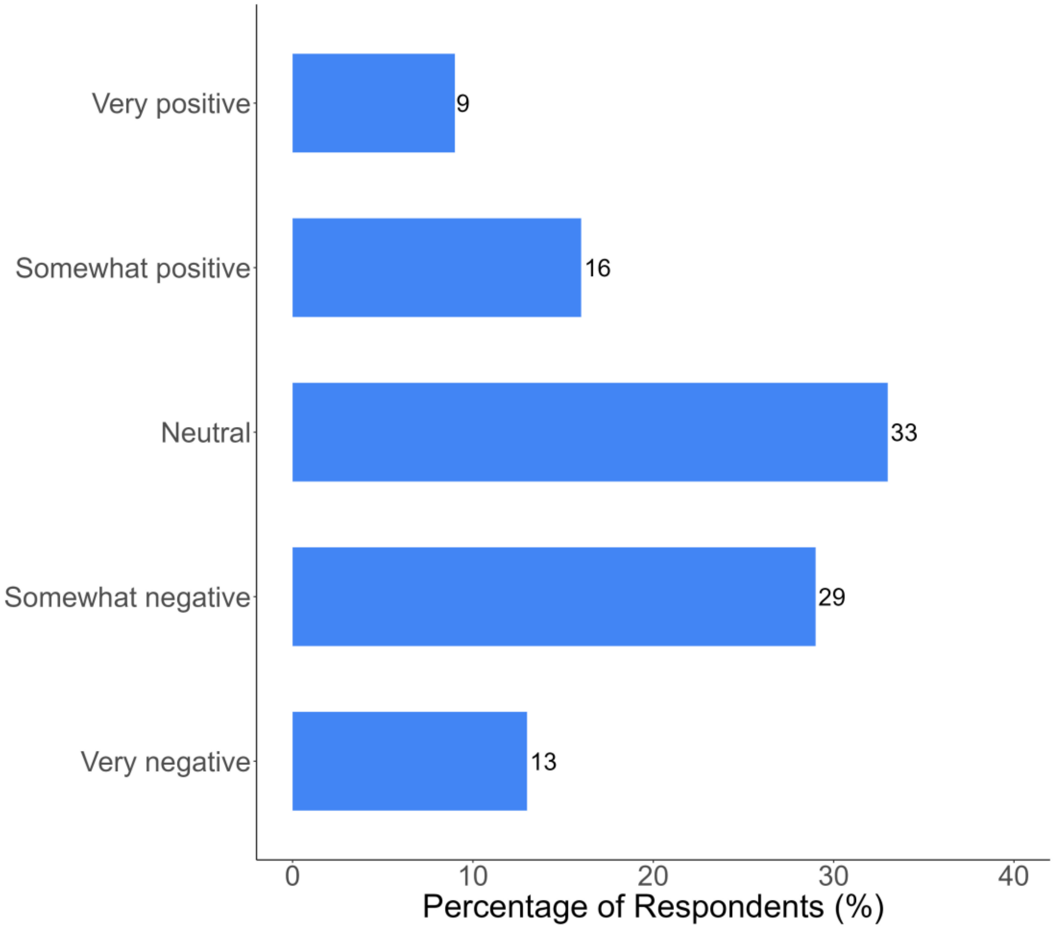

Figure 2.1 Survey Responses on Sentiments Toward the Transition from Traditional Vehicles to Electric Vehicles

The findings indicate that respondents who have never worked with or don't have EVs in their fleet tend to express neutral or negative feelings, while those who have experience with EVs or include them in their fleet report more positive feelings. The neutral stance appears to stem from various factors, although there is an understanding of the benefits associated with electric vehicles. As shown in **Figure 2.2**, 55% believe EVs reduce fuel costs, 36% think they lessen environmental impact, 23% acknowledge the technological advancements in EVs, and only 7% feel they offer an enhanced driving experience. Additionally, 21% of respondents have their own perspectives on the benefits of EVs.

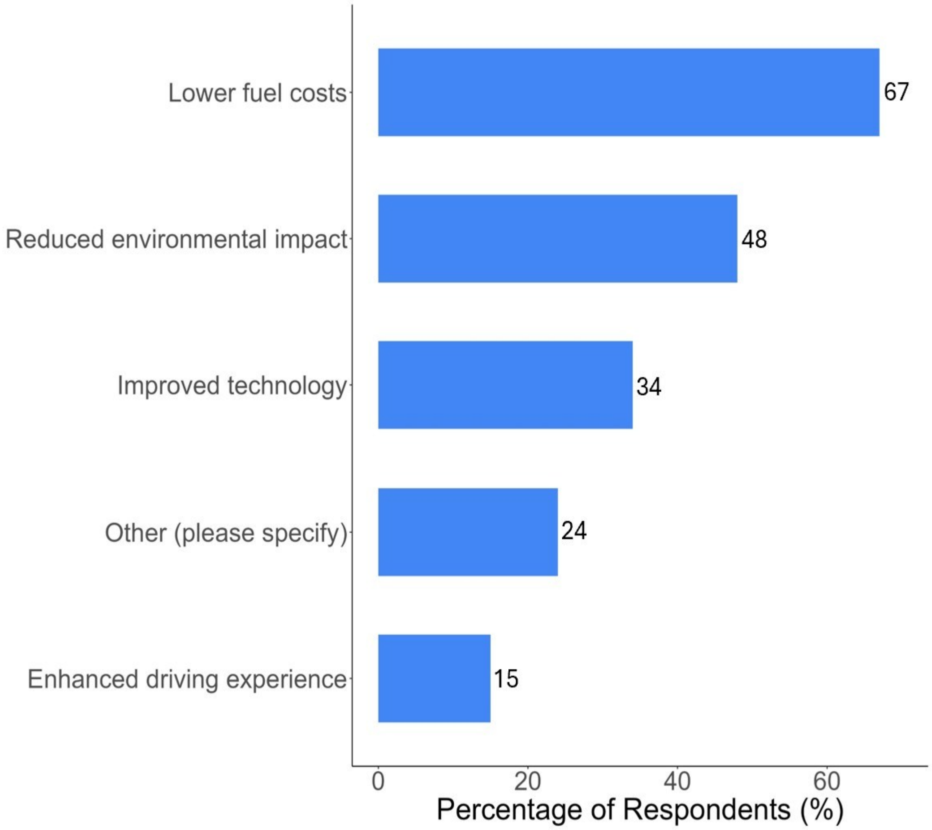

Figure 2.2 Perceived Benefits of Electric Vehicles Among Survey Respondents

2.3.1.3 Concerns and Challenges Regarding EVs

Concerns about EV adoption:

The survey showed that limited driving range is a significant concern for those considering electric vehicles (EVs), particularly for long-distance travel also shown in **Figure 2.3**. The second major issue is the time it takes to charge an EV and the availability of charging stations. Unlike traditional vehicles, which can refuel quickly, EV drivers may struggle if charging stations are not conveniently located. Additionally, 63% of respondents selected the higher initial cost of EVs can be a deterrent, as technology continues to evolve, potentially making the resale value uncertain. Maintenance and repairs pose further challenges, as skilled technicians and mechanics specialized in EVs may not be readily available, making it difficult for agencies to manage these tasks efficiently.

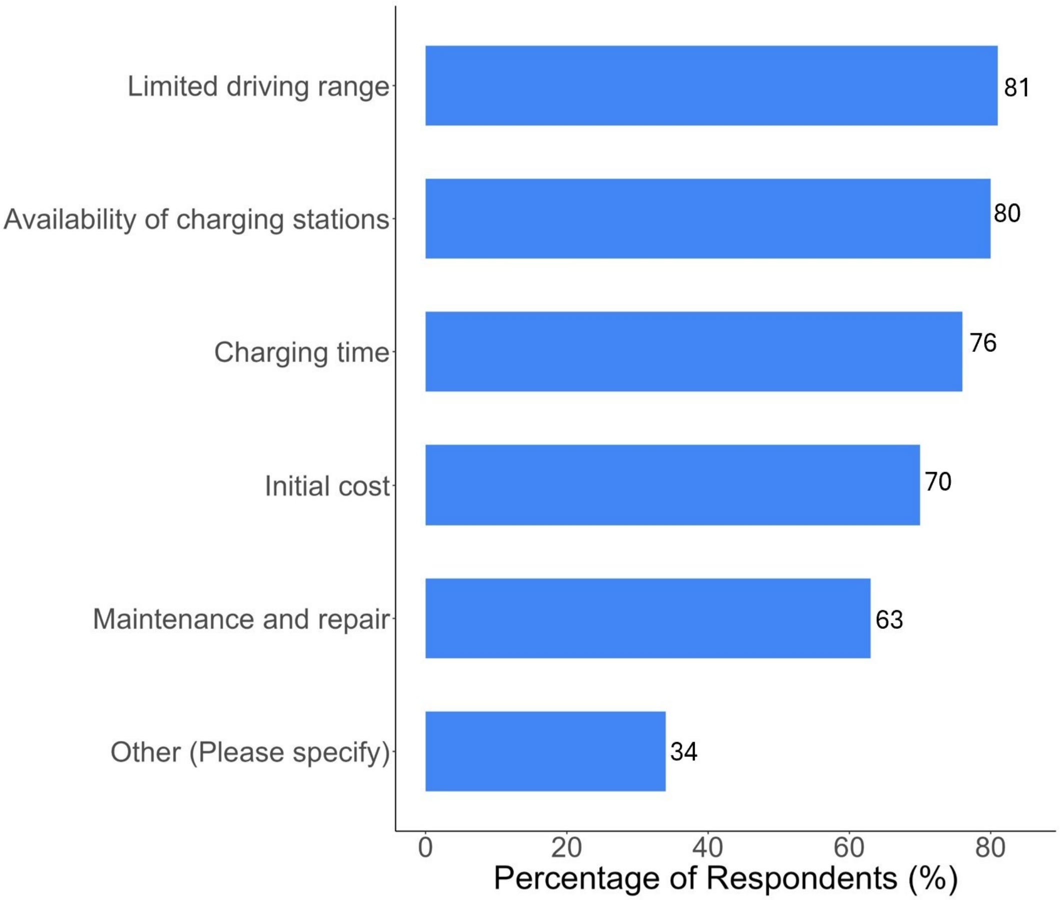

Figure 2.3 Key Concerns About Electric Vehicles Among Respondents

The other survey responses which were open-ended reveal a wide range of concerns and challenges associated with electric vehicles (EVs). Environmental issues are prominent, with worries about battery disposal, pollution from mining for battery materials, and the challenges of recycling EV components. Cold weather performance is also a significant concern, particularly in regions like Minnesota, where respondents question the reliability and power retention of EVs in freezing conditions. Infrastructure and power supply limitations are another critical issue, with doubts about the current grid's ability to support widespread EV adoption, especially during extreme weather.

Respondents also cited high battery replacement costs, the reliability of public charging stations, and the time required for charging as key challenges. Operationally, EVs are perceived as having limited driving range and power, particularly for larger vehicles, and there is concern about the dependence on foreign sources for raw materials. Additionally, the lack of technical expertise for EV maintenance and repair, coupled with the cost and feasibility of upgrading infrastructure, adds to the hesitancy. Other concerns include the quietness of EVs posing potential noise hazards, the complexity of new technology, and uncertainties about resale value and overall investment payback. These varied concerns highlight the practical, environmental, and economic factors that influence the decision to adopt EVs.

Reliability of EVs compared to traditional vehicles:

Respondents expressed varying levels of concern about the reliability of EVs: 45% are somewhat concerned, 22% are very concerned, and the remaining 33% are either neutral or not particularly concerned, as shown in **Figure 2.4.** Respondents expressed a variety of concerns regarding the reliability of electric vehicles compared to traditional vehicles. A major concern is cold weather performance, with worries about reduced battery life, charging efficiency, and the ability to maintain heat during winter operations, especially for heavy-duty vehicles. Maintenance and repair challenges were also highlighted, including the need for specialized training and certified technicians, as well as the availability of parts, particularly in rural areas. Additionally, limited charging infrastructure and long charging times were frequently mentioned, with rural respondents emphasizing the impracticality of using EVs for long shifts without sufficient support. Environmental concerns about battery production, disposal, and long-term costs were raised, along with uncertainty about the overall reliability of EVs due to their relative newness. While some respondents reported positive experiences with EVs, many expressed cautions, especially in demanding or emergency scenarios, citing the need for more data and time to fully assess their long-term performance.

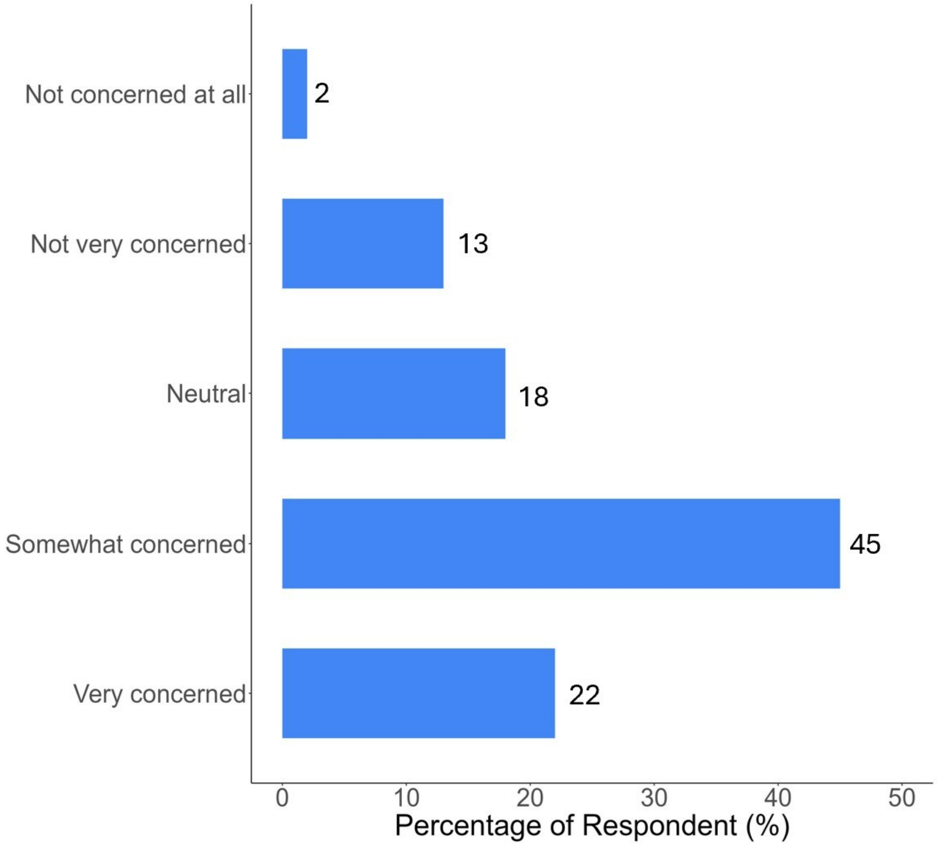

Figure 2.4 Survey Responses on Sentiments Toward the Reliability of Electric vehicles Compared to Traditional Vehicles

Safety of EVs:

More than half of the respondents have no concerns about the safety of EVs, while 42% expressed some concerns regarding their safety as shown in **Figure 2.5**. The most prominent worry is the risk of battery fires, especially during charging or following a collision. Many noted that these fires can be more challenging to extinguish compared to traditional vehicle fires, posing significant risks to first responders and those nearby. There were also concerns about the increased weight of EVs, which could lead to more severe damage in crashes, particularly for pedestrians and cyclists. Additionally, some respondents highlighted potential safety risks for mechanics working with high-voltage systems and the long-term effects of battery disposal.

Other concerns included the potential for stalling, the safety of touchscreen interfaces, and the impact of harsh conditions like road salt on vehicle components. Overall, while the chances of severe incidents are viewed as low, the consequences of such incidents are perceived as potentially severe, prompting concerns about preparedness and safety protocols. These concerns underscore the need for continued advancements in EV safety measures, enhanced training for emergency responders and mechanics, and robust safety standards to mitigate risks associated with battery technology and vehicle operation. Many respondents believe EVs are as safe as, or safer than, gasoline vehicles, especially due to lower tailpipe emissions. While some initially had concerns about cold-weather reliability, they feel these issues have been addressed over time. Advancements in technology and safety training have further reinforced the view that EVs are as secure as traditional vehicles. Overall, there is also a sense of confidence in EV safety.

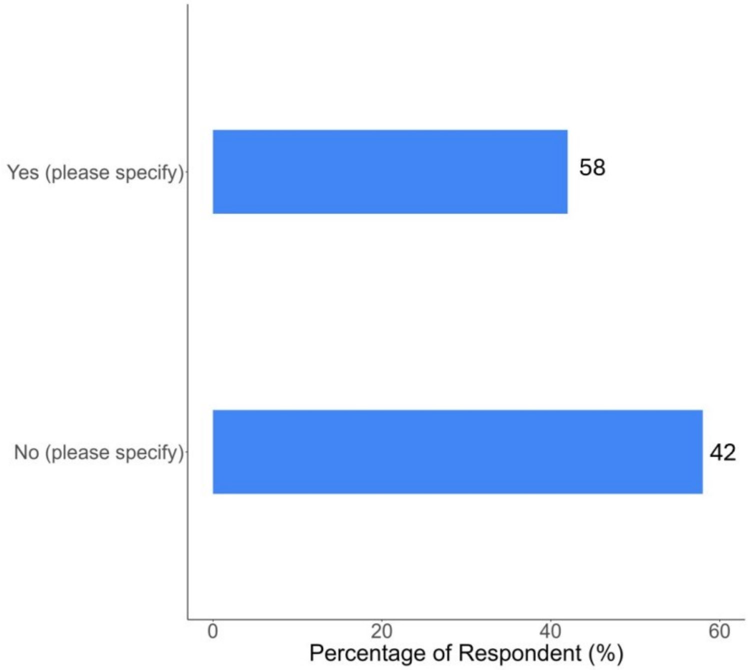

Figure 2.5 Survey Responses on Concerns Regarding Safety of Electric Vehicles

2.3.1.4 Preferences and Expectations of EV Adoption

Training for using EVs:

Regarding training before using electric vehicles (EVs) at work, 68.6% of respondents reported that they have not yet used an EV in this capacity. Additionally, 16.3% stated they received no training prior to using an EV at work, while 2.3% indicated they had received training but had not yet used an EV in their job. Finally, 10.5% confirmed they had received training before using an EV in their work. Some respondents expressed a desire for a hands-on training session, informational workshops, detailed user manuals, and online resources and videos as provided in **Figure 2.6**. They emphasized the importance of practical solutions and learning from organizations with EV experience, as well as showcasing the benefits of heavy-duty and medium/light-duty EVs through real user experiences and financial savings. The majority of respondents are familiar with aspects such as battery life, charging time, range per charge, and the environmental benefits of EVs. However, there is less familiarity with maintenance requirements and the overall cost of ownership when considering the technical characteristics of EVs.

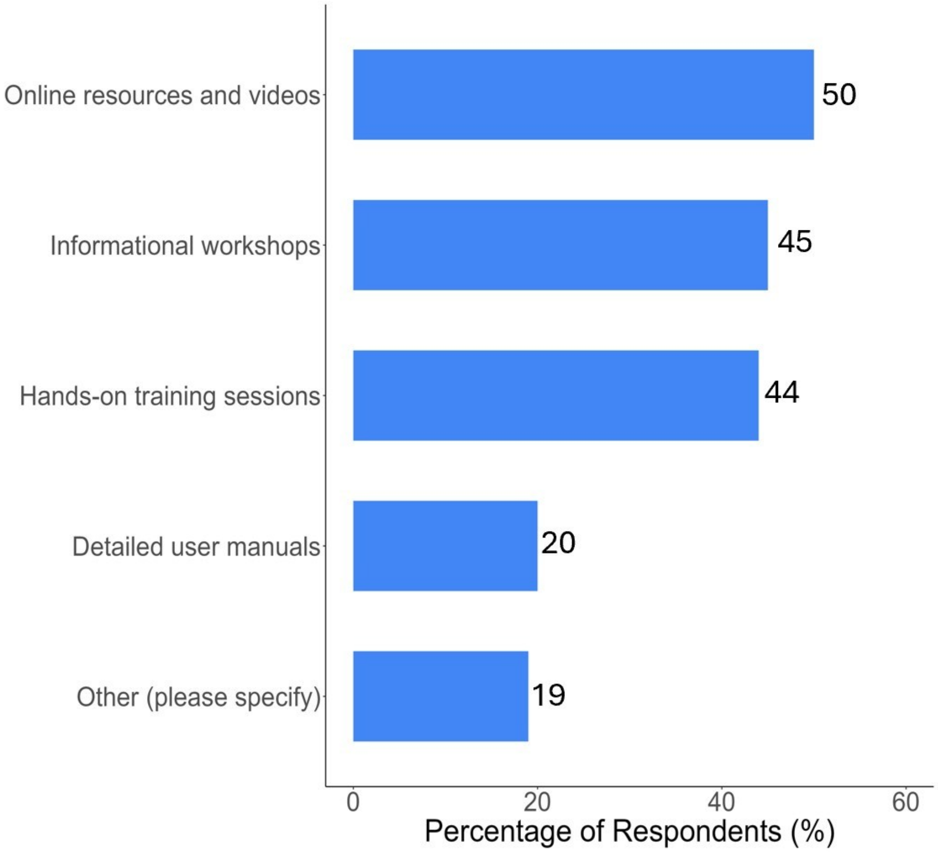

Figure 2.6 Preferred Support and Training Resources for Transitioning to Electric Vehicles

Employee Feedback and Key Considerations for Transitioning to EVs:

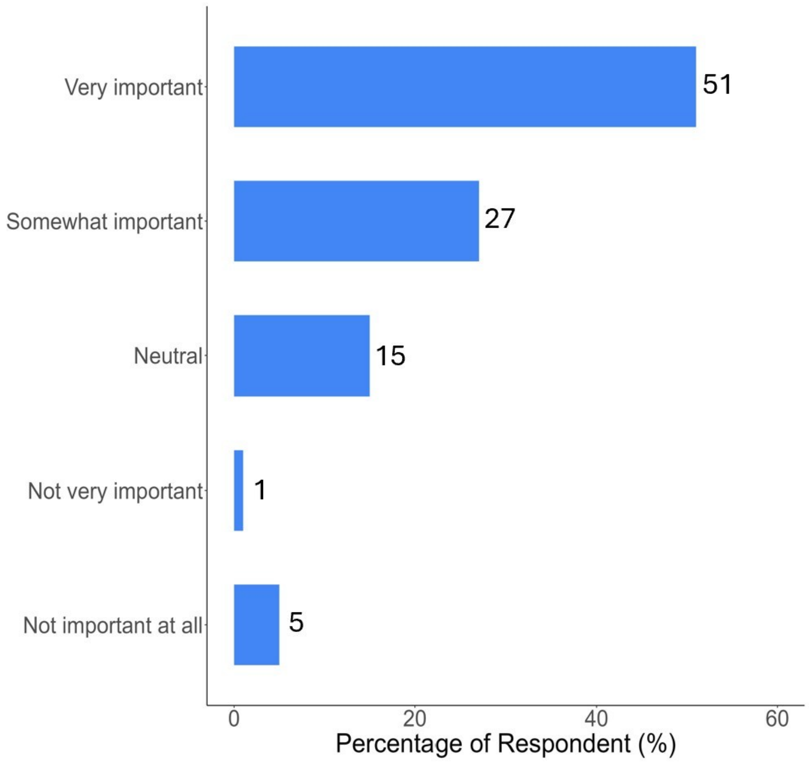

Figure 2.7 Survey Responses on Employee Feedback Consideration for Transitioning to Electric Vehicles

More than half of the respondents believe it is important for the agency to consider employee feedback when transitioning to EVs, as shown in **Figure 2.7**. **Figure 2.8** aligns with the broader discussion of EV adoption challenges and considerations. It highlights the features most desired by users, which include longer battery life (top priority at nearly 80% of respondents), faster charging times, and more charging stations. These factors correspond to concerns about the current limitations of EV technology and infrastructure. Fewer respondents chose advanced navigation systems, indicating that functional features like battery life and charging are more immediate concerns. Respondents provided a range of thoughts on transitioning to electric vehicles (EVs) within their agencies. Key considerations included ensuring that EVs meet user needs, addressing the political and financial implications of EV adoption, and the importance of staff acceptance and involvement in the transition process. Some highlighted the need for scalable charging infrastructure, while others expressed concerns about the current costs and technology limitations, particularly for specialized vehicles. Overall, there is a mix of cautious optimism and skepticism, with some advocating for gradual adoption as technology and infrastructure improve.

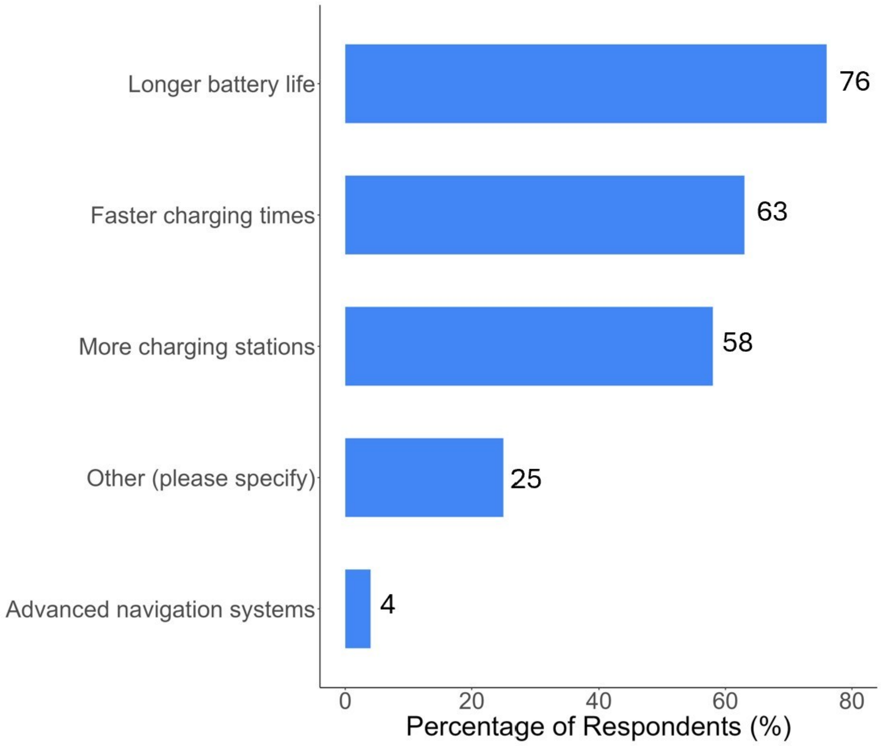

Figure 2.8 Desired Features for Agency Electric Vehicles to Enhance Work Efficiency

2.3.1.5 Perspectives on transitioning to EVs

The following addresses specific survey questions, each targeted at distinct job titles based on the respondents' self-reported roles. Fleet managers, operation managers, field staff, and mechanics were asked tailored questions to capture their unique perspectives and challenges regarding EVs. Their insights provide a comprehensive view of the issues and strategies related to managing and maintaining EV fleets. As EVs are new to the market and only make up 1-10% of the fleets for those agencies that have them, the concerns between those with or without EVs in their fleets were found to be quite similar amongst different agencies.

Challenges in managing electric fleet (Fleet Manager’s perspectives):

Managing a fleet of electric vehicles (EVs) presents several challenges compared to traditional vehicles. Key issues include the significant costs and logistics associated with installing and maintaining charging infrastructure, as well as ensuring sufficient electrical grid capacity. High initial costs and battery replacement expenses are also concerns. There is a need for specialized staff training due to a lack of existing knowledge and experience with EVs. Performance issues such as limited range, reliability in extreme weather, and battery life are highlighted, along with concerns about reduced vehicle trade-in values. Additionally, managing charging locations, times, and ensuring drivers are well-informed about

EV capabilities are operational challenges. Overall, these factors contribute to a more complex management scenario for EV fleets.

Strategies effective for encouraging the adoption of EVs (Operation Manager's perspectives)

To encourage the adoption of electric vehicles (EVs) within agencies, several effective strategies have been identified. Grant funding and substantial rebates can help offset the initial costs, while demonstration programs allow staff to experience EVs firsthand, addressing reservations and showcasing their practical benefits. Expanding charging infrastructure and improving battery technology are crucial to supporting widespread adoption. Providing data on the benefits and performance of EVs can strengthen the case for their use. Engaging with local electric providers and increasing EV visibility can also drive interest. Additionally, offering training to employees can build trust in EV technology, facilitating a smoother transition. Overall, a mix of financial incentives, practical experiences, infrastructure improvements, and education is essential for promoting EV adoption.

Key challenges in EV maintenance (Mechanic and Field staff perspectives):

Concerns about the repair and upkeep of electric vehicles (EVs) center on the high costs of battery replacement and the environmental impact of battery disposal. Respondents also mentioned the significant expense of specialized equipment and training needed for EV maintenance, as well as worries about vehicle range and frequent charging requirements. Additionally, responses indicate a general uncertainty or lack of involvement in EV maintenance, with many respondents unsure about the specific challenges or noting similarities to maintaining traditional vehicles, aside from the fuel system. Overall, there is a limited understanding of the unique maintenance demands of EVs.

2.3.2 Interviews

Five interviews were conducted with professionals who provided in-depth insights into their survey responses. All participants had experience managing agency vehicles and were responsible for fleet operations. The group included four fleet managers and one operations manager. Among the interviewees, two represented agencies with existing EVs, comprising 1-10% of their fleets. The remaining three were from agencies without EVs, with one of these agencies currently exploring EV adoption. The following details the key takeaways from these interviews.

2.3.2.1 Agency perspectives on EV adoption: Key concerns and hesitations

Infrastructure challenges and range limitations:

- Agencies in rural areas, where distances can span up to 75 miles, express skepticism about EVs ability to maintain sufficient charge. The limited charging infrastructure in these regions exacerbates this concern.
- A major challenge for adopting EVs, especially in rural or county settings, is the range limitations of current EV technology. The need for robust charging infrastructure is emphasized as essential for overcoming these challenges, particularly in areas where

vehicles cover longer distances and workdays are extended. Range anxiety remains a significant concern, especially in regions with harsh winters like Minnesota.

- For agencies with vehicles stored indoors, such as city vehicles and emergency services, there are significant concerns about the safety and practicality of installing charging stations in these settings, particularly in underground garages.

Climate Considerations:

- Extreme winter conditions, with temperatures potentially dropping to 20 degrees below zero, raise concerns about EV battery performance and overall reliability. Past negative experiences with EVs in cold climates further fuel these reservations.

Safety and practicality:

- Agencies are cautious about deploying EVs for frontline emergency services due to uncertainties surrounding their reliability and the implications of charging infrastructure on safety and emergency access.
- Some agencies are actively planning the transition to EVs, focusing on administrative fleets and specific equipment types while avoiding heavy-duty vehicles. Challenges encountered include establishing policies, managing costs, and ensuring the transition aligns with operational needs.

Financial Consideration:

- There is concern about the total cost of ownership, including uncertainties about resale value and the impact on budgeting. Agencies are cautious about the long-term reliability and maintenance of EVs, including uncertainties around battery life and determining the most suitable timing for vehicle replacement.

2.3.2.2 Expectations for EV Performance, Usability, and Reliability vs. Traditional Vehicles

Performance and reliability:

- Agencies expect EVs to provide consistent performance and match the reliability of their current vehicles, particularly for administrative and light-duty applications. However, they acknowledge potential issues such as longer charging times.
- EVs are anticipated to require less maintenance overall, with fewer mechanical parts compared to traditional vehicles. However, the transition involves adapting to new technologies, including software and electrical systems, which may necessitate additional training and equipment for mechanics.
- Current users of EVs within city settings have provided positive feedback, indicating that EVs are a good fit for urban environments with predictable usage patterns.

- The interviewees highlighted that electric vehicles (EVs) can significantly reduce idling times, thereby improving overall operational efficiency. Although EVs may not be suitable for replacing entire fleets, they are considered valuable for specific segments of the fleet.

Training and maintenance:

- There is a recognized need for specialized training for mechanics to handle EVs, particularly in diagnosing and repairing electrical and software-related issues. This needs to be addressed by coordinating training programs with manufacturers.
- Providing in-house training on EV operation and maintenance is seen as a key opportunity to prepare teams for the transition to EVs. Ensuring that employees are well-equipped to handle EV-related tasks internally, rather than outsourcing, is viewed as cost-effective and empowering.
- Maintenance costs for EVs are generally expected to be lower, though concerns exist about potential increased wear on tires and brakes, especially for heavier models. Agencies are considering these factors as they plan for EV adoption.

Battery and charging infrastructure:

- Ensuring adequate battery life and access to a widespread network of rapid charging stations is crucial for successful EV adoption. There are also concerns about the disposal and management of EV batteries at the end of their life cycle.
- For successful adoption, EVs must deliver sufficient power and performance. Agencies are cautious about transitioning to EVs if they perceive them as underpowered or if reliable charging infrastructure is not in place.

2.3.2.3 Key Factors Influencing EV Fleet Integration: Support and Challenges

Challenges and Hindrance:

- A significant barrier to EV integration is the limited availability of charging stations, particularly for fleets requiring rapid charging capabilities. This is especially critical for non-office-based tasks, such as snowplowing, where charging times directly impact productivity.
- The limited availability of EV models, especially beyond popular options, and concerns about their reliability and functionality for specific tasks, such as heavy-duty operations pose challenges.
- The need for specialized mechanics and service facilities equipped to handle EVs requires investment in training and infrastructure upgrades, which can be a hindrance if not adequately addressed.

Community and Legislative Influence:

- The push towards electrification can be heavily influenced by local government priorities. Changes in city council members or legislative agendas can shift the focus toward or away from EV integration, depending on their stance on sustainability and electrification.
- Ultimately, the decision to integrate EVs is influenced by whether it aligns with the community's needs and operational requirements. Agencies are more likely to proceed with integration if the benefits, such as reliability and functionality, are evident and supported by local priorities.

2.3.2.4 Importance of incentives and supportive policies in EV adoption

Incentives as a Positive Influence:

- Incentives are generally viewed as beneficial in encouraging EV adoption, particularly as the industry moves toward electrification. While not deemed absolutely necessary, incentives such as grants and cost-free installations (e.g., Ford's charger program) are seen as strong motivators that could facilitate the transition to EVs.
- Incentives aimed at developing charging infrastructure are highlighted as crucial. The availability of charging stations is a significant factor in the decision to adopt EVs, with agencies recognizing the importance of integrating chargers during new construction or renovation phases to reduce future costs.

Long-Term Planning and Strategic Integration:

- Some agencies emphasize the role of long-term planning over immediate incentives. Agencies mentioned that they manage vehicle replacement on five to ten-year cycles, ensuring that any transition to EVs is accounted for within their existing capital planning and funding strategies. While incentives are appreciated, they are not seen as a primary concern in this context.
- In more rural or conservative areas, there is a tendency to adopt a "wait and see" approach, with agencies preferring to observe how other regions manage EV integration before committing. In these cases, incentives could help sway decision-makers, particularly in risk-averse counties where convincing the board is a key challenge.

Supportive Policies vs. Mandates:

- There is a clear preference for incentives over compulsory mandates. Mandates are seen as potentially counterproductive, particularly in communities that may resist forced measures. Instead, positive reinforcement through grants and other supportive policies is viewed as a more effective strategy for encouraging EV adoption without triggering opposition.
- The stance on electrification can be influenced by local government and community attitudes. Changes in leadership or community priorities could shift the focus toward or

away from EV adoption, with incentives playing a potentially crucial role in facilitating this transition.

2.3.2.5 Perspective on EV adoption and sustainability goals

- Most agencies view EV adoption as supportive of broader sustainability and environmental goals, particularly in reducing emissions and reliance on fossil fuels. However, Limited infrastructure and budgetary constraints are major challenges in pursuing EVs, affecting the extent of their integration.
- Safety concerns, particularly regarding battery risks, and the need for specialized training are important considerations as the agency adopts EVs. While grant opportunities and evolving public support may play a crucial role in advancing EV adoption and achieving sustainability goals.

2.3.3 Conclusion

This chapter investigates the human factors involved in transitioning to EV fleets, incorporating insights from a survey of Minnesota agency employees and interviews with key stakeholders. The survey, which involved 86 respondents from various roles across multiple agencies, revealed a mixed sentiment towards EV adoption. While a small percentage of agencies have integrated EVs into their fleets, most respondents hold neutral views about the transition. Concerns primarily focus on the limited driving range, insufficient charging infrastructure, high initial costs, and the challenges of maintenance and repairs.

Reliability and safety of EVs are other significant concerns, especially regarding their performance in cold weather and potential safety risks associated with battery fires and increased vehicle weight. Despite these concerns, many respondents believe EVs are as safe as traditional vehicles and appreciate their lower emissions. The need for effective training and infrastructure to support EV use is highlighted, with many employees expressing a desire for hands-on training and detailed resources.

Interviews with professionals from agencies with and without EVs underscored infrastructure limitations, financial implications, and safety concerns as major barriers to adoption. Rural agencies, in particular, are cautious due to the sparse charging network and extreme weather conditions. Fleet managers and maintenance staff face challenges related to high costs, specialized training, and the complexity of EV maintenance. Financial incentives and supportive policies are seen as beneficial for encouraging EV adoption, but there is a preference for long-term planning and gradual implementation over immediate mandates.

Overall, addressing infrastructure gaps, financial concerns, and training needs is crucial for a successful transition to EV fleets. While there is optimism about the benefits of EVs, overcoming these challenges will be key to broader adoption and integration.

Chapter 3: Survey of Minnesota Agencies on Fleet Conversion Status and Needs

3.1 Introduction

Decarbonization goals and the desire to improve health outcomes have motivated local agencies to begin transitioning their fleets to electric vehicles. To accelerate fleet electrification efforts, the National Renewable Energy Laboratory (NREL) introduced the $5 million Clean Bus Planning Award Program on February 20 (National Renewable Energy Laboratory, 2024). This initiative highlights that transitioning to electric fleets is a complex process, often spanning multiple years and requiring comprehensive studies of technological and financial feasibility.

Various tools and platforms have been introduced to assist fleet operators in managing the costs and logistics of EV adoption. For instance, specialized EV management software enables fleet managers and EV users to track charging status in real-time, facilitating smoother operations (Ampcontrol, n.d.-a; Ampcontrol, n.d.-b). Additionally, EV charging financial analysis tools are available to assess the long-term economic viability of charging projects by analyzing potential revenue streams throughout the equipment's life cycle (Atlas Policy, 2019). Businesses seeking expert guidance can leverage consultancy services that design electrification plans. For example, some utilities and technology providers offer streamlined fleet electrification planning tools, helping organizations optimize their electrification strategies and charging infrastructure deployment (Work Truck Online, 2024). Furthermore, other service providers specialize in delivering end-to-end electrification solutions, including infrastructure installation and ongoing fleet maintenance (ABM).

Despite these challenges persist, primarily due to the lack of a clear and comprehensive roadmap for electrification, this often results in higher costs and discourages fleet managers from adopting EVs. With these backgrounds, this chapter focuses on better understanding the potential and requirements of Minnesota's agencies for a smoother transition to EV fleets.

To achieve this, a survey was designed and distributed to professionals engaged in fleet management and related roles across Minnesota public agencies (see **Appendix 2** for survey details). The survey aimed to gather data on current fleet characteristics, agency capacities, challenges, and opportunities for fleet electrification. Administered via the Qualtrics platform and distributed by email, the interactive survey received responses from a diverse group of professionals, including Fleet Managers, Public Works Directors, City/County Engineers, mechanics, operations managers, financial analysts, and database specialists. Out of 45 agency responses, 21 counties and cities across Minnesota provided complete survey data. These responses offer valuable insights into the current landscape and will help inform strategies for EV fleet adoption.

The survey requested detailed information, including:

- Vehicle Identification Numbers (VINs) for current fleet vehicles, or alternatively, a comprehensive list of vehicle models, makes, years, and trims. This information will be used to identify accurate EV replacement options and conduct cost analyses.
- Vehicle trip logs, including session or trip start and end times, mileage, average daily trip distance, and trip frequency to support optimization of EV fleet utilization.
- Additional details on the primary location of fleet vehicles, peak usage periods, current parking facilities, and future charging strategies.

Following the survey, follow-up questions and interview requests were sent to six counties, resulting in three responses, including one detailed interview with an agency fleet manager. These responses provided more nuanced insights through open-ended questions, helping to further clarify agency concerns, technical challenges, and ideas regarding EV fleet implementation.

3.2 Survey Results

The results of the survey are divided into two main parts:

1. **Current Fleet Status and Key Insights**

This part focuses on the current state of agency fleet operations, including existing fleet characteristics, agency capacities, and a summary of key findings.

2. **EV-Related Information and Future Planning**

For agencies without any EV fleet, the analysis highlights their thoughts on challenges and preferences based on hypothetical EV adoption scenarios.

For agencies with a partial EV fleet, the findings provide insights into their current strategies for managing EV fleets as well as their perspectives on transitioning the entire fleet to electric vehicles. Specific areas of focus include charging infrastructure availability, preferred charging types such as Level 2 or DC fast charging, and future planning for parking and charging facilities.

3.2.1 Current Fleet Status Analysis

This subsection provides insights into the existing conditions and operational patterns of agency fleets. It begins by examining key data such as Vehicle Identification Numbers, overall fleet size, and the distribution of vehicle types (passenger cars versus trucks). Trip logs are used to visualize metrics like average trips per day and typical distance covered, offering a clear picture of daily fleet utilization. The discussion also assesses peak activity periods—when vehicle demand is highest—and concludes with an overview of each agency’s parking capacity, which has implications for future expansion and electric vehicle adoption.

3.2.1.1 Vehicle Identification Numbers and Fleet Composition

A review of the provided data shows fleet sizes ranging from fewer than 10 vehicles to nearly 1,900 (**Figure 3.1**). Passenger cars outnumber trucks in some operations, while other fleets are heavily or entirely truck-based. In several cases, the sum of passenger cars and trucks does not match the total fleet size because many agencies also operate specialized vehicles—such as heavy equipment, off-road machinery, or buses, that do not fall under conventional "car" or "truck" categories. Below is a high-level snapshot of notable patterns:

- **Small Fleets (<50 vehicles):** About one-third of complete respondents have fewer than 50 total vehicles. Several of these have a few—or even zero—passenger cars, relying heavily on trucks (or, in one case, running only buses).
- **Moderate Fleets (50–100 vehicles):** Roughly 10% of complete respondents fall within this range. Both still feature a predominance of trucks, though some have a handful of passenger cars.
- **Mid-Size Fleets (101–200 vehicles):** Around 19% of complete respondents occupy this bracket. These tend to have a closer balance between passenger cars and trucks, but in most cases, trucks still represent a significant portion of the fleet.
- **Large Fleets (201–500 vehicles):** About 24% of complete respondents manage fleets in this range. A few of these agencies have more passenger cars than trucks, but the number of heavy-duty units still remains substantial, often including pickups and specialized trucks.
- **Very Large Fleets (501+ vehicles):** Approximately 14% of complete respondents have more than 500 vehicles, extending up to nearly 1,900. Two of these very large fleets contain slightly more passenger cars than trucks, while the third is dominated by trucks.

Overall Patterns:

1. 7 agencies (33%) operate with more passenger cars than trucks.
2. 13 agencies (62%) have more trucks than passenger cars (some own no passenger cars at all).
3. 1 agency (5%) operates only buses, with no passenger cars or trucks.

These results highlight that the majority rely more heavily on trucks than on standard passenger vehicles. Tracking VINs in this manner ensures accurate record-keeping and informs decisions about vehicle replacement strategies, particularly regarding the transition to EVs. Replacing passenger cars tends to be more straightforward since a broad range of electric sedans, SUVs, and vans is commercially available. In contrast, electrifying truck-heavy fleets can pose greater challenges due to a current lack of large EV truck models, and the specialized functions many trucks perform (e.g., towing, snowplowing, or hauling equipment). Consequently, agencies with high proportions of heavy-duty trucks often anticipate a phased, gradual move toward electrification as technology advances and infrastructure expands.

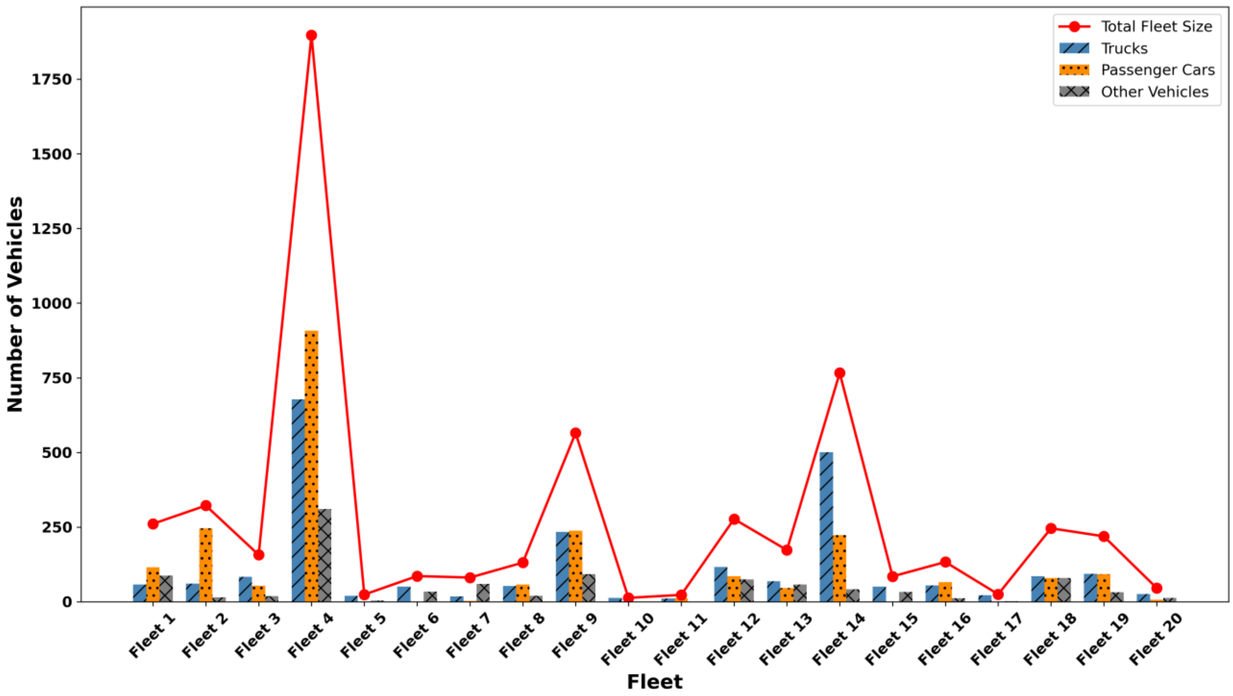

Figure 3.1 **Survey Responses on the Number of EVs in Agencies with EV Fleets**

3.2.1.2 Fleet Usage Insights

The visualizations in **Figures 3.2-3.4** examine key relationships among Fleet Size, Average Trips per Day, and Average Distance per Trip across different agencies. Each data point represents an agency reporting relevant metrics. The orange regression lines indicate overall trends, with 95% confidence intervals shown in the shaded areas.

Figure 3.2 illustrates the relationship between Fleet Size and Average Trips per Day. The upward-sloping regression line suggests that larger fleets generally handle more daily trips. However, there is considerable variation. Some smaller fleets report very high trip counts, while some larger fleets handle relatively few trips. These differences highlight a wide range of operational models and service demands, even among fleets of similar size.

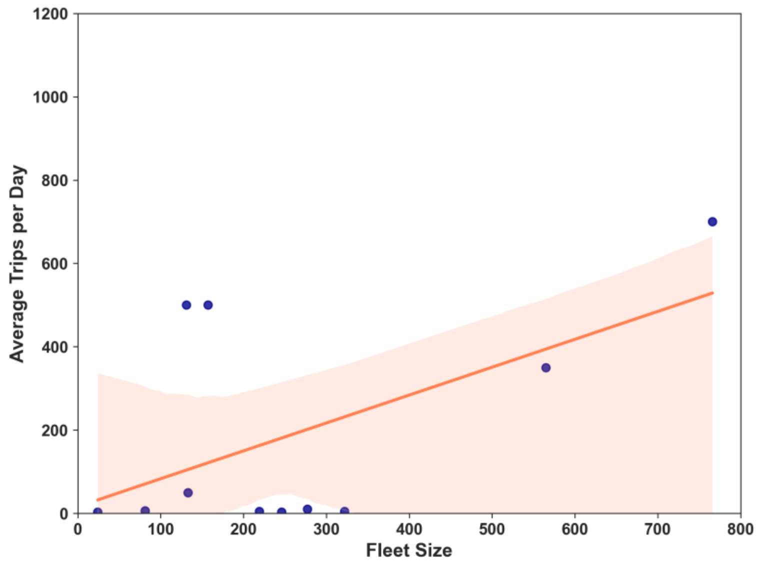

Figure 3.2 Relationship between Fleet Size and Average Trips per Day

Figure 3.3 explores the relationship between Fleet Size and Average Distance per Trip, revealing a slight downward trend. Larger fleets tend to handle shorter, more frequent trips, likely reflecting a focus on local or regional demand. In contrast, smaller fleets often undertake longer trips, potentially due to serving farther areas or fulfilling unique operational requirements.

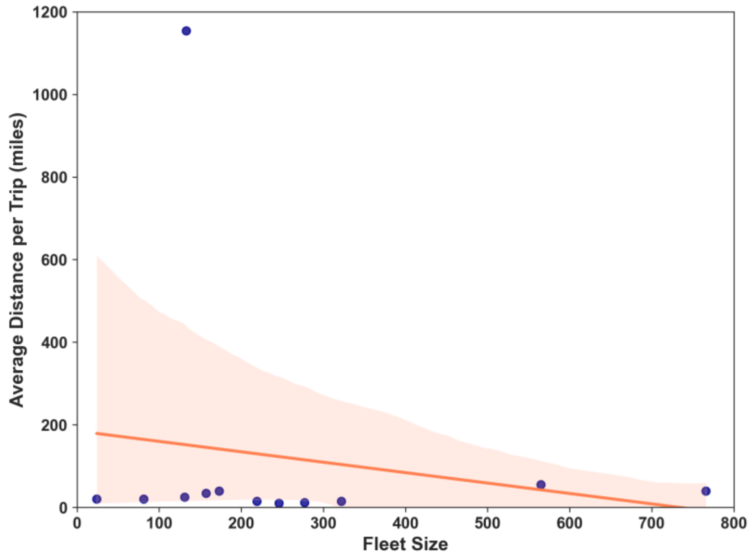

Figure 3.3 Relationship between Fleet Size and Average Distance per Trip

Figure 3.4 examines the relationship between Average Trips per Day and Average Distance per Trip. The negative slope implies that fleets making many daily trips often cover shorter distances on average (e.g., frequent local or in-town driving). Conversely, those with fewer daily trips sometimes travel farther per run. One extreme outlier shows a very high average distance, likely reflecting unique operational requirements (e.g., specialized long-haul routes).

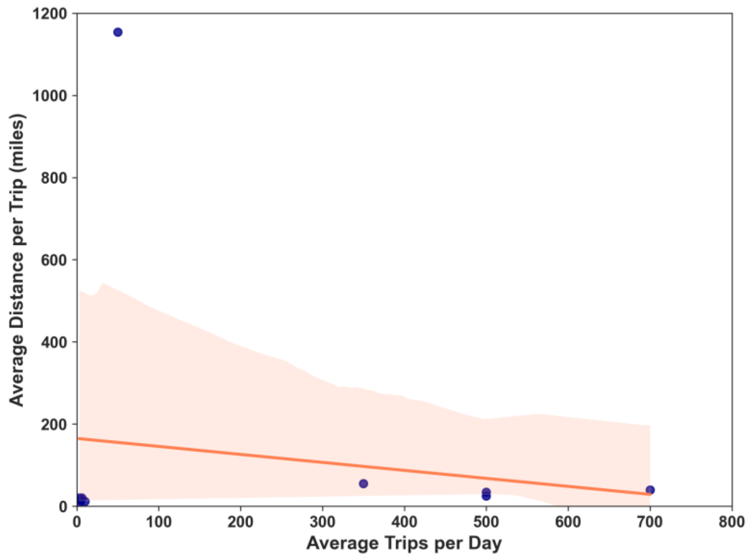

Figure 3.4 Relationship between Average Trips per Day and Average Distance per Trip

In general, no single trend applies universally. Geographic scope, fleet specialization, and operational context all affect daily trip counts and distances. Agencies evaluating electrification or looking to optimize existing operations can leverage these insights to plan around vehicle range, charging infrastructure, and scheduling constraints, particularly those running many short trips each day or consistently covering long distances.

Additionally, the time of day (peak) also matters. Survey data reveals that 71% of respondents experience their busiest times between 8:00 AM and 11:00 AM, 13% see peak hours from 11:00 AM to 2:00 PM, and 17% note alternative windows (e.g., 7:00 AM–3:30 PM, 8:00 AM–4:00 PM, or all-day demand). Identifying these “rush hours” is vital for planning staff assignments and charging opportunities.

3.2.1.3 Parking Capacity for EVs and Anticipated Challenges

A review of responses from agencies shows that about 57% believe their current parking facilities can accommodate the charging infrastructure needed for an EV fleet, while the remaining 43% do not. Even among those indicating “yes,” many anticipate difficulties like installing chargers for every vehicle, reconfiguring spaces to separate EVs from non-EVs, and preventing bottlenecks during peak usage. Infrastructure costs and tight layouts were frequent concerns for those with limited space, particularly in older or underground garages.

Anticipated Challenges

Most agencies, whether they have space or not, foresee at least some obstacles to integrating EV charging into their parking facilities. Common themes include:

1. **Installation and Infrastructure Costs**: Retrofitting lots or garages with electrical upgrades can be expensive, and some budgets may not support extensive projects.
2. **Space Constraints and Layout**: Many worry that combining EV chargers with existing vehicles will cause congestion or require new, larger parking areas. A few agencies are constructing new facilities with dedicated EV parking in mind.
3. **Competing Uses for Parking Spots**: As EV charging stalls occupy prime locations, agencies must decide how to balance availability among electric, non-electric, and specialized vehicles (e.g., police cruisers, and service trucks).
4. **Power Availability and Location**: Providing adequate electricity for medium- or heavy-duty EV charging is especially challenging, requiring higher-capacity connections and potentially more extensive upgrades.

3.2.2 EV-Related Information and Future Planning

This subsection presents the findings from the survey questions designed to gather information about agencies' current EV equipment, management practices, and professional opinions on expanding their EV fleets. Among all responses (both complete and incomplete), 20% indicated that they currently have EVs as part of their fleet. The distribution of EVs within these agencies is illustrated in **Figure 3.5**.

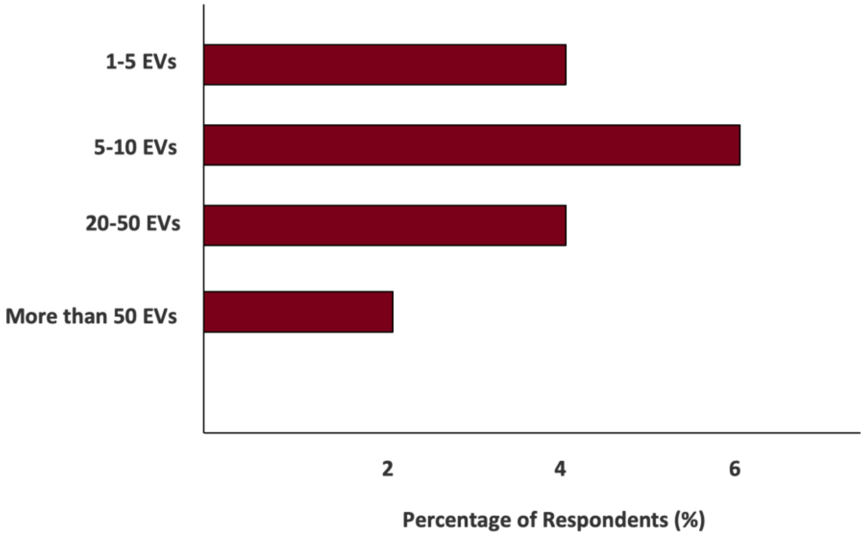

Figure 3.5 Survey Responses on the Number of EVs in Agencies with EV Fleets

3.2.2.1 Charging Strategies

Among the agencies with EV fleets, their current charging strategies and opinions on future charging plans were analyzed in the context of transitioning their entire fleets to electric vehicles. **Table 3.1** summarizes the responses from these agencies, providing insights into their existing practices and anticipated changes as they expand their EV adoption.

Table 3.1 Current Charging Strategies and Future Charging Plans of Agencies with EV Fleets

Number of EVs	Current Charging Strategy	Future Charging Plan
1-5	100% Depot	100% Depot
1-5	75% Depot + 25% Public	50-75% Depot + 25% En-route + 25% Public
5-10	75% Depot + 25% En-route	75% Depot + 25% Public
5-10	100% Depot	26-50% Depot + 26-50% En-route
5-10	100% Depot	75% Depot + 1-25% public
20-50	75% Depot + 25% Public	75% Depot + 25% Public
20-50	100% Depot	75% Depot + 25% (Public or En-route)
> 50	25% Depot Charging + 75%: Nonpublic Charging stations	100% Nonpublic Charging Stations

The responses in **Table 3.1** highlight distinct trends in charging strategies based on fleet size:

- Small Fleets (1–5 EVs): Primarily rely on depot charging, with some agencies planning to incorporate public and en-route options in the future.
- Medium Fleets (5–10 EVs): Current strategies remain depot-focused, but future plans show increased use of public and en-route charging for greater flexibility.
- Large Fleets (20–50 EVs): A balance between depot and public charging dominates current strategies, with future plans indicating a growing preference for en-route options.
- Very Large Fleets (More than 50 EVs): Agencies favor nonpublic charging, with future plans moving entirely to private infrastructure for enhanced reliability.

In conclusion, depot charging remains the primary choice for agencies across all fleet sizes due to its operational convenience. However, as fleet sizes grow, there is a noticeable shift toward diversified charging strategies, including en-route and private infrastructure, to meet the increasing complexity of operational demands.

For agencies without EV fleets, survey responses indicate varied fleet sizes, ranging from fewer than 20 vehicles to over 300, as well as diverse hypothetical charging strategies. Most agencies favor depot charging as the primary strategy in hypothetical EV scenarios, with many reporting a reliance of over 75%. This reflects the operational convenience and efficiency of centralized fleet management. Public charging is considered a supplementary option for some agencies, particularly those with medium-sized fleets, with reliance reaching up to 25%. En-route charging, on the other hand, is rarely included in future strategies, indicating its limited applicability for these agencies.

Several agencies reported no existing plans for EV charging, particularly those with diverse or specialized vehicle fleets. This lack of defined strategies may represent a significant barrier to EV adoption, as these agencies are likely to face challenges in developing and implementing the necessary infrastructure. Based on the findings, it appears that many agencies perceive depot charging as a foundational strategy for future EV infrastructure, particularly for smaller fleets. However, agencies with larger or more diverse fleets may need to consider integrating public and en-route charging options to address the increasing operational complexities associated with EV transitions.

Among the agencies surveyed, only one operates electric heavy/medium-duty vehicles. As illustrated in **Figure 3.6**, the agency primarily relies on depot charging throughout the day, during peak periods of activity, it supplements with public and en-route chargers to meet operational demands.

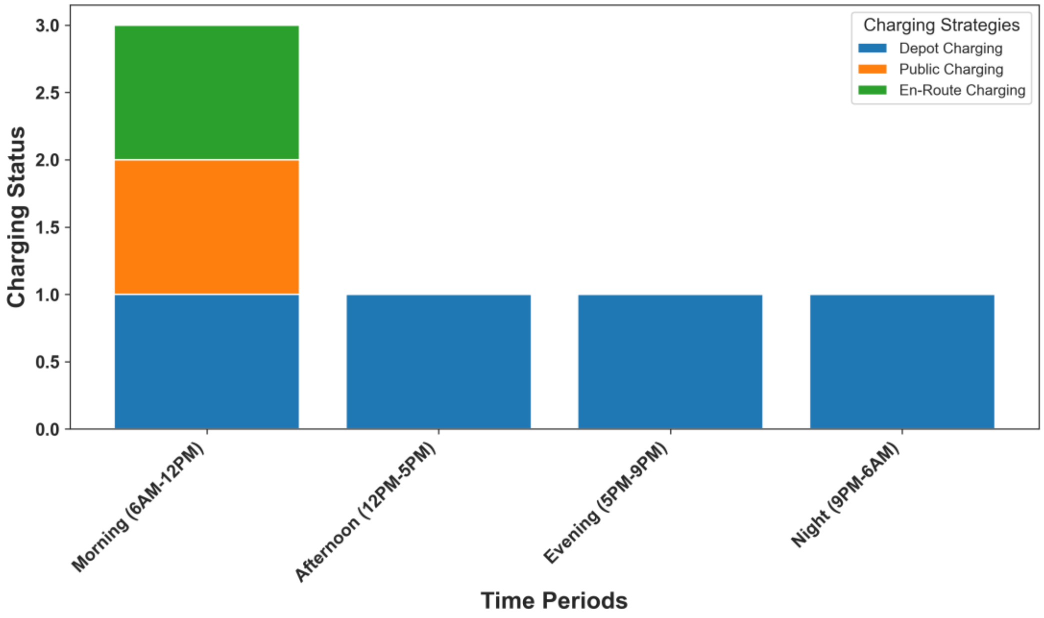

Figure 3.6 Charging Strategy and Timing for Electric Heavy/Medium-Duty Vehicles

3.2.2.2 Charger Technology and Satisfaction

Charger technology could significantly impact the efficiency and scalability of electric fleets. Survey responses from agencies with EV fleets reveal diverse charger types in use, varying levels of satisfaction, and key challenges across different fleet sizes. **Table 3.2** summarizes the charger technologies, their usage, and satisfaction levels.

Table 3.2 Charger Technology and Satisfaction Levels by EV Fleet Size

Number of EVs in Fleet	Charger Technology	Satisfaction Level
1–5	Level 1 (>75%)	Mixed: Some satisfied, others dissatisfied with charging speed
5–10	Level 2 (>75%) + Level 1 (1–25%)	Dissatisfied: Insufficient number of Level 2 chargers

Number of EVs in Fleet	Charger Technology	Satisfaction Level
5–10	DC Fast Charger (>75%)	Satisfied
5–10	Level 1 (1–25%) + Level 2 (1–25%) + DC Fast Charger	Satisfied
20–50	Level 1 (51–75%) + Level 2 (26–50%) + DC Fast Charging	Satisfied
20–50	Level 1 (51–75%) + Level 2 (26–50%)	Dissatisfied: Level 1 chargers too slow; goal is all Level 2
>50	- (Not Complete)	- (Not Complete)

The following points summarize the charging practices and challenges identified for different fleet sizes:

Smaller Fleets (1–5 EVs): Agencies with smaller fleets primarily rely on Level 1 chargers. While some find this sufficient, others report dissatisfaction due to slow charging speeds and lack of capacity to meet operational needs. This suggests that even smaller fleets could benefit from upgrades to Level 2 chargers.

Medium Fleets (5–10 EVs): Medium-sized fleets show more diverse charger adoption, including Level 2 and DC fast chargers. Agencies relying on Level 2 chargers report insufficient infrastructure, while those using DC fast chargers are satisfied, highlighting the value of faster charging technologies for operational efficiency.

Larger Fleets (20–50 EVs): Larger fleets typically use a mix of Level 1, Level 2, and DC fast chargers. Agencies that still depend heavily on Level 1 chargers express dissatisfaction, citing slow charging speeds and limited range per hour. These fleets aim to transition fully to Level 2 chargers to support more demanding applications.

Very Large Fleets (>50 EVs): Data for the largest fleets is incomplete, but the trends suggest that these fleets would require substantial investment in Level 2 and DC fast charging infrastructure to meet their operational needs.

3.2.2.3 Inter-Agency Charger Sharing: Key Findings and Considerations

The survey asked agencies about two approaches to private charger sharing: (1) offering chargers to others during off-peak times, and (2) using chargers owned by other agencies. Of the completed responses, 18% of agencies indicated a willingness to share during low-demand periods, 23% were opposed to sharing, and the remaining 59% were uncertain.

Agencies that were open to either sharing their chargers or using others' chargers often noted the importance of prioritizing their own fleets. Several respondents explained that they could only share chargers during specific hours, or that gate access and security protocols would need to be arranged to protect their facilities. Others cited cost-related concerns—particularly how to handle invoicing for electricity usage—and called for formal agreements or contracts to clarify responsibilities and address liability issues. Some agencies faced infrastructure constraints, especially in rural areas with no existing

EV chargers at all. Others mentioned that their policies prohibit charging non-government vehicles. A few agencies reported self-sufficiency for the current scale of their electric fleets and felt no immediate need to share or seek outside charging. Certain respondents said they would consider sharing or using chargers only if it would reduce their operational costs, while others planned to wait until they better understood the financial implications.

In general, the responses reflect a measured interest in charger sharing, tempered by practical barriers related to scheduling, site security, cost recovery, and administrative logistics. Many agencies remain undecided about the best way to implement inter-agency sharing, acknowledging that clear agreements, robust infrastructure, and careful planning would be needed to make it viable.

3.2.2.4 Public Charging Opportunities and Agency Closeness

Figures 3.7-**3.8** illustrate the spatial distribution of fleet locations based on reported ZIP codes, revealing potential opportunities for shared charging infrastructure among agencies. **Figure 3.7** maps the geographical spread of agency fleet ZIP codes, including those agencies that reported multiple ZIP codes. To explore the feasibility of charger sharing, **Figure 3.8** groups fleet locations by proximity, highlighting regions where multiple agencies are clustered. It is important to note that these observations are based solely on geographical proximity and do not account for other critical factors such as operational schedules, charging requirements, or agency-specific constraints. While these clusters may suggest initial opportunities for collaborative charging solutions, further analysis would be required to evaluate the feasibility of practical implementation.

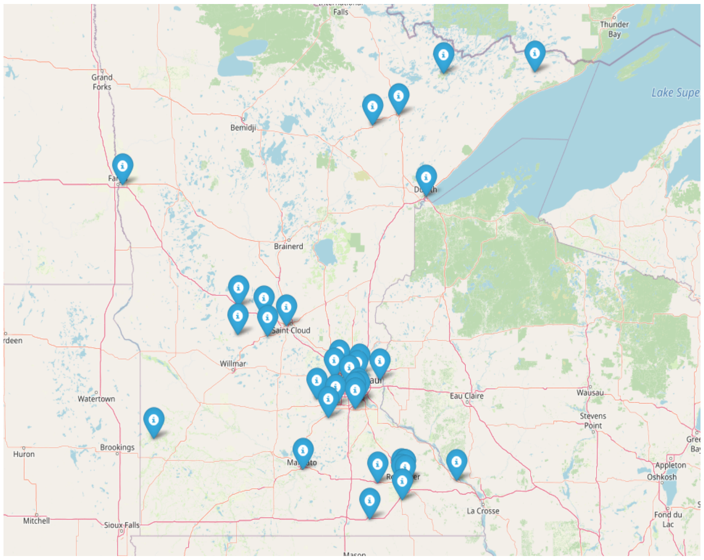

Figure 3.7 Geographic Distribution of Fleet Locations by ZIP Code

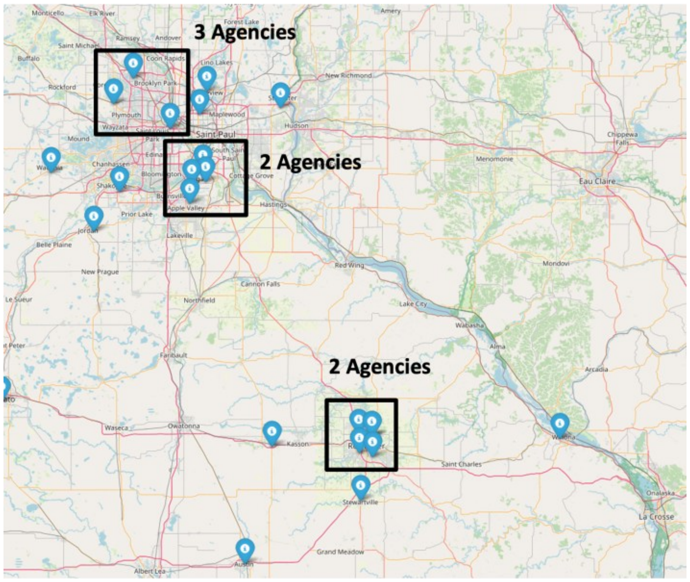

Figure 3.8 Clustering of Agency Fleet Locations

Figure 3.9 evaluates the number of nearby public charging stations for each agency. The horizontal bar chart shows the availability of chargers within a 5-mile radius of each agency's reported ZIP codes. For agencies with multiple ZIP codes, the chart aggregates charger availability across all their ZIP codes. Key findings reveal that the City of Minneapolis has the highest number of nearby chargers, reflecting robust public charging infrastructure. The City of Eagan and Apple Valley also demonstrate significant charger availability. In contrast, agencies such as the City of Roseville, Blue Earth County Public Works, and Carver County have fewer nearby chargers, highlighting areas that may require targeted investment in additional charging infrastructure. This analysis underscores the importance of regional collaboration and strategic investment to enhance public charging infrastructure and support fleet electrification across agencies.

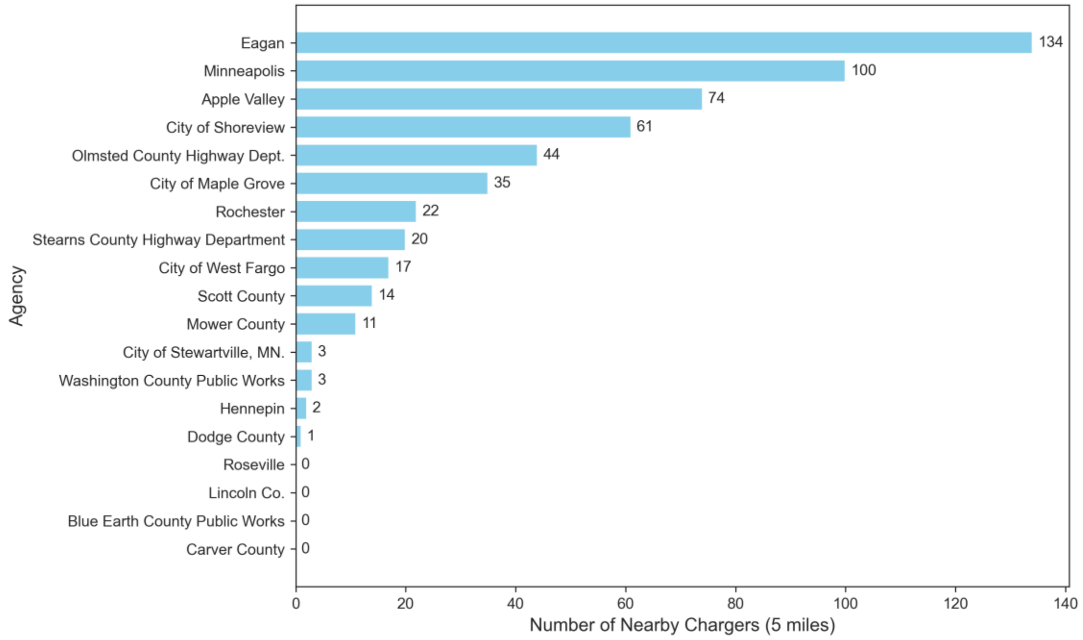

Figure 3.9 Public Charging Opportunities by Agency

3.2.3 Additional Details

Follow-up emails were sent to several agencies for clarification on their survey responses, and additional insights gathered during these exchanges are summarized below.

One agency mentioned they are planning to provide community service by allowing the public to use their EV charging stations. If this initiative proves successful, they may expand operations to additional locations. However, they anticipate challenges in balancing the prioritization of their own fleet's charging needs with accommodating public EVs. To address this, they are considering implementing regulated charging time limits to ensure equitable access. The agency also shared insights gained from discussions with surrounding counties, including the importance of selecting a reliable vendor, understanding hidden operational costs, and establishing clear policies for the public use of chargers.

Another notable perspective shared was the role of idle time in optimizing EV charging schedules without disrupting regular operations. The agency reported that, over one recorded month, their fleet accumulated a total of 24,983 minutes (416.38 hours) of idle time across 59 vehicles. Understanding idle times not only aids in scheduling EV charging during downtime but also offers insights into fleet optimization. For instance, fleets with high idle times could potentially combine tasks and reduce the overall number of vehicles needed, leading to a more efficient and right-sized EV fleet.

3.2.4 Conclusion

This chapter provides insights into the current state of Minnesota's agency fleets, their challenges, and their readiness for transitioning to EVs. The survey responses and follow-up interviews revealed a diverse set of fleet compositions, ranging from small fleets with fewer than 10 vehicles to very large operations with over 1,800. Across these fleets, most agencies demonstrated an awareness of the opportunities and challenges associated with electrification, offering thoughtful perspectives on infrastructure, operational needs, and policy considerations. Key findings include the following:

1. **Fleet Electrification Readiness:** While agencies with smaller fleets tended to express greater flexibility in adopting EVs, those with truck-heavy or specialized fleets anticipated more significant challenges. The lack of heavy-duty EV options, high infrastructure costs, and operational complexity were recurring themes.
2. **Charging Infrastructure and Parking Capacity:** About 57% of respondents reported sufficient parking capacity for EV chargers, though many noted installation costs, congestion, and competing demands for parking spaces as key concerns. For agencies without adequate parking capacity, challenges included space limitations, outdated facilities, and insufficient power availability.
3. **Charging Strategies:** Depot charging remains the preferred option for agencies of all fleet sizes, but larger fleets are exploring diversified strategies, including public and en-route charging, to meet growing operational demands. Smaller fleets, meanwhile, expressed a need for upgrading slow Level 1 chargers to faster and more reliable Level 2 options.
4. **Operational Insights:** Patterns between fleet size, daily trips, and trip distances highlighted diverse operational needs. Larger fleets often performed numerous shorter trips, while smaller fleets tended to manage longer journeys. Idle time analysis underscored the importance of optimizing vehicle usage, providing opportunities to right-size fleets and schedule charging without operational disruptions.
5. **Collaboration and Public Charging Opportunities**: Geographic analysis of agency locations and charger availability revealed opportunities for shared charging infrastructure, particularly in areas where agencies are clustered. Collaborative efforts could reduce costs and accelerate the adoption of EV fleets across municipalities.

Chapter 4: Life cycle Cost Analysis of EV Fleet Conversion

4.1 Introduction

Although the environmental upside of fleet electrification is widely accepted, its financial viability depends on the interplay of battery prices, vehicle utilization, and charging-infrastructure availability. Evidence from national-scale modeling in Australia shows that a rapid transition raises life-cycle costs by roughly 25 percent if battery prices fall slowly, yet becomes almost cost-neutral when those costs decline more quickly (Riesz et al., 2016). Firm-level studies refine this picture. Alp et al. (2022) demonstrated that truck fleets gain a cost advantage only when dense freight demand keeps vehicles productive enough to offset detours and dwell times for charging, while analysis by the Florida Solar Energy Center indicates that lower maintenance expenses materialize only when electric vehicles operate in duty cycles with consistently high utilization (Kettles, 2016). The infrastructure dimension is equally important: Levy et al. (2020) found that widespread fast-charging not only reduces range anxiety but also drives total costs downward by shortening turnaround times, thereby supporting higher daily mileage. Because conventional total-cost-of-ownership metrics can obscure these interactions, researchers have begun adopting service-based measures such as the Levelized Cost per X-mile (Comello et al., 2021), which relate cost directly to the transportation output delivered.

Overall, fleets with predictable, high-mileage routes and reliable fast-charging are first to achieve battery-electric–internal combustion engine (BEV–ICE) cost parity. Lower-utilization fleets or those with poor charging access remain costly to electrify until battery prices fall further or incentives improve. Despite these advances, most studies stop short of agency-level guidance that integrates detailed cost breakdowns. The present analysis closes that gap by pairing ten-year life-cycle cost estimates, drawing on operational data from Minnesota agencies.

4.2 Life Cycle cost analysis

A comprehensive Life Cycle Cost (LCC) analysis is essential for understanding the long-term financial implications of fleet replacement, particularly when transitioning from internal combustion engine (ICE) vehicles to battery electric vehicles (BEVs). The principal cost components considered in this analysis are the vehicle purchase price, operational expenses (primarily energy consumption), and maintenance costs. While detailed operating costs can include items such as fluids, lubricants, tires, insurance, and road taxes (Kettles, 2016), this study focuses on energy consumption, the primary factor differentiating conventional vehicles from their EV counterparts. The fleet’s annual driving mileage plays a critical role in accurately estimating energy consumption, as detailed in the following subsection.

4.2.1 Life Cycle Cost Calculation

The LCC framework adopted here evaluates the total costs incurred over a vehicle's service life, encompassing acquisition, ownership, and disposal costs (Furch et al., 2022). For this project, the analysis includes the initial purchase price, any available incentives, as well as annual operating and maintenance costs, but excludes end-of-life disposal costs. The LCC for each vehicle v is calculated using the following formulation:

$$LCC_v = \left[(P - I) + \sum\nolimits_{i=1}^{n} \left(\frac{o_i}{(1+r)^i} + \frac{m_i L_i}{(1+r)^i}\right)\right]_v$$

Where P is initial purchase cost which will be partially compensated by incentives I, o_i is operation cost in year i, m_i is maintenance cost in year i, L_i is annual mileage, r is discount rate, and n is analysis period in years. The high initial purchase cost of EVs, largely attributable to battery costs, remains a major factor in fleet transition decisions (Khaled et al., 2024).

Annual operating costs are calculated using vehicle-specific parameters, including annual mileage (L_i), miles per gallon (MPG) for ICE vehicles, miles per gallon equivalent (MPGe) for BEVs, the average electricity price (p_e), and the average fuel price (p_f). These costs are formulated as:

- For BEVs:

$$o_i^e = \frac{L_i[mi]}{MPGe\left[\frac{mi}{gal}\right]} \cdot \left(33.7\left[\frac{kwh}{gal}\right]\right) \cdot p_e\left[\frac{\$}{kwh}\right]$$

- For ICEs:

$$o_i^c = \frac{L_i[mi]}{MPG\left[\frac{mi}{gal}\right]} \cdot p_f\left[\frac{\$}{gal}\right]$$

It is assumed that the annual operating cost remains constant over the analysis period; therefore, the yearly index is omitted and the cost is simply denoted as o. With $\alpha = \sum_{i=1}^{n} \frac{1}{(1+r)^i}$, this allows for the following simplified LCC equation:

$$LCC_v = \left[(P - I) + \alpha \cdot o + \sum\nolimits_{i=1}^{n} \frac{m_i L_i}{(1+r)^i}\right]_v$$

EV alternatives for each ICE vehicle were identified with the DRVE tool (Atlas Public Policy, 2024). The tool takes Vehicle Identification Number (VIN) data and annual Vehicle Miles Traveled (VMT) as inputs. This analysis relies on DRVE Version 2.0 (released in April 2024), which incorporates vehicle specifications, purchase prices, and incentives to recommend the most suitable EV replacement for every ICE model. An expected service life of ten years is assumed for all vehicles. **Figure 4.1** presents a comparative analysis of LCCs for ICE and BEV technologies using the average reported annual mileage from the City of Minneapolis fleet. However, mileage varies significantly across individual vehicles, so the results should not be interpreted as a definitive conclusion about the cost-effectiveness of any specific make or model.

Notably, LCC calculations were performed only for vehicles with reported annual mileage or sufficient odometer data; vehicles lacking such information were excluded. Maintenance costs were determined on a per-mile basis, as detailed in **Table 4.1**, with rates sourced from the DRVE tool. The table differentiates maintenance costs by vehicle technology, class, and years in service.

Table 4.1 Maintenance cost per mile estimates derived from the DRVE User Guide (Atlas Public Policy, 2024; Burnham et al., 2021).

Technology	Year	BEV	PHEV	ICE
Light-Duty Vehicles	Year 1-5 Year 6+	$0.0610 $0.0793	$0.0900 $0.1170	$0.1010 $0.1313
Medium-Duty Vehicles	Year 1-5 Year 6+	$0.0660 $0.1440	N/A	$0.1100 $0.2400
Heavy-Duty Vehicles	Year 1-5 Year 6+	$0.2550 $0.4800	N/A	$0.4250 $0.8000

The LCC analysis was conducted for all eligible ICE vehicles and their recommended BEV replacements, excluding vehicles already electrified. For consistency, city-cycle MPG and MPGe ratings were used (highway values excluded). A discount rate of 4.53% was applied throughout the analysis (Raustad and Fairey, 2014). Plug-in hybrid electric vehicles (PHEVs) were not considered in this study, as the focus was on a direct comparison between ICE and BEV technologies. The analysis uses a gasoline price of $2.98 per gallon, reflecting last month's average for regular fuel in Minneapolis (American Automobile Association, 2025), and an electricity rate of $0.159 per kWh (PowerOutage.us).

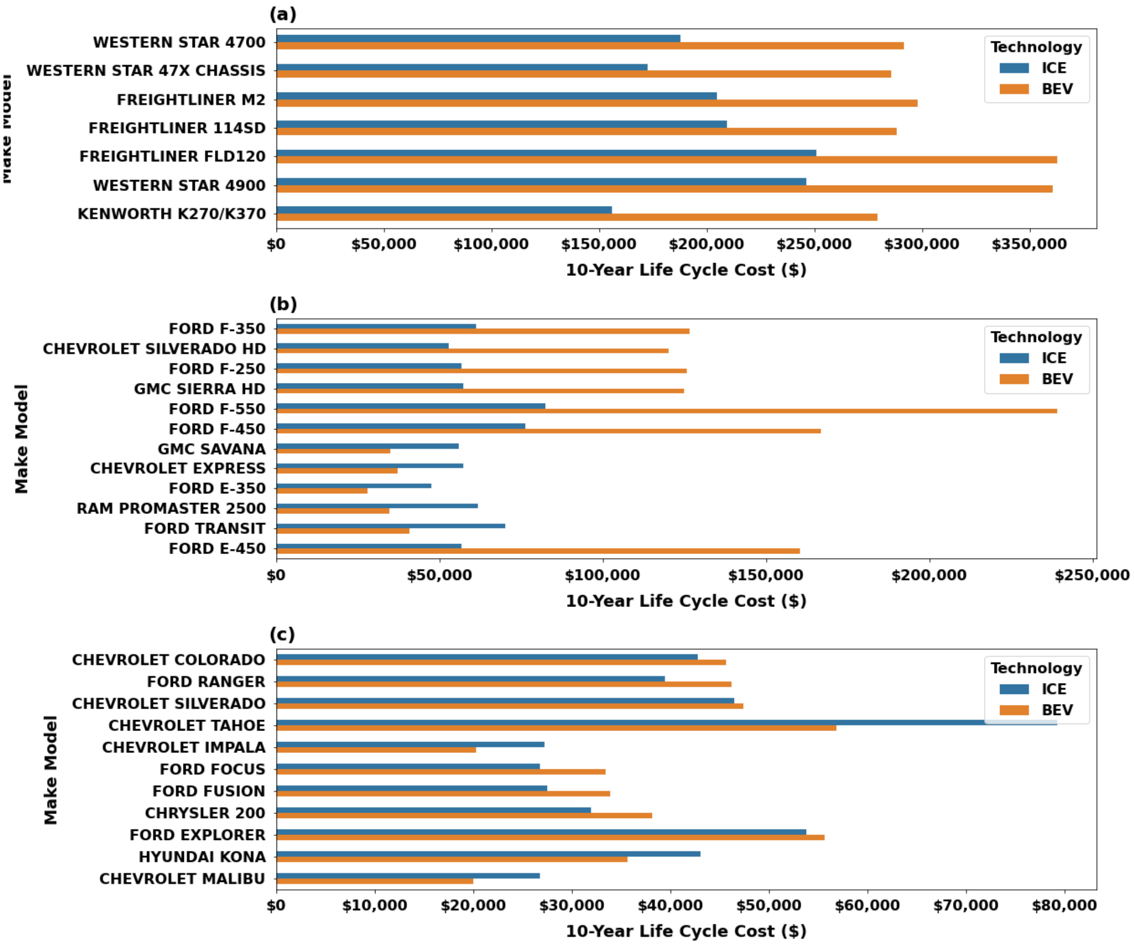

Figure 4.1 Comparison of 10-Year LCC between ICE and BEV technologies across various vehicle classes using fleet data from the City of Minneapolis. (a) heavy-duty vehicles (class 7-8), (b) medium duty vehicles (class 3-6), (c) passenger vehicles (light-duty).

In addition to life cycle cost analysis, it is essential to evaluate the payback period before transitioning an agency fleet to electric vehicles. The payback period is defined as the number of years required for the cumulative savings generated by operating a BEV to offset its higher initial purchase cost compared to an ICE vehicle. Define the ICE upfront cost as the vehicle's purchase price, and the BEV upfront cost as the BEV purchase price minus any incentives. The upfront cost difference is then:

- Upfront cost difference = BEV upfront cost – ICE upfront cost

Because BEVs generally incur lower annual energy and maintenance expenses than ICE vehicles (U.S. Department of Energy – Energy Efficiency and Renewable Energy, n.d.-b), the cumulative savings from these lower running costs will, over time, close the upfront-cost gap. The payback year is the first year in which cumulative savings exceed that gap. **Table 4.2** summarizes the annual cost savings for each vehicle class over a ten-year period and indicates the payback year if it occurs within this timeframe. If the payback is not achieved within ten years, it is reported as "No Payback." A "No Payback" outcome arises when the upfront gap is simply too large, either because the BEV model is still expensive or because annual mileage is too low to generate sufficient savings. Payback can also fail if BEV operating costs rise above ICE costs, for example, if electricity prices climb, though at the assumed rate of $0.159 kWh^{-1}, all annual savings remain positive. Conversely, if the upfront cost difference is negative (i.e., the BEV, after incentives, costs less than the ICE), the payback period is labeled as "Instant," since the investment is immediately recovered.

Table 4.2 Total saving and payback period for each vehicle class based on average annual mileage using fleet data and trip history from the City of Minneapolis.

Vehicle Name	BEV Alternative	Use Case	GVWR Category	Upfront_Cost_Diff	Total_Savings_10Y	Payback_Period (10-Year Horizon)
WESTERN STAR 4900	2024 FREIGHTLINER ECASCADIA 116 291 KWH	Tractor	Heavy-Duty Vehicles (Class 7-8)	157000	42497	No Payback
WESTERN STAR 4700	2024 FREIGHTLINER EM2 194 KWH	Heavy-Duty Straight Truck	Heavy-Duty Vehicles (Class 7-8)	146000	42028	No Payback
KENWORTH K270/K370	2024 FREIGHTLINER EM2 194 KWH	Heavy-Duty Straight Truck	Heavy-Duty Vehicles (Class 7-8)	146000	22679	No Payback
FREIGHTLINER M2	2024 FREIGHTLINER EM2 194 KWH	Heavy-Duty Straight Truck	Heavy-Duty Vehicles (Class 7-8)	146000	52412	No Payback
FREIGHTLINER FLD120	2024 FREIGHTLINER ECASCADIA 116 291 KWH	Tractor	Heavy-Duty Vehicles (Class 7-8)	157000	45157	No Payback
FREIGHTLINER 114SD	2024 FREIGHTLINER EM2 194 KWH	Heavy-Duty Straight Truck	Heavy-Duty Vehicles (Class 7-8)	115000	36353	No Payback
WESTERN STAR 47X CHASSIS	2024 FREIGHTLINER EM2 194 KWH	Heavy-Duty Straight Truck	Heavy-Duty Vehicles (Class 7-8)	146000	32667	No Payback
RAM PROMASTER 2500	2023 FORD TRANSIT VAN CARGO	Cargo Van	Medium Duty Vehicles (Class 3-6)	-22500	4556	Instant
GMC SIERRA HD	2023 LIGHTNING SYSTEMS ZEV4	Medium-Duty Pickup	Medium Duty Vehicles (Class 3-6)	71500	3825	No Payback
GMC SAVANA	2023 FORD TRANSIT VAN CARGO	Cargo Van	Medium Duty Vehicles (Class 3-6)	-15500	5251	Instant

Vehicle Name	BEV Alternative	Use Case	GVWR Category	Upfront_Cost _Diff	Total_Savings_ 10Y	Payback_Period (10-Year Horizon)
FORD TRANSIT	2023 FORD TRANSIT VAN CARGO	Cargo Van	Medium Duty Vehicles (Class 3-6)	-15500	13777	Instant
FORD F-550	2023 ROUSH FORD F-650	Medium-Duty Straight Truck	Medium Duty Vehicles (Class 3-6)	167500	13053	No Payback
FORD F-450	2023 PHOENIX MOTORCARS FORD E-450	Medium-Duty Straight Truck	Medium Duty Vehicles (Class 3-6)	96500	5943	No Payback
FORD F-350	2023 LIGHTNING SYSTEMS ZEV4	Medium-Duty Straight Truck	Medium Duty Vehicles (Class 3-6)	62500	7956	No Payback
FORD F-550	2023 ROUSH FORD F-650	Medium-Duty Pickup	Medium Duty Vehicles (Class 3-6)	177500	12909	No Payback
FORD F-250	2023 LIGHTNING SYSTEMS ZEV4	Medium-Duty Pickup	Medium Duty Vehicles (Class 3-6)	73500	4400	No Payback
CHEVROLET EXPRESS	2023 FORD TRANSIT VAN CARGO	Cargo Van	Medium Duty Vehicles (Class 3-6)	-11500	8591	Instant
FORD E-450	2023 PHOENIX MOTORCARS FORD E-450	Medium-Duty Straight Truck	Medium Duty Vehicles (Class 3-6)	115500	11880	No Payback
FORD E-350	2023 FORD TRANSIT VAN CUTAWAY	Medium-Duty Straight Truck	Medium Duty Vehicles (Class 3-6)	-11500	10430	Instant
FORD E-350	2023 FORD TRANSIT VAN CUTAWAY	Cargo Van	Medium Duty Vehicles (Class 3-6)	-16500	451	Instant
FORD F-350	2023 LIGHTNING SYSTEMS ZEV4	Medium-Duty Pickup	Medium Duty Vehicles (Class 3-6)	72500	3572	No Payback

Vehicle Name	BEV Alternative	Use Case	GVWR Category	Upfront_Cost_Diff	Total_Savings_10Y	Payback_Period (10-Year Horizon)
CHEVROLET SILVERADO HD	2023 LIGHTNING SYSTEMS ZEV4	Medium-Duty Pickup	Medium Duty Vehicles (Class 3-6)	68500	1021	No Payback
CHEVROLET IMPALA	2023 CHEVROLET BOLT EV	Car	Passenger Vehicles (Light-Duty)	-5700	1286	Instant
CHEVROLET MALIBU	2023 CHEVROLET BOLT EV	Car	Passenger Vehicles (Light-Duty)	-5700	1030	Instant
HYUNDAI KONA	2024 CHEVROLET EQUINOX 1LT	SUV/MPV	Passenger Vehicles (Light-Duty)	900	8300	1
CHEVROLET SILVERADO	2023 FORD F-150 LIGHTNING 4WD	Medium-Duty Pickup	Passenger Vehicles (Light-Duty)	6195	5253	No Payback
CHRYSLER 200	2023 TESLA MODEL 3 RWD	Car	Passenger Vehicles (Light-Duty)	9070	2822	No Payback
FORD RANGER	2023 FORD F-150 LIGHTNING 4WD	Light Pickup	Passenger Vehicles (Light-Duty)	9930	3127	No Payback
FORD FUSION	2023 FORD MUSTANG MACH-E RWD LFP	Car	Passenger Vehicles (Light-Duty)	7695	1309	No Payback
FORD FOCUS	2023 FORD MUSTANG MACH-E RWD LFP	Car	Passenger Vehicles (Light-Duty)	7695	945	No Payback
FORD EXPLORER	2024 KIA EV9 STANDARD RANGE RWD	SUV/MPV	Passenger Vehicles (Light-Duty)	10640	8862	No Payback
CHEVROLET TAHOE	2024 KIA EV9 STANDARD RANGE RWD	SUV/MPV	Passenger Vehicles (Light-Duty)	-6800	15627	Instant
CHEVROLET COLORADO	2023 FORD F-150 LIGHTNING 4WD	Light Pickup	Passenger Vehicles (Light-Duty)	6195	3347	No Payback

Each vehicle class in Table 4.2 aggregates results from multiple vehicles in the City of Minneapolis fleet. Payback calculations are based on the average annual mileage for each class. To further assess the influence of annual mileage on payback outcomes, **Table 4.3** reports the 10th percentile, and 90th percentile annual mileages observed within each class, as well as the corresponding payback periods.

For vehicle classes where annual savings are positive but insufficient at current mileage to offset the upfront cost difference within ten years, we estimate the minimum annual mileage required for finite payback. The present value of ten-year summation of operation and maintenance costs is:

- For ICE:

$$\boldsymbol{C^c = \sum_{i=1}^{10} \frac{1}{(1+r)^i} \cdot \left[o_i^c = \frac{L_i}{MPG} \cdot p_f \right] + \frac{m_i^c L_i}{(1+r)^i}} \ ,$$

- For BEV:

$$C^e = \sum_{i=6}^{10} \frac{1}{(1+r)^i} \cdot \left[o_i^e = \frac{L_i}{MPGe} \cdot (33.7) \cdot p_e \right] + \frac{m_i^e L_i}{(1+r)^i}$$

Assuming uniform annual mileage ($L_i = L$ for all i):

$$C^c = L \cdot \overline{C^c}, \quad C^e = L \cdot \overline{C^e}$$

Define the present value of savings (P_B) and the upfront cost difference (P_C):

$$P_B = C^c - \ C^e \ , P_c = \text{Upfront cost difference}$$

When $P_c > P_B$, the required uniform annual mileage, L, for payback within ten years (shown in the last column of **Table 4.3**) is given by:

$$L \geq \frac{P_c}{\overline{C^c} - \ \overline{C^e}}$$

Table 4.3 Payback period for each vehicle class based on 10th, 90th percentiles annual mileage of fleet in the same vehicle calss using fleet data and trip history from the City of Minneapolis. The last column reports the required annual mileage (L^*) needed to achieve payback within ten years.

Vehicle Name	Use Case	GVWR Category	10th percentile mileage	Payback of 10th percentile mileage	90th percentile Mileage	Payback of 90th percentile Mileage	Annual Mileage_For_10Y _Payback
WESTERN STAR 4900	Tractor	Heavy-Vehicles	6488	No Payback	6488	No Payback	23,971 miles
WESTERN STAR 4700	Heavy-Straight Truck	Heavy-Vehicles	1624	No Payback	14360	No Payback	22,483 miles
KENWORTH K270/K370	Heavy-Straight Truck	Heavy-Vehicles	3492	No Payback	3492	No Payback	22,483 miles
FREIGHTLINER M2	Heavy-Duty Straight Truck	Heavy-Vehicles	4107	No Payback	12192	No Payback	22,483 miles
FREIGHTLINER FLD120	Tractor	Heavy-Vehicles	6894	No Payback	6894	No Payback	23,971 miles
FREIGHTLINER 114SD	Heavy-Straight Truck	Heavy-Vehicles	2206	No Payback	7950	No Payback	17,709 miles
WESTERN STAR 47X CHASSIS	Heavy-Straight Truck	Heavy-Vehicles	2634	No Payback	7504	No Payback	22,483 miles
RAM PROMASTER 2500	Cargo Van	Medium-Vehicles	2068	Instant	2068	Instant	_
GMC SIERRA HD	Medium-Pickup	Medium-Vehicles	858	No Payback	7237	No Payback	60,647 miles
GMC SAVANA	Cargo Van	Medium-Vehicles	2383	Instant	2383	Instant	_
FORD TRANSIT	Cargo Van	Medium-Vehicles	1559	Instant	12055	Instant	_
FORD F-550	Medium-Straight Truck	Medium-Vehicles	1212	No Payback	5203	No Payback	39,407 miles
FORD F-450	Medium-Straight Truck	Medium-Vehicles	2646	No Payback	11022	No Payback	90,832 miles

Vehicle Name	Use Case	GVWR Category	10th percentile mileage	Payback of 10th percentile mileage	90th percentile Mileage	Payback of 90th percentile Mileage	Annual Mileage_For_10Y _Payback
FORD F-350	Medium-Straight Truck	Medium-Vehicles	2634	No Payback	11947	No Payback	56,271 miles
FORD F-550	Medium-Pickup	Medium-Vehicles	1086	No Payback	4816	No Payback	39,670 miles
FORD F-250	Medium-Pickup	Medium-Vehicles	1837	No Payback	5718	No Payback	62,343 miles
CHEVROLET EXPRESS	Cargo Van	Medium-Vehicles	1761	Instant	7611	Instant	_
FORD E-450	Medium-Straight Truck	Medium-Vehicles	821	No Payback	4288	No Payback	23,099 miles
FORD E-350	Medium-Straight Truck	Medium-Vehicles	1886	Instant	1886	Instant	_
FORD E-350	Cargo Van	Medium-Vehicles	204	Instant	204	Instant	_
FORD F-350	Medium-Pickup	Medium-Vehicles	749	No Payback	6512	No Payback	61,495 miles
CHEVROLET SILVERADO HD	Medium-Pickup	Medium-Vehicles	466	No Payback	1490	No Payback	58,102 miles
CHEVROLET IMPALA	Car	Passenger Vehicles	441	Instant	2525	Instant	_
CHEVROLET MALIBU	Car	Passenger Vehicles	930	Instant	1305	Instant	_
HYUNDAI KONA	SUV/MPV	Passenger Vehicles	9115	1	9115	1	_
CHEVROLET SILVERADO	Medium-Pickup	Passenger Vehicles	2543	No Payback	5868	9	5,233 miles
CHRYSLER 200	Car	Passenger Vehicles	64	No Payback	5825	No Payback	10,180 miles
FORD RANGER	Light Pickup	Passenger Vehicles	3369	No Payback	3425	No Payback	10,788 miles
FORD FUSION	Car	Passenger Vehicles	271	No Payback	3532	No Payback	9,236 miles
FORD FOCUS	Car	Passenger Vehicles	279	No Payback	2356	No Payback	9,236 miles

Vehicle Name	Use Case	GVWR Category	10th percentile mileage	Payback of 10th percentile mileage	90th percentile Mileage	Payback of 90th percentile Mileage	Annual Mileage_For_10Y _Payback
FORD EXPLORER	SUV/MPV	Passenger Vehicles	8441	No Payback	8441	No Payback	10,134 miles
CHEVROLET TAHOE	SUV/MPV	Passenger Vehicles	2160	Instant	14639	Instant	_
CHEVROLET COLORADO	Light Pickup	Passenger Vehicles	1890	No Payback	3759	No Payback	5,233 miles

4.2.2 Comparing Life Cycle Costs Across Agencies

Multiple agencies, including Hennepin County, Scott County, Blue Earth County, Stearns County, and Carver County, provided fleet VINs and annual mileage estimates for this analysis. Using these data, **Figure 4.2** summerizes the aggregated 10-year LCC of each agency's ICE fleet versus its recommended BEV alternatives. Fleets already operating as electric or those for which the optimal replacement was a plug-in hybrid electric vehicle (PHEV) were excluded, as PHEV transitions fall outside the scope of this study. **Figure 4.2** includes a pair-to-pair replacement of each ICE vehicle with an equivalent-duty BEV alternative, and the agency-reported annual mileage for each vehicle was then used to calculate operational costs; no right-sizing of the fleet or mileage adjustments were applied. However, agencies should note that right-sizing vehicles where feasible or increasing annual mileage utilization could directly reduce the cost gap between ICE and BEV options. As illustrated in the figure, when BEVs exhibit a higher 10-year LCC compared to ICE vehicles, the primary factor is the higher upfront cost. Even though BEV operational costs are generally lower than those of ICE vehicles, low mileage usage does not allow sufficient operational savings to overcome the higher initial investment. Agencies should consider the following points:

- Variability in local electricity tariffs, fuel pricing, and available incentives, as this analysis assumes uniform energy prices, maintenance costs, and incentives across all agencies.
- Additional infrastructure-related expenses for charging stations, which are not included here but will be detailed separately in the following section.
- The potential impact of changes in fleet utilization over time, as this analysis is based on a single year of mileage data without adjustments for fleet growth, shrinkage, or duty changes.

Figure 4.2 highlights significant variation in LCCs across agencies, primarily driven by fleet size and annual mileage differences. For example, Hennepin County has the highest total 10-year LCC for both ICE and BEV fleets, reflecting its larger fleet size and higher cumulative mileage. Conversely, Blue Earth County reports the lowest total LCC, consistent with its smaller fleet and lower annual mileage. Overall, moving to a BEV fleet typically raises life-cycle costs relative to retaining ICE vehicles, but the magnitude of that difference varies by agency, reflecting each fleet's composition and operating patterns. In some cases, Lincoln County, for instance, high ICE operating costs already outweigh the higher BEV purchase price, so electrification would actually lower total life-cycle costs.

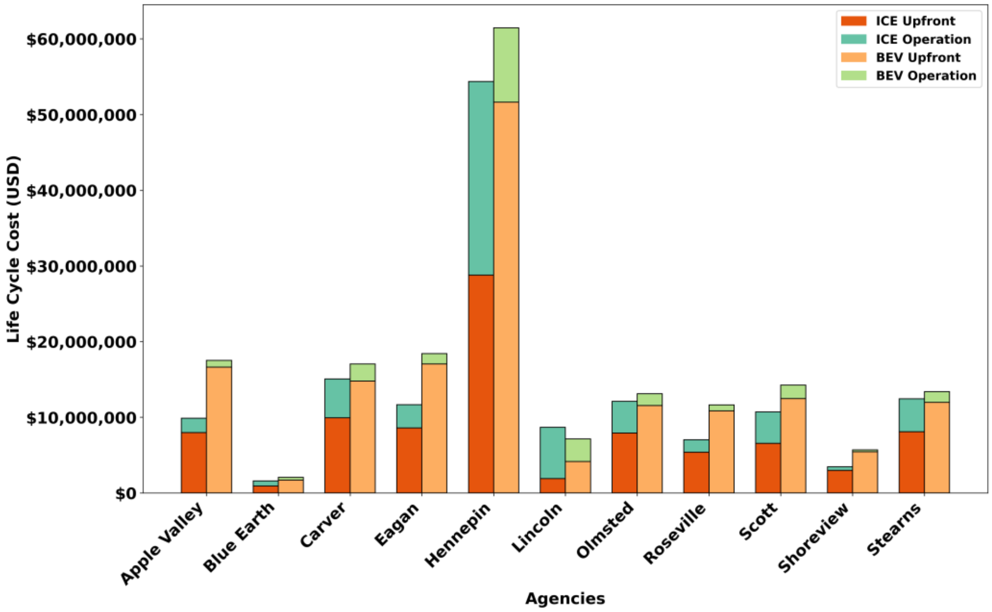

Figure 4.2 Comparison of 10-year life-cycle costs (LCC) between ICE and BEV fleets across agencies using reported annual mileage.

Figure 4.3 provides a class-level view of these costs, with panels (a) light-duty, (b) medium-duty, and (c) heavy-duty. Agencies can use this graphic to identify the best starting points for fleet electrification:

1. *Light-duty vehicles*: In most agencies, BEVs and ICE vehicles are already at life-cycle cost parity, and in some cases ICE fleets even cost more. This makes Light-duty fleet a strong starting point for fleet electrification. Purchase incentives or modest increases in annual utilization can further strengthen the cost advantage of BEVs.

2. *Medium-duty vehicles:* This class remains the most difficult to electrify cost-effectively. Without substantial increases in utilization or right-sizing, the upfront BEV cost continues to outweigh long-term operational savings.

3. *Heavy-duty vehicles:* BEVs tend to outperform ICE vehicles due to substantially lower energy and maintenance costs, despite higher upfront prices. Agencies such as Lincoln and Hennepin already report favorable outcomes in this category. However, the market for heavy-duty BEV models is still developing, and availability remains limited.

Prioritizing electrification of light- and heavy-duty fleets, where life-cycle cost parity or advantage is already evident, will help agencies maximize early benefits. For medium-duty vehicles, adopting a phased strategy that considers operational needs, right-sizing opportunities, and potential funding support will help manage the transition more effectively. It is important to note that the current model does not account for Minnesota-specific winter effects, such as range reduction, or possible mid-life battery replacements, both of which could impact BEV operating costs. Agencies are advised to conduct sensitivity analyses using local duty-cycle and climate data to further refine their life-cycle cost estimates.

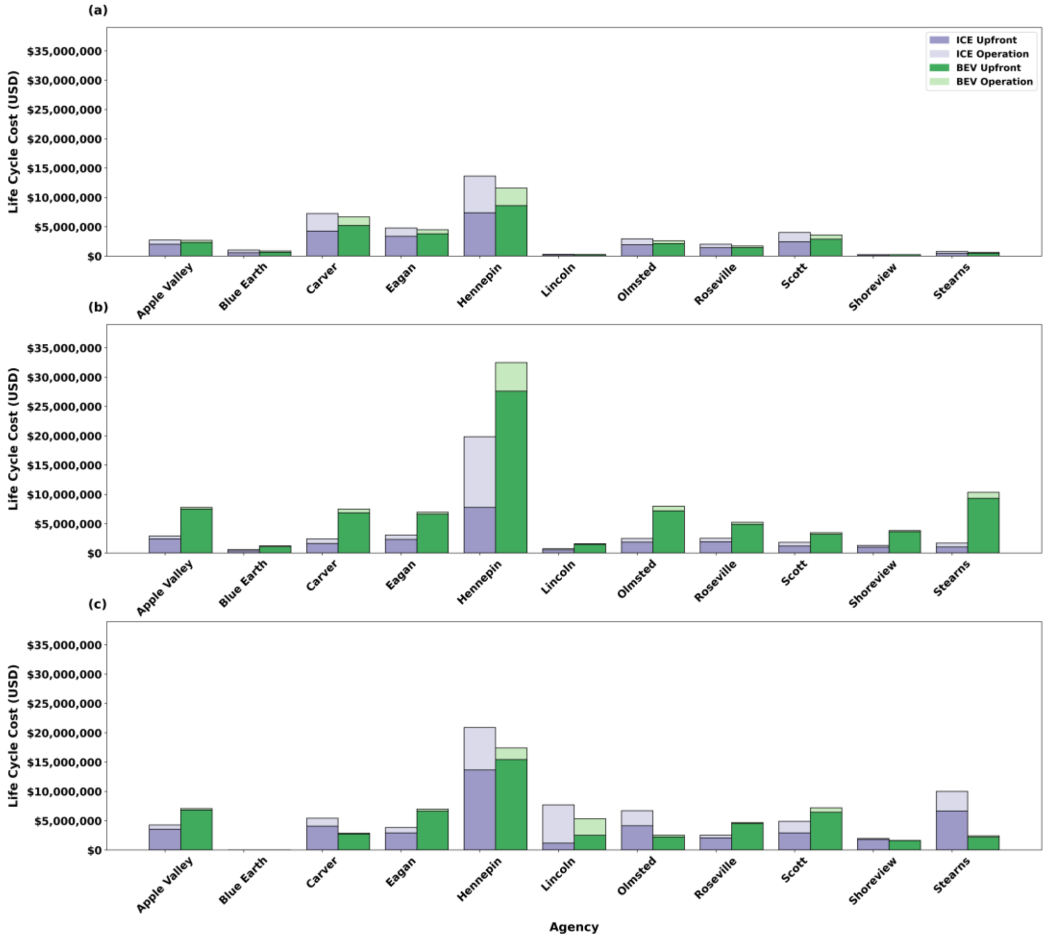

Figure 4.3 Comparison of 10-year life-cycle costs between ICE and BEV technologies by vehicle class across agencies: (a) light duty; (b) medium duty ; (c) heavy duty.

4.2.3 Conclusion

This chapter provided a detailed 10-year life cycle assessment for public agency fleets across Minnesota, leveraging shared fleet data. Based on the analysis, the financial case for electrification is highly contingent on vehicle class and operational patterns. For light-duty vehicles, battery electric alternatives are already at or near cost parity with internal combustion engine vehicles, making them a financially sound starting point for fleet transition. In contrast, medium-duty vehicles remain the most challenging to electrify economically, as their higher upfront costs are not sufficiently offset by operational savings under current utilization rates. Heavy-duty vehicles show a more promising financial profile, where significant savings in energy and maintenance could outweigh the substantial initial investment, particularly in high-mileage applications. The analysis further confirms that achieving cost parity often requires vehicles to meet specific annual mileage thresholds, a level many current fleet vehicles do not reach. Therefore, proactively increasing the annual mileage of BEVs after transition directly accelerates the payback period.

Chapter 5: Charging Infrastructure Planning

5.1 Introduction

The strategic planning of charging infrastructure is a critical determinant for a successful fleet electrification. Moving beyond vehicle selection, this chapter utilizes recent Minneapolis trip data to analyze actual usage patterns. Based on this analysis, we develop an optimization model for determining optimal charger placement, quantity, type, and a phased implementation strategy designed to maintain operational efficiency under budgetary constraints.

5.2 Agency Fleet Driving Patterns

The City of Minneapolis was the only agency to provide detailed trip history data; therefore, the analysis in this section is based on trip records from the Minneapolis fleet, collected over five days in October 2024. The Dashboard for Rapid Vehicle Electrification (DRVE)(Atlas Public Policy, 2024), an Excel-based tool, was used to match existing vehicles to suitable EV alternatives based on their VINs. Vehicles for which no appropriate EV alternative was identified were excluded from further analysis. The dataset records vehicle positions every 20 to 30 seconds while the ignition is active, enabling precise mapping of vehicle movement and stops. For this study:

- **Stop:** is defined as the first point where the vehicle becomes idle after traveling at least 0.1 miles from the previous position.
- **Trip:** refers to the travel segment between two consecutive stops.
- **Tour:** is a sequence of trips starting and ending at the same stop.
- **Fleet Group:** groups tours with the same vehicle class that originate from the same location.

The data show where and how far vehicles actually drove during the week, and which vehicle types made those trips.

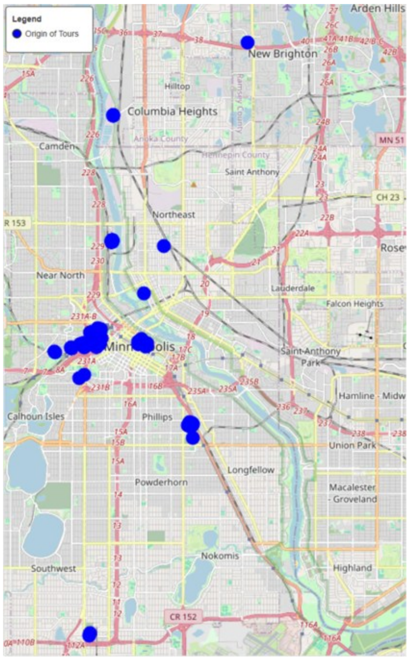

Figure 5.1 Origin location of tours in the City of Minneapolis.

Figure 5.1 illustrates the origin locations of all tours, with 166 unique vehicles initiating trips from these points. **Figure 5.2** provides two complementary perspectives on the distribution of tour lengths. The top subplot illustrates the frequency of tours across different length intervals, showing how often tours of varying distances occur, regardless of which vehicle completed them. In contrast, the bottom subplot displays the number of unique vehicles that have completed at least one tour within each tour length bin. While the top chart emphasizes how common short tours are in the overall dataset, the bottom chart highlights how many vehicles are associated with those shorter tours. This distinction is important because it shows that not only are shorter tours more frequent, but they also involve a large portion of the fleet. Together, the two plots indicate that daily operational patterns, both in terms of trip volume and vehicle participation, generally fall within distances that are manageable for electric vehicles on a single charge, reducing the need for mid-day recharging.

Vehicles in the dataset span a range of models and body types, but for the purposes of charging analysis, all are classified as light-duty, medium-duty, or heavy-duty. Each class differs in driving range requirements and charging needs, as well as fuel type distribution (gasoline, diesel, flexible fuel, or electric). **Table 5.1** provides a summary of the fleet's composition by class, fuel type, and tour length. Out of 7,701 tours, 7,487 (97 %) use gasoline, 5,797 by light-duty cars and 1,690 by medium-duty trucks. Diesel appears in 118 tours (1.5 %), almost all medium-duty (105) with just 13 heavy-duty runs. Flexible-fuel vehicles account for 68 tours (0.9 %), and battery-electric vehicles for 28 tours (0.4 %), both confined to light-duty, short trips. Distance-wise, 3,135 tours are 0–20 miles and 4,149 are 21–60 miles, so 94 % of all activity stays within 60 mile range.

This implies that 1) most daily work is short-range, many vehicles can finish a day on a single charge; 2) light-duty vehicles dominate short trips, making them strong early candidates for electrification; and 3) Charger placement near common start locations (depots) will cover the majority of use cases.

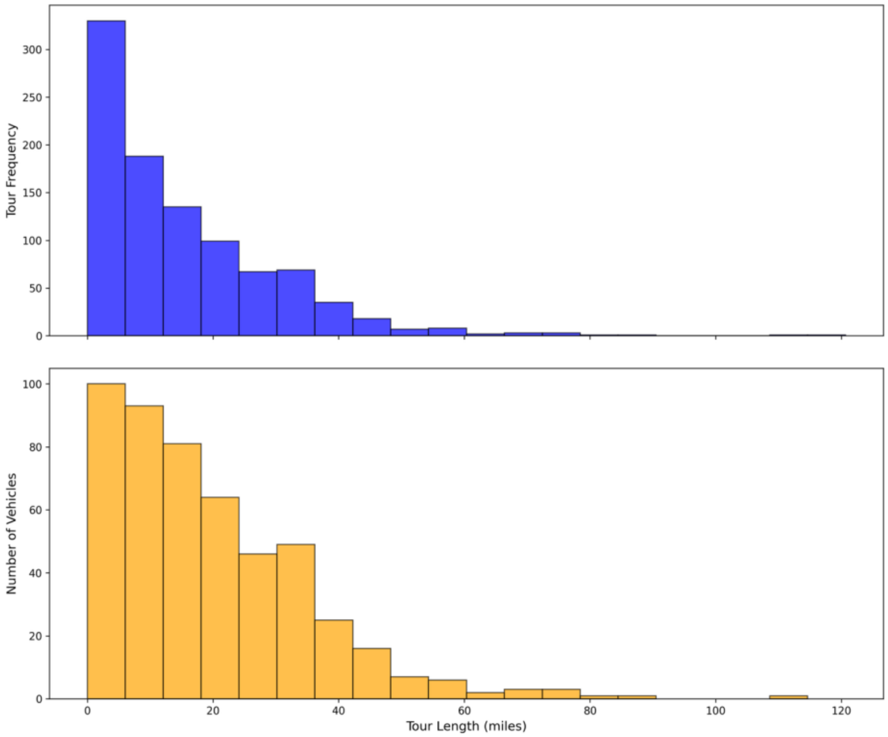

Figure 5.2 Distribution of tour lengths by frequency (top) and by number of vehicles (bottom).

Table 5.1 Fleet composition by duty class, fuel type, and tour length.

Vehicle GVWR Category	Fuel Type	Short (0-20 mi)	Medium (21-60 mi)	Long (61-150 mi)	Total Tours
Heavy-Duty Vehicles (Class 7-8)	Diesel	13	0	0	13
Heavy-Duty Vehicles (Class 7-8)	Electric	0	0	0	0
Heavy-Duty Vehicles (Class 7-8)	Flexible Fuel Vehicle (FFV)	0	0	0	0
Heavy-Duty Vehicles (Class 7-8)	Gasoline	0	0	0	0
Medium Duty Vehicles (Class 3-6)	Diesel	87	18	0	105
Medium Duty Vehicles (Class 3-6)	Electric	0	0	0	0
Medium Duty Vehicles (Class 3-6)	Flexible Fuel Vehicle (FFV)	0	0	0	0

Vehicle GVWR Category	Fuel Type	Short (0-20 mi)	Medium (21-60 mi)	Long (61-150 mi)	Total Tours
Medium Duty Vehicles (Class 3-6)	Gasoline	816	790	84	1690
Passenger Vehicles (Light-Duty)	Diesel	0	0	0	0
Passenger Vehicles (Light-Duty)	Electric	28	0	0	28
Passenger Vehicles (Light-Duty)	Flexible Fuel Vehicle (FFV)	68	0	0	68
Passenger Vehicles (Light-Duty)	Gasoline	2123	3341	333	5797

5.2.1 Fleet Usage Insights and Charging Station Location Candidates

Survey responses from agencies indicate a strong preference for on-site charging, rather than reliance on public or en-route charging stations. To support this operational preference, candidate charging station sites were selected from the tour origin points identified in **Figure 5.1**. Rather than designating every origin as a candidate (which would be redundant), origin locations were spatially clustered, and the most central site in each cluster was chosen as the charging station candidate. As shown in **Figure 5.3**, four main charging station locations were identified: Hiawatha Maintenance Facility, Recycling Operations Facility, Courthouse Municipal Ramp, Currie Maintenance Facility. All tours originating within each cluster are assumed to use the corresponding charging station.

For electrification planning, each unique combination of spatial cluster and vehicle class is treated as a distinct fleet group, as detailed in **Table 5.2**. These fleet groups may include tours operated at different times throughout the day. To determine the minimum number of EVs required for each fleet group at any given time, ensuring the agency's operation is maintained, the following factors are considered:

- **Tour frequency:** Number of tours operated within each time window, reflecting service demand.
- **Average tour duration:** The typical time each vehicle is in use during a tour.

Figure 5.4 presents operational metrics and minimum fleet requirements for Fleet Group 8 (as a representative example; corresponding plots for all fleet groups are provided in **Appendix D. Tour Counts**.), displaying tour frequency (5.4a), average tour duration (5.4b), and the minimum required EVs per time period (5.4c). To compute minimum vehicle requirements, we grouped historical tours by time slice and calculated average travel times for light-duty vehicle tours originating near Currie Maintenance Facility. These travel times determine when vehicles return to the depot for potential reuse. The minimum required vehicles at each time period equals the number of tours needed minus returning vehicles, where tour frequency represents service demand. Fractional values in tour frequency result from averaging the number of tours over all days for each time period. Although these fractional values are shown for illustrative purposes, the minimum number of vehicles is rounded up to the nearest whole number in the subsequent analysis to reflect practical fleet planning. This approach ensures that

EV fleet sizing is data-driven and closely aligned with the agency's actual operational needs, taking into account both how often vehicles are deployed and how long they are required to be in service.

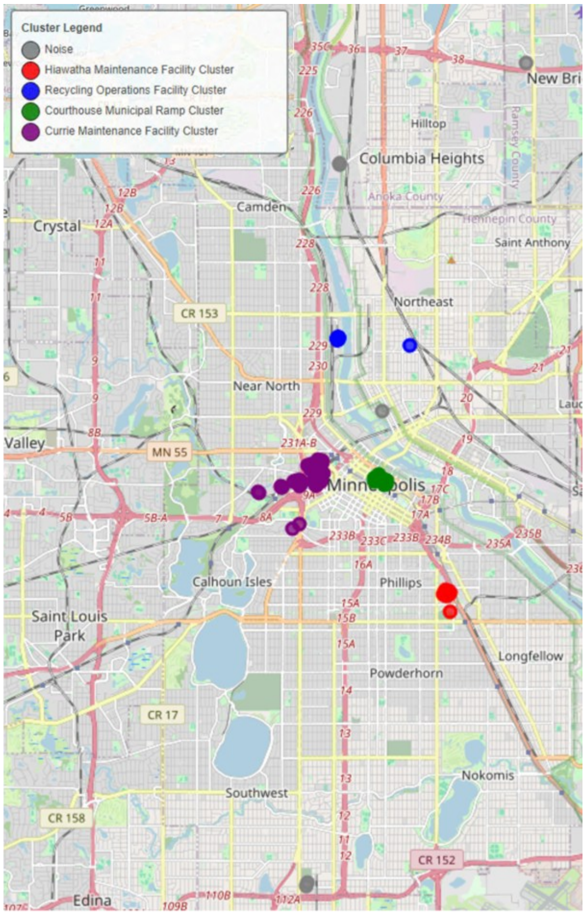

Figure 5.3 Clustered origin location of tours

Table 5.2 Fleet group identification

Fleet Group	Descriptions
Fleet Group 1	Heavy duty vehicles tours originated from locations close to Hiawatha Maintenance Facility
Fleet Group 2	Medium duty vehicles tours originated from locations close to Hiawatha Maintenance Facility
Fleet Group 3	Light duty vehicles tours originated from locations close to Hiawatha Maintenance Facility
Fleet Group 4	Medium duty vehicles tours originated from locations close to Recycling Operations Facility
Fleet Group 5	Light duty vehicles tours originated from locations close to Recycling Operations Facility
Fleet Group 6	Light duty vehicles tours originated from locations close to Courthouse Municipal Ramp
Fleet Group 7	Medium duty vehicles tours originated from locations close to Currie Maintenance Facility
Fleet Group 8	Light duty vehicles tours originated from locations close to Currie Maintenance Facility

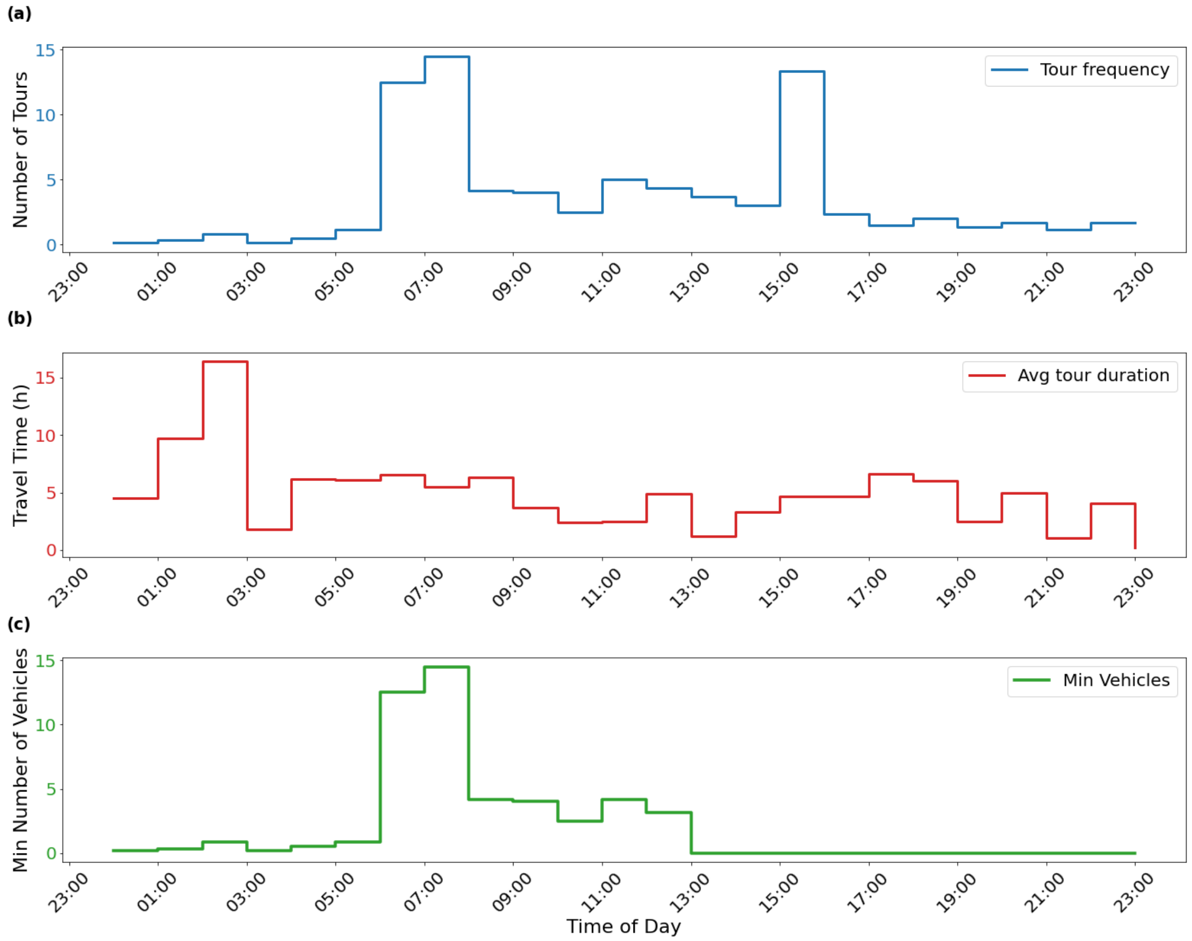

Figure 5.4 Estimated tour metrics and minimum fleet requirement per time interval for Fleet Group 8. (a) tour frequency, (b) tour duration, (c) minimum required fleet.

5.3 Siting and Sizing Charging Infrastructure and EV Fleet

An optimization model (tool) was developed to determine the optimal number of EVs, as well as the location, quantity, and type of charging stations required to meet operational demands reliably. This model balances cost, operational feasibility, and budgetary constraints, supporting agencies in transitioning their fleets through a multi-phased approach. The optimization model is designed to minimize costs for several critical factors:

- **Operational Costs of Non-Electrified Fleet Groups:** During each phase, remaining non-electrified fleet groups continue to incur conventional fuel and operational expenses. The model seeks to reduce these costs by prioritizing which fleet groups to electrify in each phase for maximum cost savings.
- **EV Maintenance Costs:** As fleet groups become electrified, projected EV maintenance expenses are incorporated, ensuring overall costs remain predictable and controlled.
- **Charging Costs:** These include expenses for electricity consumption, with the charging schedule optimized to minimize overall energy costs while meeting operational requirements.

- **Deadheading Costs:** In scenarios where charging infrastructure is not available at every fleet depot, vehicles must travel additional distances (deadheading) to charge. This increases costs and operational complexity, which the model seeks to minimize by strategically placing chargers.
- **Penalty Costs for Unmet Fleet Demand:** To guarantee service reliability, a penalty is applied if the available charging infrastructure at any phase fails to meet charging demand, incentivizing the allocation of sufficient resources throughout the transition.

The optimization model is designed with practical feasibility as a core principle, operating under constraints that include phased budget limits and the imperative to maintain uninterrupted agency operations through adequate charging schedules and EV fleet sizing. A key feature is its multi-phase implementation strategy, which optimizes the transition across sequential budget periods to balance cost-effectiveness with operational continuity. For this analysis, the transition is structured across three progressive phases. The model aims to fully utilize the allocated budget in each phase to minimize long-term operational costs. Furthermore, agencies can set specific targets for the minimum number of vehicles, by type, to be converted to EVs by the final phase. The model incorporates four charger types: Level 1 (L1), Level 2 (L2), Direct Current Fast Chargers (DCFC), and Megawatt Charging Systems (MCS). Their deployment is governed by vehicle compatibility constraints: light-duty vehicles can use L1, L2, or DCFC; medium-duty vehicles require DCFC; and heavy-duty vehicles are assigned to MCS. To promote infrastructure efficiency, the model assigns fleet groups without dedicated depot charging to the nearest active station, encouraging resource sharing across the agency.

We assume maximum charger power ratings of L1 = 1.9 kW, L2 =7.2 kW, DCFC = 250 kW, and MCS = 1 MW, consistent with recommended ranges (Argonne National Laboratory, 2023; U.S. Department of Energy – Energy Efficiency and Renewable Energy, n.d.-a). Additional cost parameters include penalty rates of $70, $100, and $300 per unit of unsatisfied charging demand for light-, medium-, and heavy-duty EVs, respectively. Vehicle deadheading costs are set at $1.1, $1.5, and $5 per mile for the respective vehicle classes, covering both energy expenses for depot travel and driver compensation. The capital costs for chargers are $1,500 for a Level 1 (L1) unit, $6,500 for Level 2 (L2), $40,000 for a DCFC, and $475,000 for a Megawatt Charging System (Smith and Castellano, 2015; Bernard et al., 2022). Electric vehicle procurement costs are $40,000 for light-duty, $100,000 for medium-duty, and $225,000 for heavy-duty models. We assume battery energy capacities of 65 kWh (light-duty), 100 kWh (medium-duty), and 530 kWh (heavy-duty), consistent with the recommended values in Chevrolet (2023); Mao et al. (2025); Ragon (2025). A comprehensive summary of these parameters is provided in **Table 5.3**, and the complete mathematical formulation is provided in **Appendix C: Optimization Model.**

Table 5.3 Parameter values

Category	Parameter	Value
Infrastructure	Maximum Chargers per Station	10
	Opening New Station Cost ($/station)	50,000
	Charger Installation Cost ($/charger)	L1: 1,500, L2: 6,500, DCFC: 40,000, MCS: 475,000
	Maximum Charger Power (kW)	L1: 1.9 , L2: 7.2 DCFC: 250 , MCS: 1,000
Vehicle	Driving Range (mile)/ Purchase Cost ($)/ Battery Capacity (kWh)	Heavy Duty: 190 / 225k / 530 Medium Duty: 130 / 100k / 100 Light Duty: 240 / 40k / 65
Operations	Penalty($/vehicle)/ Deadheading ($/mile)	Heavy Duty: 300 / 5 Medium Duty: 100 / 1.5 Light Duty: 70 / 1.1

5.3.1 Fleet and Infrastructure Requirements

As summarized in **Table 5.4**, the model was tested with a phased budget allocation of $1M, $2M, and $3M for Phases 1, 2, and 3, respectively. No minimum EV adoption targets were set for any vehicle class, allowing the model to freely determine the optimal EV fleet and charger mix within the budgetary constraints. For the City of Minneapolis dataset, which has an operational requirement for 158 gasoline and diesel vehicles, as derived from the analysis in **Figure 5.4**, the model recommends a fleet of 93 EVs to maintain operations during the analyzed one-week period. Due to budget limitations, the model elected to leave Fleet Group 7 unelectrified. The optimization results also indicate a need for one additional heavy-duty vehicle in Fleet Group 1 to accommodate charging downtime.

It is important to note that the fleet sizes derived from **Figure 5.4** represent a lower-bound estimate based on one week of historical data. Future analyses using extended timeframes would yield more robust estimates by accounting for schedule variability and operational uncertainties.

Table 5.4 further details the outcomes, including the phased composition of fleet groups, EV counts, charger types and quantities, and associated costs. The model ensures total expenditures on vehicles and charging infrastructure remain within each phase's budget, with costs itemized to clarify financial trade-offs for agency planning. The budget values used here are illustrative for model demonstration; agencies can adjust these inputs according to their specific financial constraints and strategic priorities.

Table 5.4 Fleet electrification phases with associated EV counts, chargers, and budget allocations.

Phases	# Fleet Groups	# EVs	#Chargers		EV cost ($) $(\times 1000)$		Charger + Station Cost ($) $(\times 1000)$
Phase 1 (budget: 1M)	3	16	8	L1 = 2 L2 = 3 DCFC = 3 MCS = 0	700	L = 15 M = 1 H = 0	292.5
Phase 2 (budget: 2M)	4	66	8	L1 = 2 L2 = 3 DCFC = 3 MCS = 0	2,000	L = 65 M = 1 H = 0	0
Phase 3 (budget: 3M)	7	93	12	L1 = 4 L2 = 3 DCFC = 4 MCS = 1	2,410	L = 74 M = 17 H = 2	568
Total (budget: 6M)	7	93	12	L1 = 4 L2 = 3 DCFC = 4 MCS = 1	5,110	L = 74 M = 17 H = 2	860.5

5.3.2 Charging Activity and Operational Impacts

Figure 5.5 illustrates the hourly charging activity at the selected station across all transition phases. The bars represent the number of EVs charging per hour, color-coded by phase, while the shaded backgrounds delineate night, day, and evening periods. This visualization provides insight into the evolution of charging demand as electrification advances. In Phase 1, when only three fleet groups are electrified, most charging occurs at night (super off-peak), minimizing both costs and operational disruption. As more fleet groups transition in Phase 3, the growing EV fleet requires more chargers and leads to higher demand. Consequently, charging activities spread across more off-peak hours to accommodate this load.

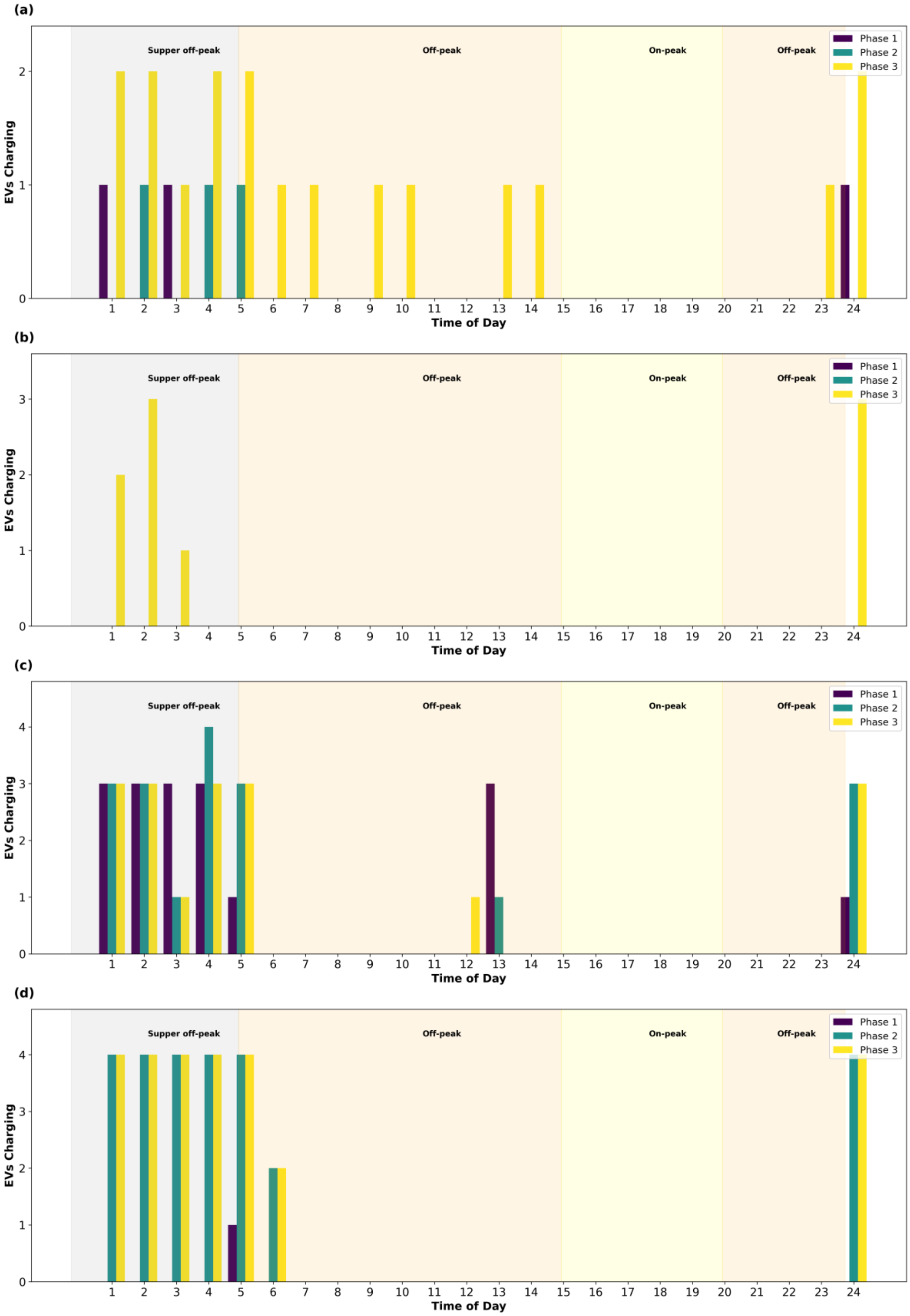

Figure 5.5 Hourly charging activity at two selected charging stations across three transition phases. (a) Hiawatha Maintenance Facility, (b) Currie Maintenance Facility.

5.3.3 Total Cost Evaluation

By simultaneously minimizing five key daily cost components—operational costs for non-electrified routes, EV maintenance, charging, penalties for unmet demand, and deadheading—the model offers a holistic framework for planning a phased EV fleet transition. As shown in **Figure 5.6** (a), Phase 1 operational costs are driven by non-electrified fleet groups (1, 2, 5, 7, and 8). As these groups are electrified, a marked reduction in these costs is achieved by Phase 3. The Baseline phase reports estimated daily operating cost prior to electrification. EV maintenance costs rise as the electrified fleet expands. Furthermore, deadheading costs are present in Phases 1 and 2 because budget constraints prevented the deployment of a charging station at every depot. However, by the final phase, the model opts to open a station at each depot, successfully eliminating deadheading and reducing its cost to zero. **Figure 5.6** (b) breaks down these costs by fleet group for the final phase and the baseline (without electrification), demonstrating that for electrified groups, the primary operating expense is now EV maintenance, the scale of which directly corresponds to the size of each fleet. Under the specific budget constraints of this numerical analysis, only Fleet Group 7 remains non-electrified after the final phase, so its ICE operating cost is unchanged from the baseline.

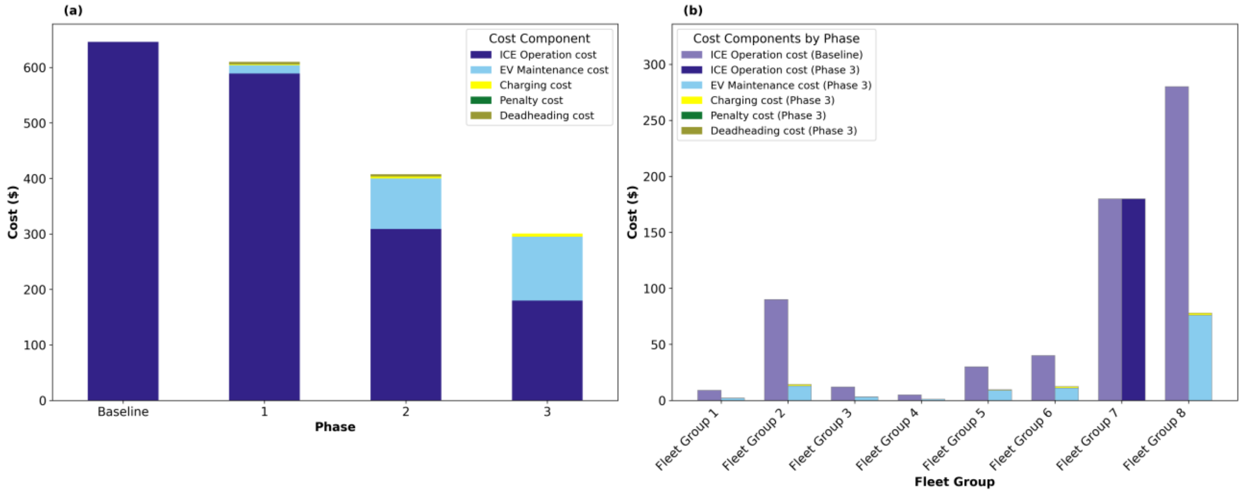

Figure 5.6 Breakdown of cost components across electrification phases and routes.(a) Aggregated costs across all Fleet Groups for each electrification phase.(b) Daily operational costs per route after the completion of the fleet electrification process.

The strategy introduced in this section can be summarized as follows:

- Expect fuel costs to fall and EV upkeep to take a larger share over time.
- Revisit charger siting after Phase 1 to cut deadheading where it is highest.
- If budgets allow, a second charging site can lower extra miles and improve resilience.

5.3.4 Sensitivity Analysis

To guide strategic decision-making, **Tables 5.5, 5.6,** and **5.7** summarize the outcomes of a sensitivity analysis, revealing how operational savings, fleet size, and charger deployment vary under different budgetary and policy constraints.

The primary trade-off exists between budgetary constraints and strategic ambition, as defined by minimum EV adoption targets. Higher budgets consistently enable greater operational cost savings, with the maximum saving observed being 76.10% under a single-phase $9M budget. However, the analysis also demonstrates that a single, large budget infusion is not necessarily the most efficient path. Multi-phase strategies can achieve similar or only marginally lower savings (e.g., 76.10% in one phase vs. 76.04% in two phases with the same total budget) while potentially offering managerial benefits by spreading capital expenditure over time.

A central finding is the significant impact of setting minimum EV targets, particularly for heavy-duty vehicles. As shown in **Table 5.5** and **Table 5.6**, the most ambitious fleet target (1, 50, 60) is infeasible across most budget scenarios, only becoming viable under the highest total budgets (e.g., $9M). This infeasibility occurs because the high upfront cost of procuring a large number of EVs, especially the expensive heavy-duty unit and its requisite MCS charger, exhausts the budget before sufficient charging infrastructure can be built to support the entire fleet. This underscores that aggressive mandates without corresponding financial support can render an electrification plan impossible to execute.

Furthermore, the model demonstrates notable flexibility in charging infrastructure deployment to meet operational needs within a given budget. **Table 5.7** shows that for identical budget and target scenarios, the model often proposes different mixes of Level 1, Level 2, and DCFC (e.g., for target (0, 20, 30) under a $6M budget, it selects (9: L1, 1: L2, 2: DCFC)). This indicates that multiple infrastructure strategies can yield similar financial and operational outcomes, allowing agencies to make secondary adjustments based on space, electrical capacity, or driver convenience without compromising the core economic goal. Finally, the analysis validates that a phased implementation can strategically manage financial risk. By allocating funds incrementally, agencies can achieve early wins and learn from initial phases, making them more resilient than a single, high-stakes investment, especially when navigating the high costs and uncertainties of heavy-duty vehicle electrification.

Table 5.5 Daily operation cost saving

Phases	**Budget ($)**	**Minimum Planned EV Fleet [Heavy/Medium/Light]**			
	$\times 1000$	**(0, 20, 30)**	**(0, 30, 40)**	**(0, 40, 50)**	**(1, 50, 60)**
One Phase	**5000**	49.28%	21.19%	Infeasible	Infeasible
	6000	59.31%	59.31%	Infeasible	Infeasible
	7000	64.30%	64.30%	63.00%	Infeasible
	8000	72.87%	72.88%	72.90%	Infeasible
	9000	76.10%	76.10%	76.10%	75.10%
Two Phases	**(2500, 2500)**	49.26%	21.17%	Infeasible	Infeasible
	(3000, 3000)	52.40%	49.29%	Infeasible	Infeasible
	(3500, 3500)	64.30%	64.30%	63.00%	Infeasible
	(4000, 4000)	72.9%	72.86%	72.88%	Infeasible
	(4500, 4500)	76.10%	76.04%	76.03%	74.00%
Three Phases	**(2000, 2000, 1000)**	49.22%	21.19%	Infeasible	Infeasible
	(2000, 2000, 2000)	52.30%	49.28%	Infeasible	Infeasible
	(2000, 2000, 3000)	53.43%	52.36%	48.09%	Infeasible
	(3000, 3000, 2000)	53.49%	53.49%	52.41%	Infeasible
	(3000, 3000, 3000)	53.49%	53.49%	53.49%	52.10%

Table 5.6 Number of (Heavy/Medium/Light) EVs

Phases	**Budget ($)**	**Minimum Planned EV Fleet [Heavy/Medium/Light]**			
	$\times 1000$	**(0, 20, 30)**	**(0, 30, 40)**	**(0, 40, 50)**	**(1, 50, 60)**
One Phase	**5000**	(0, 20, 64)	(0, 30, 40)	Infeasible	Infeasible
	6000	(0, 34, 60)	(0, 34, 60)	Infeasible	Infeasible
	7000	(0, 35, 75)	(0, 35, 69)	(0, 40, 67)	Infeasible
	8000	(0, 51, 60)	(0, 51, 60)	(0, 51, 60)	Infeasible
	9000	(0, 51, 75)	(0, 51, 75)	(0, 51, 75)	(2, 50, 66)
Two Phases	**(2500, 2500)**	(0, 20, 65)	(0, 30, 40)	Infeasible	Infeasible
	(3000, 3000)	(0, 20, 69)	(0, 30, 64)	Infeasible	Infeasible
	(3500, 3500)	(0, 35, 76)	(0, 35, 69)	(0, 40, 66)	Infeasible
	(4000, 4000)	(0, 51, 61)	(0, 51, 60)	(0, 51, 61)	Infeasible
	(4500, 4500)	(0, 53, 77)	(0, 51, 84)	(0, 51, 69)	(2, 51, 64)
Three Phases	**(2000, 2000, 1000)**	(0, 20, 61)	(0, 30, 40)	Infeasible	Infeasible
	(2000, 2000, 2000)	(0, 20, 69)	(0, 30, 62)	Infeasible	Infeasible
	(2000, 2000, 3000)	(2, 20, 76)	(0, 30, 69)	(0, 40, 60)	Infeasible
	(3000, 3000, 2000)	(2, 20, 76)	(2, 30, 75)	(0, 40, 72)	Infeasible
	(3000, 3000, 3000)	(2, 20, 76)	(2, 30, 76)	(2, 40, 76)	(2, 50, 67)

Table 5.7 Number of chargers (L1, L2, DCFC, MCS)

Phases	Budget ($) × 1000	Minimum Planned EV Fleet [Heavy/Medium/Light]			
		(0, 20, 30)	**(0, 30, 40)**	**(0, 40, 50)**	**(1, 50, 60)**
One Phase	**5000**	(6, 1, 5, 0)	(3, 0, 5, 0)	Infeasible	Infeasible
	6000	(9, 1, 2, 0)	(9, 1, 2, 0)	Infeasible	Infeasible
	7000	(2, 15, 4, 0)	(8, 0, 5, 0)	(4, 1, 3, 0)	Infeasible
	8000	(5, 1, 4, 0)	(19, 1, 4, 0)	(6, 10, 5, 0)	Infeasible
	9000	(9, 3, 5, 0)	(7, 0, 7, 0)	(3, 0, 9, 0)	(5, 19, 2, 1)
Two Phases	**(2500, 2500)**	(8, 0, 4, 0)	(3, 0, 6, 0)	Infeasible	Infeasible
	(3000, 3000)	(7, 1, 4, 0)	(8, 1, 5, 0)	Infeasible	Infeasible
	(3500, 3500)	(16, 13, 3, 0)	(8, 10, 3, 0)	(1, 1, 5, 0)	Infeasible
	(4000, 4000)	(7, 0, 5, 0)	(1, 9, 6, 0)	(10, 0, 6, 0)	Infeasible
	(4500, 4500)	(1, 9, 9, 0)	(9, 7, 6, 0)	(12, 0, 4, 0)	(13, 5, 4, 1)
Three Phases	**(2000, 2000, 1000)**	(2, 0, 7, 0)	(1, 3, 5, 0)	Infeasible	Infeasible
	(2000, 2000, 2000)	(7, 9, 3, 1)	(1, 4, 6, 0)	Infeasible	Infeasible
	(2000, 2000, 3000)	(11, 0, 5, 1)	(5, 1, 4, 1)	(2, 0, 3, 0)	Infeasible
	(3000, 3000, 2000)	(15, 0, 4, 1)	(15, 8, 4, 1)	(9, 0, 4, 1)	Infeasible
	(3000, 3000, 3000)	(14, 6, 4, 1)	(13, 7, 4, 1)	(16, 3, 4, 1)	(8, 3, 4, 1)

5.3.5 Practical Guideline for Sizing & Siting Charging Infrastructure and EV Fleets

Although the numerical results presented here use the City of Minneapolis as a case study, the same workflow can be applied by any agency. By substituting its own trip-history data, an agency can follow the steps below to pinpoint the best depot locations, determine the minimum BEV fleet size, and design a cost-effective charging network customized to its operating patterns. **Figure 5.7** summarizes the procedure in a flowchart.

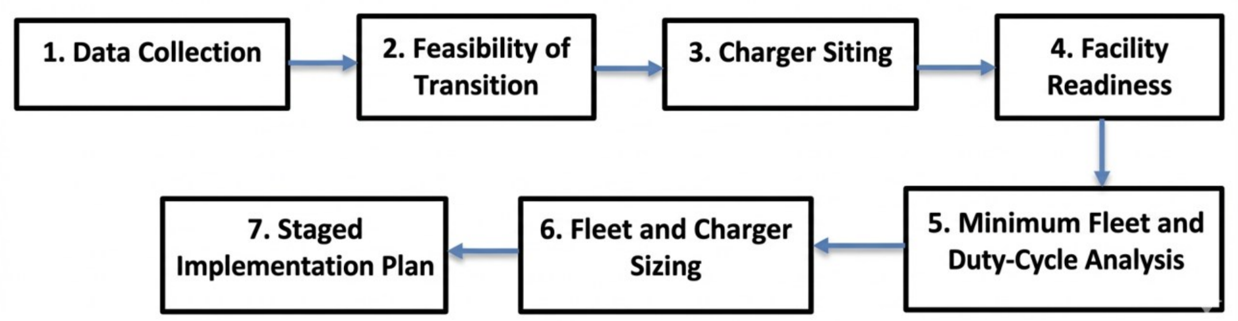

Figure 5.7 Guideline steps for charger siting and EV fleet sizing

Following **Figure 5.7**, the steps are:

1. **Data Collection:**
    - **Action:** Compile 6-12 months of trip data and map all trip start/end points.
    - **Output:** Clean trip dataset and identify common tour start points as potential charging station locations.
    - **Example:** The potential charging station candidates have been plotted in **Figure 5.1** for the City of Minneapolis.
2. **Feasibility of Transition:**
    - **Action:** Check tours' maximum operating mileage and compare those mileages with EV ranges.
    - **Output:** Determine whether depot-only charging is sufficient or en-route/public charging is needed.
    - **Example:** The City of Minneapolis data analysis shows that more than 94% of tours are less than 60 miles, indicating great feasibility for adopting BEVs.
3. **Charger Siting:**
    - **Action:** Cluster nearby locations from Step 1 to eliminate redundancies.
    - **Output:** Short-list of possible charging station locations.
    - **Example:** Using City of Minneapolis data, the resulting short-list charging station locations were reduced to 4 strategic depots (**Figure 5.3**): Hiawatha Maintenance Facility, Recycling Operations Facility, Courthouse Municipal Ramp, and Currie Maintenance Facility. These locations can supply charging for tours starting nearby.
4. **Facility Readiness:**
    - **Action:** For each short-listed depot/site, complete a facility and code readiness check to confirm the location can realistically support the proposed chargers. This includes:
        - *Electrical capacity and panel upgrades*: Validate that the facility's power infrastructure can sustain the load of different type of chargers, while incorporating surplus capacity to facilitate future expansion.
        - *Conduit and raceway installation*: Embed electrical pathways during initial construction phases to avoid the need for costly retrofits as the fleet expands.
        - *Ventilation and fire safety*: Synchronize charging hardware with existing HVAC and suppression systems to mitigate thermal and fire risks within enclosed storage facilities.
        - *Physical layout and protection*: Design the site architecture to include necessary operational clearances, protective bollards, and ADA-compliant stall design.
        - *Smart load management systems*: Leverage software integration to dynamically optimize charging schedules, thereby minimizing peak demand costs.
        - *Compliance with Minnesota building code and federal ADA standards*: Ensure compliance with state and federal regulations, specifically regarding accessible charging spaces.
        - *Structural Requirements*: Incorporate mandatory structural modifications, such as the installation of fire breaks and additional walls, to meet safety standards.

- **Output:** A site-specific construction and upgrade plan that ensures regulatory compliance and accommodates future scalability.
- **Example:** This step is outside the scope of the optimization model and relates to facility-level implementation, so these construction and code requirements were not explicitly represented in the model. The model assumes that a feasible station power capacity can be provided at selected depots. In implementation, the facility readiness check is needed to validate that assumption by confirming the depot's actual electrical capacity, identifying required upgrades and construction work, verifying code/ADA compliance, and determining whether load management is needed to operate the planned chargers within site constraints.

5. **Minimum Fleet and Duty-Cycle Analysis:**
    - **Action:** Group tours by time intervals within the day, and estimate the minimum number of vehicles required in each time interval to support agency operations.
    - **Output:** Daily fleet-usage profile showing vehicle demand.
    - **Example:** For the City of Minneapolis (**Figure 5.4**), for instance, the average tour departing between 7:00 and 8:00 lasts approximately 5.45 hours and is served by 14 vehicles. By 13:00 (7:00 + 5.45 = 12:45), those 14 vehicles will have returned to the depot. If only four vehicles are needed at 13:00, no additional fleet is required at that time because the returned vehicles can be reused (14 available > 4 required).
6. **Fleet and Charger Sizing:**
    - **Action[1]:** For each budget or electrification phase: Select depots from the short-list, specify charger types and capacities, calculate EV fleet size, meeting the minimums from Step 4, repeat/iterate to minimize total cost within budget constraints.
    - **Output:** Least-cost mix of EVs, chargers, and required depot upgrades.
    - **Example:** In the City of Minneapolis case, the model selected Hiawatha and Currie Maintenance Facilities, where most tours originate from, as optimal charging sites, allocating four chargers to support a 93-vehicle fleet (see **Table 5.4**).
7. **Phased Implementation Plan:**
    - **Action:** Develop an execution timeline aligned with fiscal-year budgets, and refresh data annually and rerun the analysis to reflect updated costs and operational changes.
    - **Output:** Phased roll-out schedule and continuous improvement loop.
    - **Example:** For the City of Minneapolis, and for demonstration purposes, a three-phase electrification plan was assumed, one phase per year, with hypothetical budgets that enabled full fleet electrification by the final phase.

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[1] These decisions are made using an optimization model developed in this study, which identifies the most cost-effective combination of depots, chargers, and vehicle purchases under budget constraints.

5.3.6 Conclusion

This chapter provides a detailed assessment of charging-infrastructure costs. Using trip-history data, we develop a methodology to (i) estimate the fleet size required to meet the agency’s operating schedule, (ii) optimize electric-vehicle adoption, and (iii) identify cost-effective locations for charging infrastructure. We demonstrated the application of this approach through a numerical analysis for the City of Minneapolis, thereby establishing a replicable framework that other agencies can employ using their own data. The assessment yielded practical insights, including high confidence in EV range sufficiency, as the vast majority of daily tours were under 60 miles, indicating that en-route charging is generally unnecessary and simplifying infrastructure planning. Furthermore, the analysis of charging schedules revealed that nighttime, super off-peak charging can support operations with a limited number of fleet groups per charger. However, assigning more vehicles to each charger, while feasible, introduces a need for supplemental daytime charging during off-peak hours, requiring efficient demand scheduling.

Chapter 6: Recommendations and Identification of Potential Funding Sources

6.1 Project Summary

This chapter summarizes the research findings to create a recommendation blueprint for Minnesota agencies transitioning to electric vehicle (EV) fleets. The blueprint provides a clear roadmap, outlining key challenges and opportunities, and detailing the necessary preparatory steps for successful fleet electrification. An important focus of this task is to consolidate potential federal and state-level funding sources to help agencies navigate the financial hurdles of this transition. The recommendations were disseminated to Minnesota agencies through a webinar organized by the Local Road Research Board (LRRB): https://www.youtube.com/watch?v=j1MWAh8n8FI.

6.2 Blueprint for EV Fleet Electrification

The blueprint for fleet electrification is structured around a four-step roadmap, designed to help agencies proactively plan their transition by focusing on four key areas: 1) strategic planning, 2) financial considerations, 3) operational adjustments, and 4) infrastructure development.

Step 1: Assessing and Prioritizing: The initial step involves a thorough assessment of the current fleet to identify optimal candidates for early conversion. This is the foundation for a data-driven approach to fleet electrification.

- **Data Collection:** Agencies should begin by grouping all vehicles by duty class (light, medium, heavy) (labeled “Fleet Group” in the brochure) and use data analysis tools to compare the total cost of ownership (TCO) for both internal combustion engine (ICE) and battery electric vehicle (BEV) alternatives. This analysis should consider all costs, not just the upfront purchase price, and include incentives and state or federal grant funding for BEV purchases.
- **Identify Quick Wins:** Based on the TCO analysis, agencies should prioritize vehicles that offer the most immediate benefits. This could include vehicles with high annual mileage (for example, over 15,000 miles for light-duty and over 25,000 miles for heavy-duty vehicles) and those with predictable, fixed routes that reduce *range anxiety* (worry of an EV driver that the battery will run out of charge before reaching the destination or the next charging point). Light-duty vehicles, especially those for administrative use, are often an ideal starting point, as their TCO can quickly match or fall below that of ICE vehicles.
- **Conduct Pilot Conversion:** Acquire a small fleet of light-duty vehicles with limited depot charging or with reliance on public charging. Employ the pilot EVs in more predictable duty cycles aligned with the agency’s work plan to assess range and reliability. Include end users in pilot programs and evaluation processes to surface practical concerns and improve buy-in.

Step 2: Financial Planning: This step is critical for securing the necessary capital and leveraging available support to make the transition economically viable.

- **Adopt Life-Cycle Costing:** To make an informed decision, agencies must look beyond initial purchase prices and calculate the full 10-year total life-cycle costs (LCC). This calculation should include critical inputs like historical and projected annual mileage, local electricity and fuel prices, maintenance costs, and any incentives or grants that would offset the purchase costs.
- **Leverage Incentives:** Agencies should actively pursue models where BEVs become more affordable than their ICE counterparts after rebates and tax credits. Federal and state grants can be a powerful tool to bridge the financial gap, especially where the upfront cost gap between battery-electric (BEV) and ICE vehicles is largest (often heavy-duty).
- **Phased Investments:** A multi-phase approach allows for a manageable transition considering financial and infrastructure limitations. A recommended timeline could be:

Phase 1: Focus on electrifying light-duty vehicles that offer the highest return on investment. Leverage BEV purchase incentives and work through fleet subgroups that have higher annual mileage.

Phase 2: Gradually expand the transition to include heavy-duty fleets as the technology matures and costs decline. Heavy-duty EVs may offer significant operational cost savings despite current high upfront costs and greater charging infrastructure needs.

Phase 3: Address medium-duty vehicles, waiting for costs to drop and for more suitable models to become available.

Step 3: Operational Transition: This step centers on optimizing fleet utilization building on fleet usage data and preparing the workforce to ensure a smooth and effective shift to EV technology.

- **Right-Size Your Fleet:** A successful transition would offer an opportunity to optimize fleet size. Agencies should analyze vehicle utilization and consider replacing underutilized ICE vehicles with fewer, more efficient BEVs with optimized scheduling.
- **Boost Utilization:** To accelerate the payback period, agencies should aim to increase the annual mileage of their BEVs, especially for heavy-duty trucks which need to log more miles per year for fuel savings to offset the high upfront costs.
- **Workforce Preparation:** Staff training is a crucial component of adoption. Agencies should:
    - Develop orientation sessions for fleet users covering topics like cold-weather operations, charging procedures, and basic EV maintenance.
    - Offer certification programs and workshops for maintenance technicians, focusing on battery systems and high-voltage safety.
    - Coordinate with emergency services and first responders to build protocols for EV-related incidents, which can help alleviate concerns from drivers and the public.

Step 4: Charging Infrastructure Planning: A well-designed charging strategy is essential to support the electrified fleet and ensure uninterrupted daily operations. The following constitute main tasks for infrastructure planning:

- **Data Collection:** Analyze recent trip data to understand tours (trip chains), origins/destinations, and daily mileage. Use this to spot frequent start locations and high-use depots that are strong candidates for charging sites.
- **Feasibility of Transition**: For each depot, test whether tours' travel mileage can be covered under the EV range and with depot charging only. As needed, en-route charging at frequently visited remote locations, or public charging could be utilized to supplement depot charging to extend EV fleets' operational range.
- **Charging Siting**: Clustering charging needs at selected depots reduces the need for a distributed number of chargers and highlights the most efficient starting locations, customized to the agency's tour records, for charging infrastructure. The most efficient approach is to prioritize shared charging stations at central depots rather than individual chargers.
- **Facility Readiness:** Conduct a comprehensive site assessment to validate that electrical infrastructure can support current and future charger loads, installing conduits early to avoid costly retrofits. The design must strictly adhere to fire safety, ventilation, and ADA standards, incorporating physical protections like bollards and structural fire breaks. Finally, integrate smart load management systems to optimize charging schedules and minimize peak demand costs.
- **Minimum Fleet and Duty-Cycle Analysis:** Right-size the fleet (Step 3) and define the time-dependent minimum fleet required to support the agency's hours of operation. This enables cost-efficient planning of charging infrastructure and fleet size, customized to the agency schedule, and improves the management of shared chargers.
- **Fleet and Charger Sizing:** Because agency budget constraints prevent a full transition at once (managed by phased investments, Step 2), use a data-driven method or an optimization model when available to determine, in each phase, how many vehicles to electrify and how many chargers to install at each depot subject to the phased budget.

6.3 Human Factors Component

The research found that human factors, or the behaviors, attitudes, and decision-making processes of individuals, play a crucial role in the success of fleet conversion. A key finding was that staff who received EV-specific training held significantly more favorable views of EVs. To ensure a smooth transition and address potential resistance, agencies should focus on the following:

- **Role-Based Communication:** Different roles within an agency will have different priorities and concerns. End-users (i.e., drivers) need to be included in pilot programs and engaged in discussions to surface practical concerns about daily operations. In contrast, differentiated communication should address role-specific priorities, such as range reliability for operators and cost savings for fleet managers.

- **Targeted Training:** Agencies must provide comprehensive, hands-on training tailored to various roles. This includes:
- **Drivers and Operators:** Training should cover operational specifics, such as best practices for cold-weather driving, understanding the vehicle's range and charging needs, and how to use charging stations.
- **Maintenance Technicians:** Technical training on EV systems, battery management, and high-voltage safety is essential to ensure the fleet can be properly serviced and maintained in-house.
- **Management and Planning Staff:** These personnel need a solid understanding of the long-term TCO, infrastructure requirements, and how to navigate the funding landscape.
- **Building a Culture of Trust:** Proactive and transparent communication is key to overcoming "range anxiety" and other concerns. By openly sharing data on successful pilot programs and providing clear information, agencies can build trust and enthusiasm among their staff.

6.4 Funding Opportunities

Several federal programs can help local agencies overcome cost barriers. Agencies can combine formula funds (programmed through the Metropolitan Planning Organization/Area Planning Organization (MPO/APO) and the Minnesota Department of Transportation (MnDOT)) with discretionary grants (applied to directly when a Notice of Funding Opportunity (NOFO) or Request for Proposals (RFP) opens). Formula programs such as the Carbon Reduction Program (CRP) and the Congestion Mitigation and Air Quality Improvement Program (CMAQ) are selected through the planning process and programmed in the Transportation Improvement Program (TIP) and Statewide Transportation Improvement Program (STIP). Discretionary programs such as the Charging and Fueling Infrastructure Discretionary Grant Program (CFI) and the United States Environmental Protection Agency (EPA) Clean School Bus Program require direct applications. In Minnesota, the National Electric Vehicle Infrastructure Formula Program (NEVI) is administered by the MnDOT, and the Minnesota Pollution Control Agency (MPCA) periodically offers state grants for charging infrastructure. **Table 6.1** summarizes example funding programs, including eligible applicants, what each fund covers, and official websites for more information.

Agencies are encouraged to actively explore opportunities at the state level. While programs and their availability can change, they can be a key source of financial support. MnDOT and the Local Road Research Board (LRRB) are excellent resources for staying up-to-date on new and existing state-specific programs, grants, and technical assistance.

Table 6.1 Funding Opportunities for Fleet Electrification

Program	What it funds (EV-related)	Who can apply	How to apply	Typical timing/notes
Carbon Reduction Program (CRP)	Projects that reduce on-road CO_2 (e.g., EVs/charging if eligible under 23 USC 175)	States, MPOs; local agencies as subrecipients	Work with MPO/APO to get projects into TIP/STIP	Rolling via MPO/State programming cycles; check your MPO call-for-projects. (Federal Highway Administration). Also see: MnDOT Carbon Reduction Program page
Congestion Mitigation and Air Quality Improvement (CMAQ)	Emission-reducing transportation projects (may include EV fleet upgrades/charging in eligible areas)	State & local governments	Submit to MnDOT/MPO under CMAQ calls; selected projects programmed in TIP/STIP	MPO/State calls; cadence varies by region. (Federal Highway Administration) Also see: FHWA CMAQ program page.
Charging & Fueling Infrastructure (CFI)	Community & corridor charging infrastructure	Units of local governments, states, MPOs, tribes, others listed in NOFO	Direct to USDOT/FHWA via Grants.gov when NOFO opens	Competitive windows; monitor FHWA and Grants.gov for NOFOs. (Department of Transportation)
National Electric Vehicle Infrastructure program (NEVI) in Minnesota	DC fast charging along AFCs; state-run competitive grants	Private or public entities; teams must include a network provider + site control	Apply to MnDOT when RFPs are posted; MnDOT administers formula funds	RFP-based; check MnDOT NEVI page for rounds/requirements. (Minnesota Department of Transportation)
EPA Clean School Bus (CSB)	Zero-emission/clean school buses (per NOFO/rebate)	School districts and eligible partners	Direct to EPA (rebates or grants) via portal/Grants.gov	EPA opens periodic rebate/grant rounds; check CSB site for current windows. (US EPA)

Program	What it funds (EV-related)	Who can apply	How to apply	Typical timing/notes
MPCA EV Fast-Charging Grants (MN)	Public DCFC stations (match caps/requirements set by MPCA)	Profit, nonprofit, and public entities, including state, local, and Tribal governments.	Apply to MPCA when RFPs are posted	Current cycle lists award cap and deadline on MPCA site. (PCA Minnesota)
MnDOT Grants Portal (MN overview)	MnDOT-administered opportunities (incl. NEVI)	Varies by program	Watch MnDOT Grants page for RFPs/calls	Portal aggregates active opportunities and links to RFPs. (Minnesota Department of Transportation)

Chapter 7: Conclusion

In this research project, we explored the multifaceted transition to electric vehicle fleets within Minnesota's public agencies. **Chapter 2** investigated the human factors component through a survey of 86 employees, revealing a predominantly neutral sentiment toward adoption, with major concerns being limited driving range, insufficient charging infrastructure, and high initial costs. The analysis found that only 21 distinct agencies have integrated EVs into their fleets, representing a small 1-10% of their total vehicles. **Chapter 3** surveyed fleet composition and agency readiness, analyzing data from 21 counties and cities and revealing fleet sizes ranging from under 10 to more than 1,800 vehicles. It found that 57% of agencies believe they have sufficient parking for chargers and that depot charging is the preferred strategy for most, although larger fleets plan to incorporate up to 25% public and en-route charging, and it identified significant opportunities for inter-agency charger sharing based on geographic clustering. **Chapter 4** provided a detailed financial and operational analysis, with a 10-year life-cycle cost analysis demonstrating that light-duty BEVs have already reached cost parity with ICE vehicles, making them a strong starting point. In **Chapter 5**, the designed optimization model for phased charging infrastructure, tested with a sample budget allocation of $1 million , $2 million , and $3 million across three phases, showed how strategic deployment could electrify a majority of fleet groups and reduce daily operational costs by up to 76.10% under optimal budget scenarios. **Chapter 6** synthesized these findings into a strategic blueprint and funding guide, recommending a prioritized, data-driven approach that begins with light-duty vehicles and aligns financial planning with operational adjustments and infrastructure development.

Recognizing the study's limitations is essential, as they also point to clear directions for future research and implementation. First, the phased electrification framework depends on agency-specific budget allocations and timelines; while the approach can achieve electrification targets by the end of the planning horizon under the tested assumptions, it requires calibration to local financial constraints, and operational priorities. Second, several implementation-critical factors are not represented in the high-level modeling and must be addressed at the facility level. In practice, charger deployment must be grounded in each site's actual electrical capacity, including any required panel, transformer, or service upgrades to support Level 2 and DC fast charging. Early planning for conduits and raceways is also necessary to avoid costly retrofits, and chargers in enclosed or partially enclosed areas may require ventilation and fire-safety coordination. In addition, site layouts must comply with Minnesota building and fire codes and federal accessibility standards, including appropriate clearances, equipment protection (e.g., bollards), safety separation or fire-break features, and ADA-compliant charging stalls and accessible routes. Smart load management systems are similarly important in practice, as they help align charging operations with electrical constraints, optimize charging schedules, and reduce peak-demand costs.

From a modeling perspective, additional simplifications also introduce limitations. To reduce complexity, vehicles are grouped by duty class rather than modeled individually, which may overlook within-class differences in usage patterns that affect feasibility and charging needs. Likewise, time-of-use savings and buffer capacity recommendations rely on approximate fleet minimums derived from tour frequency and travel-time metrics; these inputs are uncertain and may shift with unexpected operational changes. Future work should address these limitations by refining assumptions, validating parameters with agency-specific data, incorporating richer operational information, and explicitly modeling uncertainty to strengthen robustness and applicability.

In conclusion, this project provides a comprehensive foundation for public agencies to navigate the electric vehicle fleet transition, balancing financial viability, operational reality, and human factors through a strategic and phased implementation pathway.

References

ABM. (n.d.). Expert answers to every fleet electrification question. ABM EV Charging Solutions. Retrieved from https://info.abm.com/simplifyEV-fleet-guide.html

Accenture. (2023). *Lead the charge: Fleet electrification accelerated.* Accenture.

Alp, O., Tan, T., & Udenio, M. (2022). Transitioning to sustainable freight transportation by integrating fleet replacement and charging infrastructure decisions. *Omega: The International Journal of Management Science*, *109*, 102595.

American Automobile Association. (2025). Minnesota average gas prices. AAA gas prices. Retrieved from https://gasprices.aaa.com/?state=MN

Ampcontrol. (n.d.). *AmpEdge: The local EV controller for fleet charging sites*. EV Management Reports. Retrieved from https://www.ampcontrol.io/reports/ampedge-the-local-controller-for-fleet-charging-sites-report

Ampcontrol. (n.d.). *Interested in open charge point protocol?* EV Management Reports. Retrieved from https://www.ampcontrol.io/reports/ocpp-report

Argonne National Laboratory. (2023). FAQ: Charging for heavy-duty electric trucks. Argonne National Laboratory. Retrieved from https://www.anl.gov/sites/www/files/2023-03/MCS_FAQs_Final_3-13-23.pdf

Atlas Public Policy. (2024). *Dashboard for rapid vehicle electrification (DRVE) tool: User guide (Version 2.0).* Electrification Coalition. Retrieved from https://electrificationcoalition.org/wp-content/uploads/2024/04/DRVE-User-Guide.pdf

Berkeley, N., Bailey, D., Jones, A., & Jarvis, D. (2017). Assessing the transition towards battery electric vehicles: A multi-level perspective on drivers of, and barriers to, take up. *Transportation Research Part A: Policy and Practice*, *106*, 320-332.

Bernard, J., Allwood, J., & Hildermeier, J. (2022). *Charging solutions for battery-electric trucks.* International Council on Clean Transportation.

Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M. A., . . . Ou, S. (2021). *Comprehensive total cost of ownership quantification for vehicles with different size classes and powertrains.* Argonne National Laboratory.

Comello, S., Glenk, G., & Reichelstein, S. (2021). Transitioning to clean energy transportation services: Life-cycle cost analysis for vehicle fleets. *Applied Energy*, *285*, 116408.

County of Santa Clara. (2018). *Plug-in electric vehicles and infrastructure: A white paper for the Cities Association of Santa Clara County.* Santa Clara County, CA.

Daniels, L., & Nelder, C. (n.d.). *Preparing fleet managers for the coming wave of electrified vehicles.* Rocky Mountain Institute.

Decrinis, L., Freibichler, W., Kaiser, M., Sunstein, C. R., & Reisch, L. A. (2023). Sustainable behaviour at work: How message framing encourages employees to choose electric vehicles. *Business Strategy and the Environment*, *32*, 5650-5668.

Di Foggia, G. (2021). Drivers and challenges of electric vehicles integration in corporate fleet: An empirical survey. *Research in Transportation Business and Management*, *41*, 100627.

Driivz. (2022). *The road to successful fleet electrification.* Driivz.

Executive Chevrolet. (2023). *2023 Chevy Bolt EUV range*. Executive Chevrolet. Retrieved from https://www.executivechevy.com/chevy-research/2023-chevy-bolt-euv-range/

Farhar, B. C., Maksimovic, D., Tomac, W. A., & Coburn, T. C. (2016). A field study of human factors and vehicle performance associated with PHEV adaptation. *Energy Policy*, *93*, 265-277.

Furch, J., Konečný, V., & Krobot, Z. (2022). Modelling of life cycle cost of conventional and alternative vehicles. *Scientific Reports*, *12*, 10661.

Gahlaut, A., & Shapiro, B. (2023). *How cities and counties can electrify their fleets.* RMI. Retrieved from https://rmi.org/insight/how-cities-and-counties-can-electrify-their-fleets/

Genesee Finger Lakes Regional Planning Council. (2022). *Genesee–Finger Lakes Regional fleet electrification study.* Genesee Finger Lakes Regional Planning Council.

Javed, B., Kandlikar, M., & Giang, A. (2024). Local energy transitions in small transportation fleets. *SSRN.* https://doi.org/10.2139/ssrn.4853520

Jossi, F. (2023). Why Minnesota's push to electrify government vehicles is going slower than expected. *Minnesota Reformer.* Retrieved from https://minnesotareformer.com/2023/04/06/why-minnesotas-push-to-electrify-government-vehicles-is-going-slower-than-expected/

Kettles, D. (2016). *Electric vehicle fleet implications and analysis.* Washington, DC: Electric Vehicle Transportation Center.

Khaled, M. S., Abdalla, A. M., Abas, P. E., Taweekun, J., Reza, M. S., & Azad, A. K. (2024). Life cycle cost assessment of electric, hybrid, and conventional vehicles in bangladesh: A comparative analysis. *World Electric Vehicle Journal*, *15*, 183.

Kyriakidis, M., Happee, R., & de Winter, J. C. (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. *Transportation Research Part F: Traffic Psychology and Behaviour*, *32*, 127-140.

Lane, B., & Potter, S. (2007). The adoption of cleaner vehicles in the UK: Exploring the consumer attitude—action gap. *Journal of Cleaner Production*, *15*, 1085-1092.

Levy, J., Riu, I., & Zoi, C. (2020). *The costs of EV fast charging infrastructure and economic benefits to rapid scale-up.* EVgo.

Mahdavian, A., Shojaei, A., McCormick, S., Papandreou, T., Eluru, N., & Oloufa, A. A. (2021). Drivers and barriers to implementation of connected, automated, shared, and electric vehicles: An agenda for future research. *IEEE Access*, *9*, 22195-22213.

Mao, S., Qu, Z., & Rodriguez, F. (2025). *Zero-emission medium- and heavy-duty vehicle market in China, H1 2025.* International Council on Clean Transportation.

McKinsey & Company. (2022). *Fleet decarbonization: Operationalizing the transition.* McKinsey & Company.

National Renewable Energy Laboratory. (2024). Clean bus planning awards support fleet electrification with custom transition plans. NREL News. Retrieved from https://www.nrel.gov/news/program/2024/clean-bus-planning-awards-support-fleet-electrification-with-custom-transition-plans.html

Nesbitt, K., & Sperling, D. (1998). Myths regarding alternative fuel vehicle demand by light-duty vehicle fleets. *Transportation Research Part D: Transport and Environment*, *3*, 259-269.

Nesbitt, K., & Sperling, D. (2001). Fleet purchase behavior: Decision processes and implications for new vehicle technologies and fuels. *Transportation Research Part C: Emerging Technologies*, *9*, 297-318.

New York City Taxi and Limousine Commission. (2022). *Nissan LEAF electric taxi pilot program: Pilot evaluation.* New York: New York City Taxi and Limousine Commission.

Office of State and Community Energy Programs. (2024). *Blueprint 4A: Electric vehicles and fleet electrification.* U.S. Department of Energy. Retrieved from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.energy.gov/sites/default/files/2023-04/EV_Blueprint_v04_508.pdf

PowerOutage.us. (n.d.). *Electricity rates by state*. PowerOutage.us. Retrieved from https://poweroutage.us/electricity-rates

Ragon, P. L. (2025). *Real-world use cases for zero-emission trucks: Heavy tractor-trailers for goods transport in the European Union.* International Council on Clean Transportation.

Rainieri, G., Buizza, C., & Ghilardi, A. (2023). The psychological, human factors and socio-technical contribution: A systematic review towards range anxiety of battery electric vehicles' drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *99*, 52-70.

Raustad, R., & Fairey, P. (2014). *Electric vehicle life cycle cost assessment.* Electric Vehicle Transportation Center.

Riesz, J., Ambach, D., & Donovan, S. (2016). Quantifying the costs of a rapid transition to electric vehicles. *Applied Energy*, *180*, 287-300.

Schoettle, B., & Sivak, M. (2014). A survey of public opinion about connected vehicles in the US, the UK, and Australia. *014 International Conference on Connected Vehicles and Expo (ICCVE)* (pp. 87-692). IEEE.

Sierzchula, W. (2014). Factors influencing fleet manager adoption of electric vehicles. *Transportation Research Part D: Transport and Environment*, *31*, 126-134.

Smith, M., & Castellano, J. (2015). C*osts associated with non-residential electric vehicle supply equipment: Factors to consider in the implementation of electric vehicle charging stations.* U.S. Department of Energy, Vehicle Technologies Office.

Tousignant, A., Spencer, M., & Jensen, J. (2021). *Transition to electric vehicles: 10 steps for your public fleet.* Washington State University Energy Program.

U.S. Department of Energy – Energy Efficiency and Renewable Energy. (n.d.). *Electric vehicle charging station locations*. Alternative Fuels Data Center. Retrieved from https://afdc.energy.gov/fuels/electricity-stations

U.S. Department of Energy – Energy Efficiency and Renewable Energy. (n.d.). *Maintenance and safety of electric vehicles*. Alternative Fuels Data Center. Retrieved from https://afdc.energy.gov/vehicles/electric-maintenance

U.S. Government Accountability Office. (2022). *Federal vehicle fleets: Observations on the transition to electric vehicles.* Washington, DC: U.S. Government Accountability Office.

Work Truck Online. (2024). *PowerGuide to streamline fleet electrification planning for utilities and customers*. Work Truck Online. Retrieved fom https://www.worktruckonline.com/10232998/powerguide-to-streamline-fleet-electrification-planning-for-utilities-and-custom

Zmud, J. P., & Sener, I. N. (2017). Towards an understanding of the travel behavior impact of autonomous vehicles. *Transportation Research Procedia*, *25*, 2500-2519.

Appendix A:
Human Factors survey questions

General Information

Which agency do you work for?

What title best describes your current role in your agency?

- Fleet Manager
- Field Staff
- Operations Manager
- Other (please specify)

How many years have you been in your current role?

- Less than 1 year
- 1-3 years
- 4-6 years
- More than 6 years

How often do you use agency vehicles?

- Daily
- Weekly
- Monthly
- Rarely (less than once per month)
- Never

What is your age group?

- 18-29
- 30-39
- 40-49
- 50+

Please specify your gender identity.

- Male
- Female
- Non-binary
- Prefer not to say
- Other (please specify)

Agency Context

What is the size of the passenger vehicle fleet at your agency (to your knowledge)?

○ 1-10 vehicles
○ 11-50 vehicles
○ 51-100 vehicles
○ More than 100 vehicles

What type of vehicles are in your fleet? (select all that apply)

○ Passenger cars
○ Light commercial vehicles
○ Heavy trucks
○ Specialized vehicles (e.g., construction, emergency)
○ Other (please specify)

What percentage of your fleet currently consists of electric vehicles (EVs) to the best of your knowledge?

○ 0%
○ 1-10%
○ 11-25%
○ 26-50%
○ More than 50%

What is the size of the vehicle fleet at your agency (to your knowledge), including all vehicle types?

○ 1-10 vehicles
○ 11-50 vehicles
○ 51-100 vehicles
○ More than 100 vehicles

Adoption and understanding of EVs

How do you feel about the transition from traditional vehicles to electric vehicles (EVs)?

○ Very positive
○ Somewhat positive
○ Neutral
○ Somewhat negative
○ Very negative

What benefits do you associate with using EVs? (Select all that apply)

○ Reduced environmental impact

- ○ Lower fuel costs
- ○ Improved technology
- ○ Enhanced driving experience
- ○ Other (please specify)

Concerns and Challenges

What concerns do you have about using EVs? (Select all that apply)

- ○ Limited driving range
- ○ Availability of charging stations
- ○ Charging time
- ○ Maintenance and repair
- ○ Initial cost
- ○ Other (please specify)

How concerned are you about the reliability of EVs compared to traditional vehicles?

- ○ Very concerned
- ○ Somewhat concerned
- ○ Neutral
- ○ Not very concerned
- ○ Not concerned at all

Please elaborate on your answer to Question 14. Short answer

Do you have any concerns about the safety of EVs?

- ○ Yes (please specify)
- ○ No (please specify)

Preferences & Expectations

What features would you like to see in agency EVs to support your work?

- ○ Longer battery life
- ○ More charging stations
- ○ Faster charging times
- ○ Advanced navigation systems
- ○ Other (please specify)

How familiar are you with the following technical characteristics of EVs?
(1 - Not familiar at all, 2 - Slightly familiar, 3 - Moderately familiar, 4 - Very familiar, 5 - Extremely familiar)

- ○ Battery life and charging times

- ○ Range per charge
- ○ Maintenance requirements
- ○ Total cost of ownership
- ○ Environmental benefits

Did you receive any training from your agency before using EVs?

- ○ Yes, I had training before I used an EV in a capacity at work.
- ○ No, no training before I used an EV in a capacity at work.
- ○ Yes, but I haven't used an EV in this capacity at work yet.
- ○ No, I haven't yet used an EV in this capacity.

What type of support or training would help you transition to using EVs?

- ○ Hands-on training sessions
- ○ Informational workshops
- ○ Detailed user manuals
- ○ Online resources and videos
- ○ Other (please specify)

How important is it for the agency to consider employee feedback when transitioning to EVs?

- ○ Very important
- ○ Somewhat important
- ○ Neutral
- ○ Not very important
- ○ Not important at all

Perspectives on Transitions to EV

1. What challenges do you foresee in managing a fleet of electric vehicles compared to traditional vehicles? (Answer only if you are a fleet manger)
2. How comfortable are you performing maintenance on electric vehicles compared to traditional vehicles? What challenges do you face (or anticipate facing) when working with EVs? (Answer only if you are a field staff)
3. What strategies do you think are most effective for encouraging the adoption of EVs within your agency? (Answer only if you are an operation manager)
4. What concerns related to repair and upkeep most concern you related to EVs, given your role? ((Answer only if you are a mechanic)

Please specify any other thoughts you may have to transitioning to EV vehicles are your agency.

Appendix B:
Fleet Conversion Status Survey Questions

General Information

1. Which agency do you work for?
2. What is your position in the agency you work for?

Current Fleet Information

3. Are you able to provide a list of Vehicle Identification Numbers (VIN) for vehicles in your fleet? (e.g., VIN: JH4DC4330VS801155)
   - ○ Yes, I can
   - ○ Yes, there is a list, but I am not approved to pull it
   - ○ I am not sure if there is a list
   - ○ No, the list is not available
4. Please upload a file containing your fleet's Vehicle Identification Numbers (VINs), like the example below. If your file does not include all the columns (or fields) from the example, feel free to upload the data only with the available columns you have; a single-columned VIN-only file is acceptable (*Display Condition: if the answer of Q3 is "Yes, I can"*).

VIN	(Estimated) Acquisition Year	Current Mileage
JM1DKFD72K0423204	2021	44,444
JH4DC4330VS801155	2023	NA

*We would appreciate it if you included any extra columns not shown in the example

The file can be in any readable format, e.g., CSV or Excel; however, please avoid uploading PDF files if possible. If you have multiple files and cannot upload them here, please compress them into a single ZIP file. Once compressed, you will be able to upload the ZIP file using the prompt.

5. Please share the name and position of a person in your organization who has access to the VIN list for your agency's fleet (*Display Condition: if the answer of Q3 is "I am not sure if there is a list"*).
6. Please upload a file that lists the make, model, trim, and year for each vehicle in your agency's fleet, like the example below. If your file does not include all the columns (or fields) from the example, feel free to upload the data only with the available columns you have (*Display Condition: if the answer of Q3 is "Yes, there is a list, but I am not approved to pull it" or "No, the list is not available"*).

(Internal) Vehicle ID	Make	Model	Trim	Year	Acquisition Year	Current Mileage
47217	Toyota	Camry	LE	2019	2022	64,212
2281	Mazda	CX-3	Touring	2023	2023	15,421

*We would appreciate it if you included any extra columns not shown in the example

The file can be in any readable format, e.g., CSV or Excel; however, please avoid uploading PDF files if possible. If you have multiple files and cannot upload them here, please compress them into a single ZIP file. Once compressed, you will be able to upload the ZIP file using the prompt.

We understand that organizing and uploading this file may take some of your time, but we kindly ask for your assistance, as this information is crucial for analyzing vehicle specifications and supporting our data collection efforts. Thank you for your cooperation!

7. Are you able to provide a file containing the trip logs of your agency's fleet, including details like the table below?

VIN or Internal Vehicle ID	Trip Date	Trip or Session Start Time	Trip or Session End Time	Origin	Destination	Mileage	Trip Purpose
111	9/27/2024	11:01 AM	11:44 AM	AA City Hall	111 First Ave, AA	11	Delivery
112	9/27/2024	12:44 PM	13:00 PM	111 First Ave, AA	AA City Hall	11	Return
122	9/27/2024	9:21 AM	17:11 PM	AA City Hall	MnDOT (Round Trip)	180	Meeting

*We would appreciate it if you could upload the file in the next question with any extra columns not shown in the example

From the above example, rows 1 and 2 collectively show a round trip recorded as two entries, while row 3 shows it recorded as a single entry. Both formats are perfectly acceptable, so please feel free to upload your existing file as-is in the next question, even if both formats are mixed in a single file. We will handle the post-processing using the origin and destination locations.

To reiterate, the question was about your availability to upload a trip logs file; if your file does not contain all the columns or fields from the example, that is perfectly fine as long as each entry or row represents a trip-level record. In this case, please select "Yes."

- ○ Yes
- ○ No
- ○ I need to get permission (Please provide the email address we can contact for follow-up)

☐

8. We kindly request that you provide the trip logs of your agency's fleet, as explained in the previous question.
   If your file does not contain all the columns or fields from the previous question's example, that is perfectly fine as long as each entry or row represents a trip-level record.
   The file can be in any readable format, e.g., CSV or Excel; however, please avoid uploading PDF files if possible.
   If you have multiple files and cannot upload them here, please compress them into a single ZIP file. Once compressed, you will be able to upload the ZIP file using the prompt.
   We would appreciate it if you included any extra columns that are not in the previous question's example.
   We are seeking data covering any time span, with a preference for more recent data.

Please note that any identifying information, such as the person who completed the trip, will be removed and not be used in our analyses (*<u>Display Condition</u>: if the answer of Q7 is "Yes"*).

9. Are you able to create and provide a file containing daily vehicle usage data for your agency's fleet? If daily data is unavailable, weekly, monthly, or yearly data would also be helpful. See the below example for your reference.

VIN or Internal Vehicle ID	Data Collection Period	Total Mileage for the Period	Total Number of Trips for the Period (Estimates)	Primary Purpose
442	5/4/2024	32	2	Construction
442	5/5/2024	0	0	Construction
J41DSF79	5/5/2024	42	Unknown	Unknown
455	11th week of 2024	472	25	Delivery

*We would appreciate it if you could upload the file in the next question with any extra columns not shown in the example

From the above example, given the "Data Collection Period" column, rows 1-3 show a daily summary of vehicle usage, while row 4 shows a weekly summary.

To reiterate, the question was about your availability to upload a fleet trip summaries file. If your file does not contain all the columns or fields from the example, that is perfectly fine. In this case, please select "Yes" (*<u>Display Condition</u>: if the answer of Q7 is “No”*).

  - ○ Yes
  - ○ No
  - ○ I need to get permission (Please provide the email address we can contact for follow-up)

10. We kindly request that you provide the trip summary of your agency's fleet, as explained in the previous question. If your file does not contain all the columns or fields from the previous question's example, that is perfectly fine. The file can be in any readable format, e.g., CSV or Excel; however, please avoid uploading PDF files if possible.
    If you have multiple files and cannot upload them here, please compress them into a single ZIP file. Once compressed, you will be able to upload the ZIP file through the prompt.
    We would appreciate it if you included any extra columns that are not in the previous question's example. We are seeking data covering any time span, with a preference for more recent data.
    We understand that organizing the data for creating the file and uploading it may take some of your time, but we kindly ask for your assistance, as this information is crucial for analyzing vehicle specifications and supporting our data collection efforts.
    Thank you for your cooperation! (*<u>Display Condition</u>: if the answer of Q9 is “Yes”*).
11. What is your best estimate of the average number of trips per day made by your agency's fleet? Please consider only active vehicle usage (*<u>Display Condition</u>: if the answer of Q9 is “No”*).
12. What is your best estimation of the average distance (in miles or kilometers) of each trip made by your agency's vehicles per day. If some vehicles do not make any trips on certain days, please base your response on the vehicles that do.
13. Please provide the ZIP code where the majority of your fleet is located (domiciled).
    If your fleet spans multiple ZIP codes, please list TOP 5 ZIP codes along with the number of vehicles assigned to that location.
    For the latter case, response instruction: ZIP code 1, # of vehicles at 1; ZIP code 2, # of vehicles at 2;…e.g., 55454, 15; 55455, 12; 50401, 10;...
14. Which period of the day is the busiest for your agency's fleet? Please select the time frame that best represents peak activity.
    - ○ 8:00 AM – 11:00 AM
    - ○ 11:00 AM – 2:00 PM
    - ○ 2:00 PM – 5:00 PM
    - ○ Night shift
    - ○ Other (please specify): ☐

EV-Related Information and Future Planning

15. Does your agency's fleet include any electric vehicles (EVs)?
    - ○ Yes
    - ○ No

16. What is the average number of vehicles in your agency's fleet that need to be charged each day? (<u>*Display Condition*</u>*: if the answer of Q16 is "Yes"*).
    - ○ 1-5 EVs
    - ○ 5-10 EVs
    - ○ 10-20 EVs
    - ○ 20-50 EVs
    - ○ More than 50 EVs
17. What is the size of your agency's electric heavy/medium duty vehicle fleet? Please select the appropriate range. (<u>*Display Condition*</u>*: if the answer of Q16 is "Yes"*).
    - ○ 0 E-truck
    - ○ 1-10 E-trucks
    - ○ 11-50 E-trucks
    - ○ 51-100 E-trucks
    - ○ More than 100 E-trucks
18. What percentage of your electric vehicle (EV) fleet charging is done using the following strategies? Please provide a percentage for each option (total should equal 100%). (<u>*Display Condition*</u>*: if the answer of Q16 is "Yes"*).

Charging Option	**0%**	**1–25%**	**26–50%**	**51–75%**	**More than 75%**
Depot Charging					
Public Charging					
En-Route Charging					
Employee's House					
Other Options (please specify)					

19. What percentage of each charging strategy do you believe would be the best combination for your company's future EV fleet, considering your company's budget? Please ensure the total equals 100%. (<u>*Display Condition*</u>*: if the answer of Q16 is "No"*).

Charging Option	**0%**	**1–25%**	**26–50%**	**51–75%**	**More than 75%**
Depot Charging					

Charging Option	**0%**	**1–25%**	**26–50%**	**51–75%**	**More than 75%**
Public Charging					
En-Route Charging					
Employee’s House					
Other Options (please specify)					

20. What combination of charging strategies, in terms of percentage, do you believe will meet the charging needs of your company once the entire fleet is replaced with electric vehicles (EVs)? (*Display Condition: if the answer of Q16 is “Yes”*).

Charging Option	**0%**	**1–25%**	**26–50%**	**51–75%**	**More than 75%**
Depot Charging					
Public Charging					
En-Route Charging					
Employee’s House					
Other Options (please specify)					

21. Is your agency open to collaborating by sharing its EV chargers with smaller fleet agencies during periods of low demand?
    ○ Yes
    ○ No
    ○ Maybe

22. Would your agency be willing to use other agencies' charging infrastructure to reduce charging costs?
    - ○ Yes
    - ○ No
    - ○ Maybe
23. Please specify any conditions or considerations your agency would require for sharing EV chargers with other agencies or for using another agency's charging infrastructure (e.g., time of day, costs, access restrictions).
24. Please indicate the location and time when charging typically occurs for your agency's electric heavy/medium-duty vehicles. Select all applicable options for each location and time period. (<u>*Display Condition*</u>*: if the answer of Q16 is "Yes" and the answer of Q17 is not "0 E-truck"*).

Charging Option	**Morning (6AM-12PM)**	**Afternoon (12PM-5PM)**	**Evening (5PM-9PM)**	**Night (9PM-6AM)**
Depot Charging				
Public Charging				
En-Route Charging				

25. What type of charger is currently being used for your agency's EV fleet? Please select all that apply (<u>*Display Condition*</u>*: if the answer of Q16 is "Yes").*

Charging Option	**0%**	**1–25%**	**26–50%**	**51–75%**	**More than 75%**
Level 1 Charging					
Level 2 Charging					
DC fast Charging					
Other Options (please specify)					

26. Does the current charging speed meet the needs of your agency's EV fleet? (*Display Condition: if the answer of Q16 is "Yes"*).
    - ○ Yes
    - ○ No (please specify any issues or challenges):
27. Given that EVs require parking space during charging, do you believe your agency's current parking facilities would provide sufficient space to accommodate the necessary charging infrastructure for the EV fleet?
    - ○ Yes
    - ○ No

28. What challenges do you anticipate your agency will face when utilizing its parking facilities to charge the EV fleet?
29. We value your insights! Please share any thoughts, feedback, comments, considerations, or limitations that you feel were not covered in this survey. Your input will greatly help us improve our understanding and refinement of our approach.

Appendix C:
Optimization Model

The proposed multi-phase electrification transition is formulated as an optimization problem aimed at minimizing operational costs during each planning phase. The parameters and variables considered in this project are detailed in **Table C-1.**

Table C-1 Notations

Sets	Description
I	Set of depots selected as charging station candidate locations.
A	Set of vehicle classes: $A = \{p, m, h\}$ (light/medium/heavy-duty).
J_a	Set of routes for vehicle class $a \in A$.
T	Set of time periods (e.g., hours in a day).
Φ	Set of planning phases.

Parameters	Description
U_i	Charging station capacity at station $i \in I$.
$z_{j,t}^{min}$	Minimum fleet required for route j at time $t \in T$ to maintain operations.
$e_{j,t,\varphi}$	Required fleet for route j at start of time t in phase φ to meet operational energy demand.
$c_{j,\varphi}^{o}$	Operational cost for non-electrified route j in phase φ.
$c_{j,\varphi}^{m}$	Maintenance cost of electrified route j in phase φ
$p_{t,\varphi}^{e}$	Electricity tariff during time t in phase φ.
c^{p}	Penalty cost per unit of unsatisfied operation demand.
c_{φ}^{r}	Vehicle relocation cost in phase φ.
l_{ij}	Distance between depot of route j and charging station i.
B_{φ}	The allocated budget for phase φ.
l_{φ}	Length of phase φ.

Variables	Description
$u_{i,\varphi}^{p}$	Cumulative number of chargers installed at station i through phase φ.
$u_{i,\varphi}^{p,new}$	New chargers added at station i in phase φ.
$x_{i,\varphi}$	1 if station i is open by phase φ; 0 otherwise.
$x_{i,\varphi}^{new}$	1 if station i is first opened in phase φ; 0 otherwise.
$y_{j,\varphi}$	1 if route j is electrified by phase φ; 0 otherwise.
$s_{i,j,\varphi}$	1 if route j is assigned to station i in phase φ; 0 otherwise.
$z_{j,\varphi}$	Fleet size of electrified route j in phase φ.
$z_{a,\varphi}^{new}$	New vehicles of class a purchased in phase φ.
b_{φ}	Surplus budget in phase φ.
$v_{i,j,t,\varphi}$	EVs available for route j with designated station i at t in phase φ.
$\omega_{i,j,t,\varphi}$	EVs starting charge at station i in t and fully charged by t+1 start.
$\varpi_{i,j,t,\varphi}$	Additional vehicles required at station i to meet route j's operational energy demand during period t in phase φ.

The objective function, detailed in Equation (1), comprises five distinct cost components: The first term, $\sum_{\varphi}\sum_{j} c_{j,\varphi}^{o}\,(1-y_{j,\varphi})$, represents the fuel and maintenance costs for routes that remain non-electrified during each electrification phase. Here, $(1-y_{j,\varphi})$ identifies routes that have not yet transitioned to EVs. The second term, $\sum_{\varphi}\sum_{j} c_{j,\varphi}^{m}\, y_{j,\varphi}$, covers maintenance expenses associated specifically with electrified routes. The third component, $\sum_{\varphi,t,i,j} p_{t,\varphi}^{e}\omega_{i,j,t,\varphi}$, captures electricity costs for charging EV fleets at designated stations over each time interval. Operational costs due to EVs traveling (deadheading) from their home depot without charging stations to other depots with available chargers are captured by the fourth term, $\sum_{\varphi,t,i,j} c_{j,\varphi}^{r} l_{ij}\omega_{i,j,t,\varphi}$. Here, l_{ij} represents the distance from the home depot i to depot j, which has available charging infrastructure. The term $\sum_{\varphi,t,i,j} c_{j}^{p}\,\varpi_{i,j,t,\varphi}$ penalizes situations where the available electric fleet cannot meet operational energy requirements.

$$\min \sum_{\varphi}\sum_{j} c_{j,\varphi}^{o}\,(1-y_{j,\varphi}) + \sum_{\varphi}\sum_{j} c_{j,\varphi}^{m}\,y_{j,\varphi} \;+\; \sum_{\varphi}\sum_{t}\sum_{i}\sum_{j} p_{t,\varphi}^{e}\,\omega_{i,j,t,\varphi}$$
$$+\sum_{\varphi}\sum_{t}\sum_{i}\sum_{j} c_{j,\varphi}^{r}\,l_{ij}\,\omega_{i,j,t,\varphi} \;+\; \sum_{\varphi}\sum_{t}\sum_{i}\sum_{j} c_{j}^{p}\,\varpi_{i,j,t,\varphi} \tag{1}$$

The operational constraints and relationships between planning decisions are detailed further in Equations (2)-(31).

Constraint	**Set**	**No.**
$x_{i,\varphi-1} \le x_{i,\varphi}$	$\forall\varphi \ge 2, \forall i$	(2)
$x_{i,1} \le x_{i,1}^{new}$	$\forall i$	(3)
$x_{i,\varphi} - x_{i,\varphi-1} \le x_{i,\varphi}^{new}$	$\forall\varphi \ge 2, \forall i$	(4)
$u_{i,1}^{p,new} = u_{i,1}^{p}$	$\forall i$	(5)
$u_{i,\varphi}^{p} - u_{i,\varphi-1}^{p} \le u_{i,\varphi}^{p,new}$	$\forall\varphi \ge 2, \forall i$	(6)
$\sum_{p} u_{i,\varphi}^{p} \le U_i \cdot x_{i,\varphi}$	$\forall\varphi, \forall i$	(7)
$\sum_{p} \alpha_p u_{i,\varphi}^{p} \le Q_i \cdot x_{i,\varphi}$	$\forall\varphi, \forall i$	(8)
$y_{j,\varphi-1} \le y_{j,\varphi}$	$\forall\varphi \ge 2, \forall j$	(9)
$z_{j,\varphi-1} \le M \cdot y_{j,\varphi}$	$\forall\varphi, \forall j$	(10)
$\sum_{i} s_{i,j,\varphi} = y_{j,\varphi}$	$\forall\varphi, \forall j$	(11)
$s_{i,j,\varphi} \le x_{i,\varphi}$	$\forall\varphi, \forall i, \forall j$	(12)

Constraint	**Set**	**No.**
$s_{i,j,\varphi} \le \sum_{p\in P_a} u^{p}_{i,\varphi}$	$\forall\varphi, \forall i, \forall j, \forall a, \forall J_a$	(13)
$z^{new}_{a,1} = \sum_{j\in J_a} z_{j,1}$	$\forall a$	(14)
$z^{new}_{a,\varphi} = \sum_{j\in J_a} z_{j,\varphi} - \sum_{j\in J_a} z_{j,\varphi-1}$	$\forall\varphi \ge 2, \forall a$	(15)
$w_{j,\lvert\Phi\rvert} \le z_{j,\lvert\Phi\rvert}$	$\forall j$	(16)
$w_{j,\lvert\Phi\rvert} \le M \cdot y_{j,\lvert\Phi\rvert}$	$\forall j$	(17)
$w_{j,\lvert\Phi\rvert} \ge z_{j,\lvert\Phi\rvert} - M \cdot (1 - y_{j,\lvert\Phi\rvert})$	$\forall j$	(18)
$\sum_{j\in J_a} w_{j,\lvert\Phi\rvert} \ge \beta_a$	$\forall j, \forall a$	(19)
$\sum_{i\in I} c^{s}_{i,\varphi}\, x^{new}_{i,\varphi} + \sum_{i\in I}\sum_{p\in P} c^{c}_{p,\varphi}\, u^{p,new}_{i,\varphi} + \sum_{a\in\{p,m,h\}} c^{f}_{a,\varphi}\, z^{new}_{a,\varphi} + b_\varphi = B_\varphi$	$\forall\varphi$	(20)
$\omega_{i,j,t,\varphi} \le U_i\, s_{i,j,\varphi}$	$\forall\varphi, \forall i, \forall j, \forall t$	(21)
$\sum_{a\in A}\sum_{j\in J_a} \omega_{i,j,t,\varphi} \le \sum_{p\in P_a} u^{p}_{i,\varphi}$	$\forall\varphi, \forall t, \forall i, \forall a$	(22)
$\sum_{a\in A}\sum_{j\in J_a} \omega_{i,j,t,\varphi} \cdot r_a \le \sum_{p\in P_a} \alpha_p \cdot u^{p}_{i,\varphi} \cdot \delta_t$	$\forall\varphi, \forall t, \forall i, \forall a$	(23)
$z^{min}_{j,t} \cdot y_{j,\varphi} + \sum_{i\in I} \omega_{i,j,t,\varphi} \le z_{j,\varphi}$	$\forall\varphi, \forall i, \forall j, \forall t$	(24)

Constraint	Set	No.
$\sum_{t \in T} z_{j,t}^{min} \cdot y_{j,\varphi} \leq z_{j,\varphi}$	$\forall \varphi, \forall j$	(25)
$\nu_{i,j,t,\varphi} + \omega_{i,j,t,\varphi} + \varpi_{i,j,t,\varphi} - e_{j,t,\varphi}\, s_{i,j,\varphi} = \nu_{i,j,t+1,\varphi}$	$\forall \varphi, \forall i, \forall j, \forall t/\{T\}$	(26)
$\nu_{i,j,T,\varphi} + \omega_{i,j,T,\varphi} + \varpi_{i,j,T,\varphi} - e_{j,T,\varphi}\, s_{i,j,\varphi} = \nu_{i,j,1,\varphi}$	$\forall \varphi, \forall i, \forall j$	(27)
$\nu_{i,j,t,\varphi} \leq z_{j,\varphi}$	$\forall \varphi, \forall i, \forall j, \forall t$	(28)
$x_{i,\varphi}, x_{i,\varphi}^{new}, y_{j,\varphi}, s_{i,j,\varphi} \in \{0,1\}$	$\forall \varphi, \forall i, \forall j$	(29)
$u_{i,\varphi}^{p}, u_{i,\varphi}^{p,new}, z_{j,\varphi}, z_{a,\varphi}^{new}, \nu_{i,j,t,\varphi}, \omega_{i,j,t,\varphi}, \varpi_{i,j,t,\varphi} \in \mathbb{Z}_+$	$\forall \varphi, \forall i, \forall j, \forall t$	(30)
$b_{\varphi} \in \mathbb{R}_+$	$\forall \varphi$	(31)

Charging station deployment follows persistent operation rules. Equation (2) ensures stations remain open in all subsequent phases once opened. New station activations are tracked through Equations (3-4), where $x_{i,1}^{new}$ identifies initial-phase openings and $x_{i,1}^{new}$ captures new activations in later sphases. We consider four charger types that may be installed at each charging station. Let $u_{i,\varphi}^{L1}$, $u_{i,\varphi}^{L2}$, $u_{i,\varphi}^{DC}$, and $u_{i,\varphi}^{MCS}$denote, respectively, the number of Level-1, Level-2, DC fast, and megawatt (MCS) chargers installed at station i in phase φ:

$u_{i,\varphi}^{L1}$: Level-1 (AC) chargers for light-duty vehicles;

$u_{i,\varphi}^{L2}$: Level-2 (AC) chargers for light-duty vehicles;

$u_{i,\varphi}^{DC}$: DC fast chargers usable by light- and medium-duty vehicles;

$u_{i,\varphi}^{MCS}$: Megawatt Charging System (MCS) chargers for heavy-duty vehicles.

Charger installation progresses incrementally across phases: with charger types $P = \{L1, L2, DC, MCS\}$, Phase 1 installations equal the initial counts, $u_{i,1}^{p,new} = u_{i,1}^{p}$ (Eq.5) and for subsequent phases ($\varphi = 2, \dots, \Phi$) the cumulative number of chargers satisfies ($u_{i,\varphi}^{p} \leq u_{i,\varphi-1}^{p} + u_{i,\varphi}^{p,new}$) (Eq.6). Locational (space) station limits are enforced by Eq.7, which restricts the total number of chargers at operational stations to U_i. Power capacity at each station is enforced by Eq. 8, which limits the aggregated power of installed chargers to the station's maximum capacity Q_i. Here, α_p denotes the maximum power rating of charger type p.

Route electrification progresses irreversibly to full adoption. Equation 9 enforces progressive route electrification commitment. Once route j is electrified in phase $\varphi - 1$ ($y_{j,\varphi-1} = 1$), it must remain electrified in all subsequent phases ($\varphi, \varphi + 1, \ldots, |\Phi|$). Equation 10 restricts purchasing new EV fleets for a route unless the route has been selected for electrification, where M represents a sufficiently large number to ensure that the upper bound of the fleet size is not artificially limited. Each electrified route must be assigned to a charging station (Equation 11), with Equation 12 restricting assignments to stations opened by that phase. All vehicles assigned to a given route share the same body class according to the definition of the route in this study. Let $a \in A = \{L, M, H\}$ index light-, medium-, and heavy-duty classes, and let J_a denote the set of routes of class a. For each class a, let P_a be the set of compatible charger types, with $P_L = \{L1, L2, DC\}$, $P_M = \{DC\}$, and $P_H = \{MCS\}$. Equation 13 permits assigning a route J_a to station i only if station i provides at least one charger of a type in P_a.

Fleet management needs to be integrated with budget constraints. Vehicle acquisitions by class (passenger/medium/heavy-duty) are calculated for Phase 1 through Equation (14) and for subsequent phases via Equation (15). Equations (16-18) provide auxiliary relationships to linearize the product term $w_{j,|\Phi|} = z_{j,|\Phi|} \cdot y_{j,|\Phi|}$, enabling Equation 19 to enforce minimum electrified fleet requirements for each vehicle class. Equation (20) ensures total expenditures (new stations + chargers + vehicles) plus budget surplus b_φ stay within the phase budget B_φ. Charging operations enforce physical and operational limits. Equation (21) prevents charger overuse by restricting $\omega_{i,j,t,\varphi}$ to the assigned station's capacity, while Equation (22) limits, for each vehicle class, the number of charging sessions from assigned routes at a station to the station's count of installed compatible chargers. In Eq. 23, r_a denotes the battery capacity (kWh) of vehicle class a, and δ_t is the duration of time period t (h). The constraint ensures that, for each station and vehicle class, the energy requested during period t does not exceed the maximum energy that the station's compatible chargers can deliver over δ_t. Fleet sizing requirements are addressed by Equation (23), ensuring $z_{j,\varphi}$ covers minimum operational needs including charging downtime, with Equation (24) providing a lower bound by aggregating the minimum required operational fleet across all time intervals.

Energy demand fulfillment employs conservation principles. Equations (26)-(27) govern electric vehicle flow through cyclic conservation: available vehicles plus newly charged units plus supplemental vehicles minus operational deployments equal the next period's availability. The variable $\varpi_{i,j,t,\varphi}$ is activated when available EVs are insufficient to meet the operational energy demand $e_{j,t,\varphi}$. Specifically, it captures the shortfall when $e_{j,t,\varphi}\, s_{i,j,\varphi} > \left(v_{i,j,t,\varphi} + \omega_{i,j,t,\varphi}\right)$, and is defined as $\max\left(0, e_{j,t,\varphi}\, s_{i,j,\varphi} - \left(v_{i,j,t,\varphi} + \omega_{i,j,t,\varphi}\right)\right)$. Finally, Equation (28) caps available vehicles at the allocated fleet size $z_{j,\varphi}$ during any interval.

Appendix D:

Tour Counts, Frequencies, and Minimum Required Fleet (All Fleet Groups)

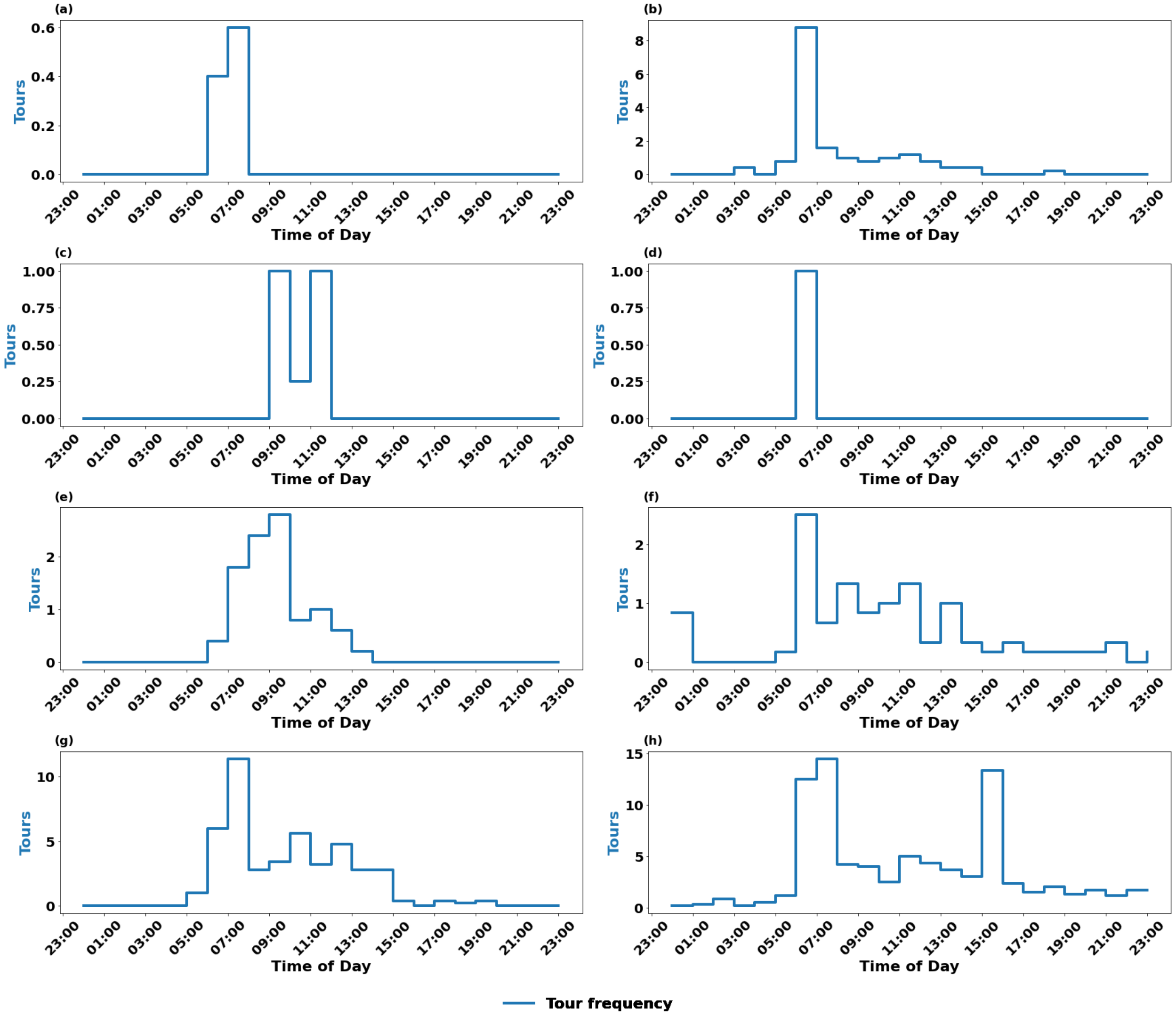

Figure D-1 Estimated tour frequency per time interval for each fleet group. (a) Fleet Group 1, (b) Fleet Group 2, (c) Fleet Group 3, (d) Fleet Group 4, (e) Fleet Group 5, (f) Fleet Group 6, (g) Fleet Group 7, (h) Fleet Group 8.

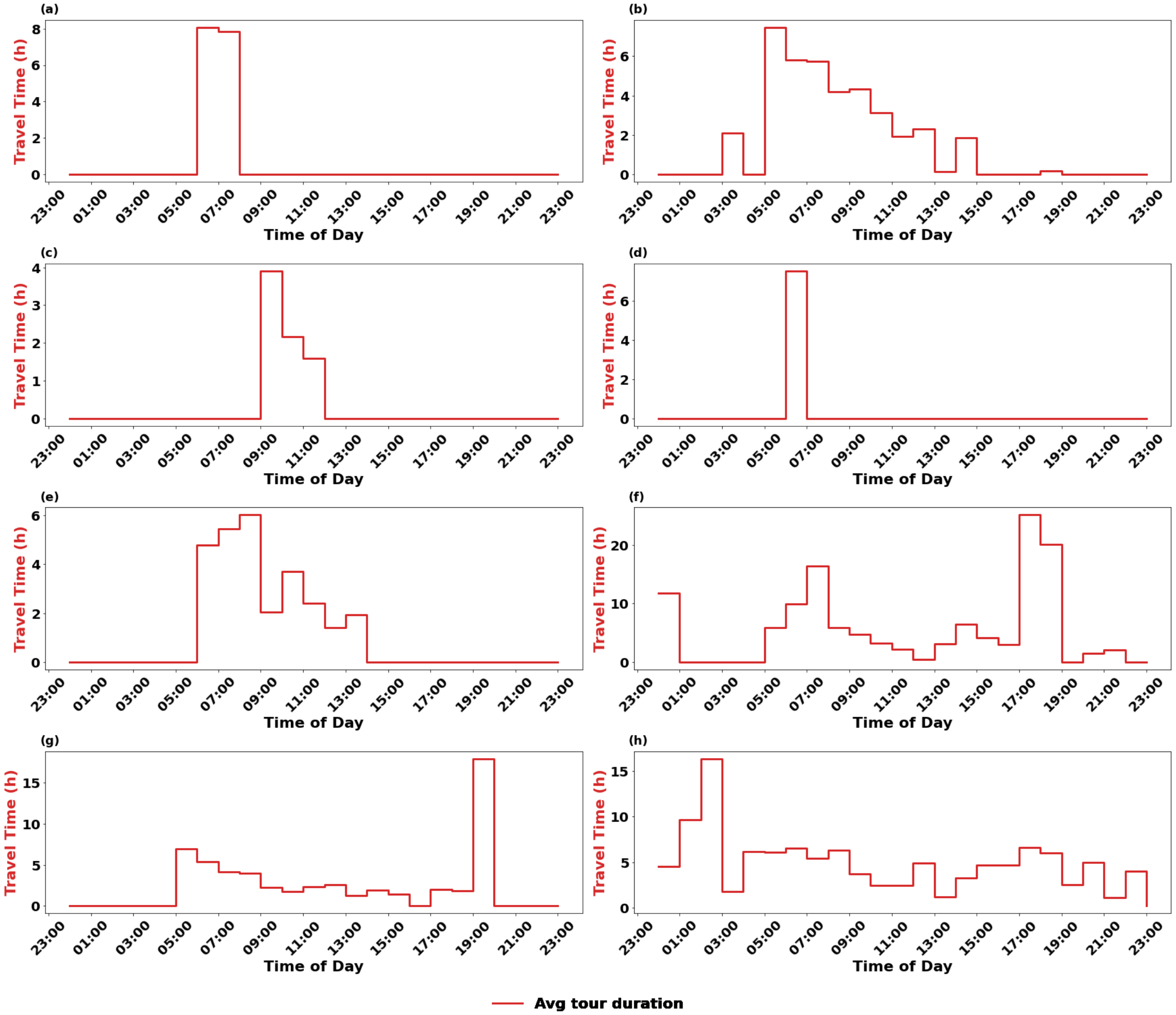

Figure D-2 Estimated average tour duration per time interval for each fleet group. (a) Fleet Group 1, (b) Fleet Group 2, (c) Fleet Group 3, (d) Fleet Group 4, (e) Fleet Group 5, (f) Fleet Group 6, (g) Fleet Group 7, (h) Fleet Group 8.

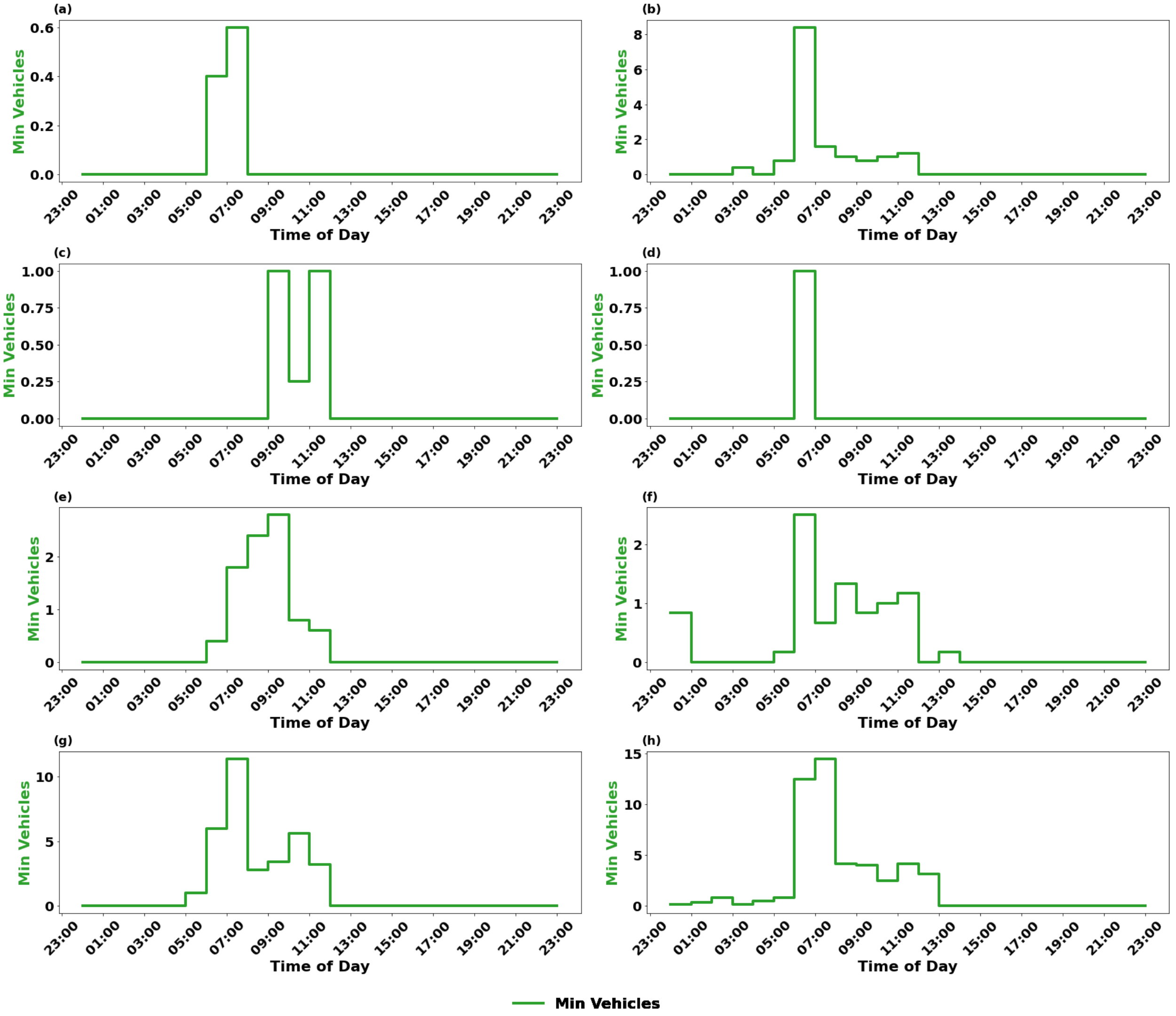

Figure D-3 Estimated minimum number of electric vehicles required per time interval for each fleet group. (a) Fleet Group 1, (b) Fleet Group 2, (c) Fleet Group 3, (d) Fleet Group 4, (e) Fleet Group 5, (f) Fleet Group 6, (g) Fleet Group 7, (h) Fleet Group 8.