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The Cost-Effectiveness of Zero-Emission Vehicles for Military Police Patrol at Marine Corps Base Camp Pendleton

March 2024

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Department of Defense Management

Naval Postgraduate School

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Prepared for the Naval Postgraduate School, Monterey, CA 93943.

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ABSTRACT

Executive Order 14057 requires all federal government agencies to transition to vehicles that do not generate carbon pollutant emissions. While environmentally conscious, this order has unique implications for law enforcement agencies that rely extensively on police vehicles to ensure the security of their communities. My research examines the changes that law enforcement agencies may realize in transitioning to a zero-emission fleet. Specifically, I perform a cost-effectiveness analysis that compares the Dodge Durango police pursuit vehicle (PPV), the most common gasoline-vehicle in use by the Marine Corps, to the Chevrolet Blazer PPV, a newly developed zero-emission PPV. I analyze cost data from the General Services Administration and vehicle test results from Michigan State Police for model year 2024 police vehicles. As a result, I find that the Blazer is 40% more effective than the Durango, but over a seven-year period, the zero-emission PPV is 14% ($537-thousand) or 27% ($1.1-million) more expensive depending on the type and quantity of charging infrastructure procured to support the fleet. However, the zero-emission fleet is 26% ($2-million) or 19% ($1.4-million) less expensive when accounting for the social cost of carbon. I recommend the Marine Corps further this research by commencing limited-scale implementation with the Blazer PPV.

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To my advisors: Dr. Nussbaum, Dr. Tick, and Dr. Friedman. Thank you for your guidance, for equipping me with the tools to further explore my own academic potential, and the autonomy to paint the canvas the way I saw fit.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AIE	agency-incurred expense
BEV	battery-electric vehicle
CMC	Commandant of the Marine Corps
DOD	Department of Defense
EPA	Environmental Protection Agency
EV	electric vehicle
EVSE	electric vehicle supply equipment
FCEV	fuel-cell electric vehicle
FY	Fiscal Year
GAO	Government Accountability Office
GSA	Government Services Administration
HEV	hybrid electric vehicle
kWh	kilowatt-hour
OSD	Office of the Secretary of Defense
PHEV	plug-in hybrid electric vehicle
PPV	police pursuit vehicle
PMO	Provost Marshal’s Office
SRT	special reaction team
SUV	sport utility vehicle
ZEV	zero-emission vehicle

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I. INTRODUCTION

The U.S. Marine Corps needs to assess whether the use of zero-emission vehicles (ZEVs) for military police patrol would impact its ability to protect Marine Corps installations. Such an assessment is warranted as a recent Executive Order directed all federal government agencies "to achieve 100 percent zero-emission light-duty vehicle acquisitions by 2027" (Executive Order No. 14057, 2021, Sec. 102). In effect, any federal agency that currently operates gasoline-powered vehicles must soon transition to vehicles that do not generate carbon pollutant emissions. This ZEV requirement is part of a broader environmental strategy "to reduce greenhouse gas emissions … and secure a transition to clean energy and sustainable technologies" (White House Council on Environmental Quality [CEQ], 2022, p. 1). However, the new and unfamiliar nature of ZEVs coupled with the unique operational role of police vehicles underscores a compelling need to assess the potential challenges and opportunities brought about by this transition.

A. KEY CONSIDERATIONS FOR A ZEV TRANSITION

According to a study by Longstaff et al. (2022), "Smart, mission-appropriate EV [electric vehicle] implementation for Federal law enforcement agencies will require a paradigm shift in operational, fleet, and facilities planning and management" (p. 1). Such a shift may be reasonably anticipated because law enforcement agencies tend to have relatively large fleets that engage in 24-hour operations and require complex specifications to aid patrol and emergency response duties. For example, a report by the Government Accountability Office (GAO) estimated that 102,000 law enforcement vehicles are among the roughly 377-thousand vehicles affected by the president's ZEV mandate (Latham, 2022, p. 7). Latham's report also finds that law enforcement vehicles "may have additional performance requirements that may not be met by currently available ZEV models" (p.7). In essence, the Marine Corps and other government agencies, may face difficulties in procuring the quantity and quality of ZEVs that their law enforcement mission requires.

In addition to assessing suitability and availability of ZEV technology, the Marine Corps must develop a clear picture of the cost to transition to a ZEV fleet as this will likely impact large-scale resource allocation decisions. For example, in its Fiscal Year (FY) 2024 budget request, the Department of Defense (2023-a) earmarked $31.5-million for the Marine Corps to undertake various ZEV transition initiatives (p. 16). However, the cost to meet the ZEV needs of Marine Corps law enforcement amid the service's many ZEV requirements is unclear and would benefit from further analysis. For instance, the GAO finds that "The extent and cost of the facility upgrades necessary to support a fully ZEV fleet are *uncertain* until agencies conduct site assessments across all fleet locations" (Latham, 2023, p. 8). Latham's GAO report explains that the cost to develop ZEV support infrastructure varies widely based on each agency's mission, location, and the condition of their existing electrical grid. Thus, the ZEV requirements necessary to support a specific Marine Corps law enforcement fleet will presumably differ from those needed to support the Marine Corps in other geographic and operational contexts.

Likewise, law enforcement agencies that are concerned with the down-time necessary for ZEVs to charge may need to assess whether it is more economical to invest in a surplus of vehicles or an expensive, high-speed charging solution to maintain vehicle up-time. However, some law enforcement agencies may be able to offset the costs of a ZEV transition with savings that they may realize from eliminating fuel costs and reducing maintenance expenses that typically result from operating vehicles powered by internal combustion engines. Similarly, agencies may also want to consider *indirect costs* such as the social cost of carbon and how ZEV-fleet ownership impacts the environment compared to how the ZEV-fleet impacts the organization's operational effectiveness. Nonetheless, transitioning a law enforcement fleet from gasoline-powered vehicles to ZEVs is likely to entail many considerations and be less straightforward than simply comparing the sticker prices of the two vehicles. A cost-effectiveness analysis will help the Marine Corps and other federal agencies reconcile limited resources with the operational needs of their law enforcement mission to ultimately comply with the president's environmental policy objectives.

Analyzing the impact of ZEVs on the Marine Corps' law enforcement operations is especially important because the Marine Corps' law enforcement apparatus protects military infrastructure that is inextricably linked to the nation's defense. In carrying out this vital mission, the Marine Corps' law enforcement vehicles tend to accumulate significant mileage because they are often placed on continuous patrol, sometimes across vast geographic areas, and are needed for responding promptly to incidents that endanger the personnel, property, and operations of a military installation. Thus, going from quickly filling up a police vehicle with gasoline to waiting for a ZEV to recharge may pose an operational challenge that law enforcement agencies will need to mitigate. Likewise, these ZEV planning considerations may not be equally impactful across all organizations. The specific composition and disposition of each law enforcement entity are likely to be key factors in determining the extent to which ZEV integration is feasible.

For example, the U.S. Customs and Border Protection stated to the GAO that "they do not believe that current ZEV technology can support law enforcement equipment or perform law enforcement missions in extreme environments, such as those on the borders" (Latham, 2023, p. 6). Conversely, some civilian law enforcement agencies have recently and successfully integrated ZEVs into their patrol operations. For instance, at least four U.S. police departments believe that "EVs have the range, speed and ruggedness to serve as regular patrol cars [and]… cost less to operate and maintain over the long term" (Careless, 2023, para. 1). The differing assessments of these law enforcement agencies points to an underlying notion that ZEVs might work well for some agencies and not as well for others. Nonetheless, how a ZEV fleet would specifically impact the Marine Corps' law enforcement field remains an open question.

The uncertain viability of ZEVs for law enforcement use highlights the need for the Marine Corps to perform its own analysis of the subject. Doing so is important because the Marine Corps has seventeen military police organizations that perform law enforcement duties in support of Marine Corps installations worldwide. Each military police organization relies on police-rated vehicles to accomplish a wide-range of law enforcement and security tasks. In total, the Marine Corps' law enforcement enterprise supports "a global mission that spans 25 Marine Corps installations and includes: 25,197 family housing units; 82 mess halls; 28,745 buildings on 2.5 million acres; 36 runways across 10 airfields; and 1,780 ranges and training areas" (Commandant of the Marine Corps [CMC], 2023, p. 10). However, the Marine Corps' law enforcement community has not fully assessed whether a zero-emission patrol fleet would improve or degrade their operations.

B. RESEARCH QUESTIONS

In this thesis, I examine the extent to which a ZEV transition would impact patrol operations performed by the Provost Marshal's Office (PMO) at Marine Corps Base Camp Pendleton, California—the Marine Corps' largest expeditionary training facility on the nation's west coast. As part of my research, I perform a "Cost-Effectiveness Analysis" of the two vehicles shown in Figure 1. While my analysis is primarily based on military police patrol operations performed at Camp Pendleton, it provides insights that are applicable across the Marine Corps' broader law enforcement enterprise. In performing this study, I am guided by the following research questions:

1. What does it *cost* to procure, operate, and maintain a fleet of zero-emission patrol vehicles at Camp Pendleton relative to the cost of the existing gasoline-powered patrol fleet?

2. Is a zero-emission patrol fleet more or less *effective* in carrying out the patrol mission of the Camp Pendleton PMO relative to the existing gasoline-powered patrol fleet?

Status Quo (gasoline-vehicle):
2024 Dodge Durango Police Pursuit Vehicle

Alternative (zero-emission vehicle):
2024 Chevrolet Blazer Police Pursuit Vehicle

Figure 1. Image of Police Vehicles Being Analyzed. Adapted from Stellantis (2024) and General Motors (2023).

II. BACKGROUND

In this chapter, I discuss the importance of military police operations and explain how vehicles are used by military police to promote the safety and security of military installations. As a prelude to my analysis, I provide background information about the Camp Pendleton PMO and the workload performed by its existing fleet of patrol vehicles.

A. THE IMPORTANCE OF MILITARY POLICE PATROL

The term "PMO" refers to a military police organization responsible for the law enforcement function of a Marine Corps facility. PMOs support the Marine Corps "by enforcing the law, preventing and suppressing crime, assessing command physical security posture, investigating offenses, and apprehending offenders" (Department of the Navy, 2015, p. 2-1). PMOs are especially vital in today's complex threat environment as the facilities that PMOs protect are integral to military readiness and are increasingly likely to be targeted by U.S. adversaries. This dilemma was well-summarized by the CMC (2023) when he stated: "Due to the emerging and expanding threats facing our installations, we must ensure force protection efforts enable continuity of operations, protection and safety of our families, and our forces to meet operational requirements" (p. 10). In essence, if a PMO fails to effectively secure their installation, they may weaken the nation's defense and jeopardize the Marine Corps' ability to project combat power abroad.

B. MILITARY POLICE PATROL AT CAMP PENDLETON

The Military OneSource homepage for Camp Pendleton states that the installation spans approximately 125,000 acres and 17 miles of coastline and has a daytime population of nearly 70,000 people including 42,000 servicemembers, and it houses more than 38,000 military personnel and family members. For proportional reference, "the size of Camp Pendleton is comparable to the size of the state of Rhode Island" (Military One Source, 2023). The installation is home to the I Marine Expeditionary Force, which is the Marine Corps' largest warfighting formation (LaGrone, 2023, para. 3). The Camp Pendleton PMO is the installation's principal law enforcement and security organization. The Provost

Marshal is a uniformed Military Police Officer who holds the rank of Lieutenant Colonel and is overall responsible to the Commanding Officer of Marine Corps Base Camp Pendleton for all law enforcement and security activities. As shown in Figure 2, the Camp Pendleton PMO is comprised of four major divisions (Field Operations, Criminal Investigations, Support Services, and Other Services).

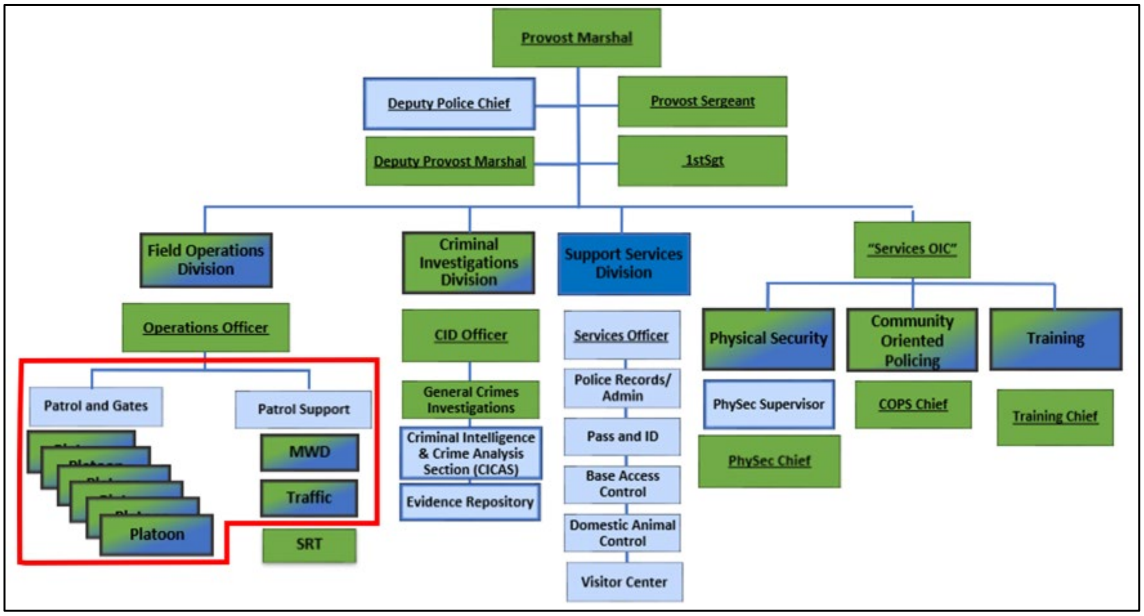

Figure 2. Organizational Chart for the Camp Pendleton PMO. Source: S. Ansbigian, email to author, (2023).

Although each division operates government vehicles that are subject to the president's ZEV mandate, this research focuses only on the Field Operations Division that performs patrol operations (outlined in red in Figure 2). The Field Operations Division operates the majority of the PMO's fleet and spends significant time driving government vehicles as it is responsible for patrolling and responding to calls for police and emergency service around the base. I have excluded the remaining sections and divisions from this analysis either because they operate medium or heavy-duty vehicles worthy of their own separate study or they operate vehicles in a limited administrative capacity for which the transition to ZEVs is presumably more straightforward.

The Field Operations Division operates at all hours of the day, every day of the year and currently relies on a fleet of 22 gasoline-powered vehicles to perform its mission. At all times, the Camp Pendleton PMO requires at least 14 of the 22 vehicles to be "in-service," patrolling the installation and responding to calls for service as needed while the remaining 8 vehicles are intermittently "out-of-service" and parked at the PMO headquarters. Given only 8 more vehicles than a single shift requires, a rotating mix of 6 vehicles are "hot-seated," meaning a vehicle transfers near-continuously from one operator to the next with virtually no down-time. When the 14 vehicles are in-service, they are strategically dispersed across 8 designated patrol zones that collectively cover all of Camp Pendleton. The 14 in-service vehicles are task-organized as follows:

- 8 vehicles are front-line patrol units dedicated to an individual patrol zone
- 1 vehicle is operated by a specialized traffic accident investigator
- 1 vehicle is operated by a specialized military working dog handler
- 2 vehicles are operated by watch supervisors who each supervise one-half of the on-duty military police personnel
- 2 vehicles are operated by area supervisors, one supervises military police operations in the northern half of the base and the other supervises operations in the southern half of the base

According to data provided by the PMO, the Field Operations Division handled over 40,000 law enforcement tasks between 2017 and 2022, which is an average of 19 calls for military police service each day. The vast majority of these tasks required one or more of the division's vehicles to react and this does not account for proactive patrols that the division performed without resulting in an explicit police service being rendered. In short, the Field Operations Division is highly reliant upon the mobility that its patrol vehicles provide. However, whether a transition to ZEVs would create advantages that the division would benefit from or disadvantages that the PMO must mitigate is currently unknown.

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III. LITERATURE REVIEW

Prior to analyzing the impact of ZEVs on Camp Pendleton's patrol fleet, it is necessary to examine existing research related to this topic. In this chapter, I explain the mechanics of a Cost-Effectiveness Analysis and provide examples of how this research method has been used to inform decision-making in various parts of society. I also detail key aspects of Executive Order 14057 that substantively affect the Marine Corps' responsibility to implement it. Finally, I provide a comprehensive review of law enforcement-specific studies and initiatives that have sought to integrate ZEVs into patrol operations. In essence, this chapter highlights areas of ZEV research that are well-established and help to inform the Marine Corps' ZEV transition efforts and it also exposes areas of research that are relevant to the Marine Corps, but warrant further analysis.

A. COST-EFFECTIVENESS ANALYSIS AND ITS USES

One of the earliest pieces of literature surrounding this research methodology aptly states "the practice of cost-effectiveness started when man first realized his resources were limited" (Quade, 1971, p. 1). While the fundamental practice of cost-effectiveness has origins that pre-date the modern world, Quade estimates that "the systematic analysis of investment alternatives from the point of view of a government had its start in economic theory with the works of a Frenchman, Jules Dupuit" (p. 8). As explained by Quade, Dupuit analyzed the benefits that roads and bridges provided to the public relative to their costs. Given that public policy decisions like these are commonly constrained by a finite set of resources, Dupuit and others have performed cost-effectiveness analyses to help policymakers determine the optimal use of few resources.

For some, a related and more familiar methodology is cost-benefit analysis. Similar to cost-benefit analysis, cost-effectiveness is an analytical technique that compares the costs and benefits of two or more alternatives to discern which provides the greatest value relative to a desired outcome. However, a distinguishing factor is that cost-benefit analysis is more appropriate when the costs and benefits under study can be readily monetized whereas cost-effectiveness is “useful in cases where major outcomes are either intangible or otherwise difficult to monetize” (Cellini & Kee, 2010, p. 496).

When cost-benefit analysts are unable or unwilling to monetize certain benefits, cost-effectiveness enables the analyst to “construct a ratio involving the quantitative, but non-monetized, benefit and the total dollar costs” (Boardman et al., 2018, p. 45). In other words, when a benefit cannot be measured in terms of money, cost-effectiveness uses a numerically weighted system to represent the extent to which each intangible benefit satisfies (or fails to satisfy) the desired outcome. The weight of these benefits is aggregated in a value function to determine the overall measure of effectiveness for each alternative. This allows for like-comparison to be made across alternatives that would otherwise be inequitable. Furthermore, the weight of these non-monetizable benefits can be measured against their direct cost to form a ratio of dollars to “units of effectiveness.”

Although cost-effectiveness analysis is extremely useful, “the main drawback … is that it only finds the cheapest way to achieve the goal of effectiveness and cannot inform whether the achievement of the goal is worth the cost” (Coppola et al., 2022, p. 3). For example, as a student at the Naval Postgraduate School, Moreau (2022) performed a cost-effectiveness analysis that concluded one aerial platform was more effective than another, but the superior platform was also more expensive on a cost per flight hour basis (p. 2). Given Moreau’s findings, the decision-maker was essentially left to decide whether the increase in the system’s overall effectiveness was *worth* its increase in cost. Likewise, my analysis determines the cost for the Camp Pendleton PMO to transition to zero-emission patrol vehicles and the extent to which a ZEV fleet is capable of achieving the organization’s objectives relative to the status quo. However, whether the cost of the alternative is *worth* the effect that it has on the desired outcome is a relatively subjective judgement left to those charged with the project’s implementation.

Despite this level of subjectivity, cost-effectiveness is still a valuable practice because it is transparent in identifying the key factors of a project that contribute to or detract from achieving a desired outcome. For example, in Moreau’s analysis, the decision maker could easily discern how Moreau’s distribution of importance weights impacted the resulting measure of effectiveness for each platform and reconsider whether the appropriate amount of weight was assigned to each attribute. To that end, this process provides decision-makers and other stakeholders with clarity and transparency over the factors that make one course of action superior to the cost and effectiveness of its alternatives.

B. MULTIPLE OBJECTIVE DECISION MAKING

A key component of cost-effectiveness analysis is what Wall and MacKenzie (2015) refer to as "Multiple Objective Decision Making." Noting that public policy decisions often entail the need to satisfy more than one objective, Wall and MacKenzie offer "a practical tool for quantitative investigation of all factors that may influence a decision … to determine why one alternative is more effective than others" (p. 1). Wall and MacKenzie require the analyst to construct an "objective hierarchy," which is a visual representation of the objectives that a project seeks to achieve. For example, Moreau's cost-effectiveness analysis identified four objectives that the Marine Corps sought to achieve with its adoption of the aerial platforms under study. Those objectives were visually displayed by Moreau with the objective hierarchy shown in Figure 3.

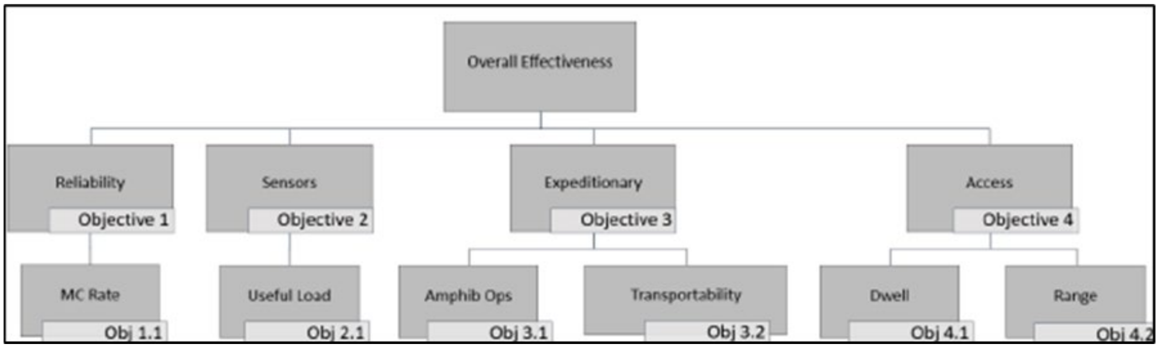


Figure 3. Example Objective Hierarchy. Source: Moreau (2022).

As shown in Figure 3, the hierarchy begins with the objective of maximizing the platform's overall effectiveness. This objective is then defined by "sub-objectives" such as reliability, sensors, expeditionary capability, and access. These objectives are further refined by asking the question: "what do you mean by that?" Wall and MacKenzie (2015) suggest this question be repeated "until all relevant objectives are recorded and their ability to be measured is obvious" (p. 5). After objectives are established, the analyst assigns "importance weights" to each one. Wall and MacKenzie state that these weights are based on "decision maker preferences" (p. 8). In effect, heavier weights are placed on objectives of great importance while lighter weights signify relatively less importance. Once objectives, decision-maker preferences, and importance weights are set, the analyst can evaluate each objective and calculate an overall "measure of effectiveness" for each alternative. Similar to Moreau, I will follow Wall and MacKenzie's process by constructing an objective hierarchy and calculating comparable measures of effectiveness for Camp Pendleton's current gasoline-powered patrol fleet and a hypothetical ZEV fleet.

A similar example of this analytical technique comes from Coppola et al. (2022), who used cost-effectiveness analysis to compare railway infrastructure development projects in Italy. Similar to Multiple Objective Decision Making, Coppola et al. used an "Analytical Hierarchy Process," which the authors described as "a valid tool for both designers and infrastructure managers for prioritizing railway station investments in the presence of multiple strategic objectives that also conflict with each other" (p. 1). As shown in Figure 4, Coppola et al. identified five project objectives that pertained to their study: safety and security, equity and social aspects, accessibility, environmental sustainability, architectural quality. The authors further defined these objectives by the corresponding attributes shown in Figure 4.

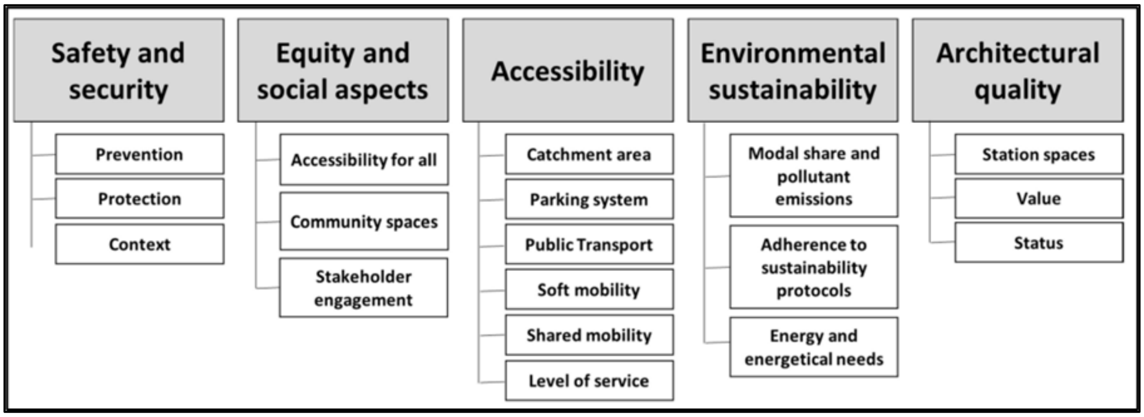


Figure 4. Example Analytical Hierarchy. Source: Coppola et al. (2022).

While Coppola et al. laud this methodology, the authors highlight a drawback that relates to the subjectivity of assigning weights to attributes. To guard against this, Coppola et al. state that the weights of the objectives must be decided "a priori," meaning prior to evaluating each alternative's measure of effectiveness (p. 16). By doing this beforehand, Coppola et al. suggest that "it is possible to legitimately orient the results of the analysis towards strategic planning decisions, without incurring a subjective and biased derivation of the weights aimed at privileging one investment alternative rather than another" (p. 16). As such, my analysis will also establish the objectives of the project and the weights of their attributes before I evaluate each alternative. Changes to importance weights may be appropriate after the fact, but documenting and substantiating these factors ahead of time forces researchers and decision makers to be transparent about their rationale for emphasizing one attribute over another.

C. THE OBJECTIVES OF EXECUTIVE ORDER 14057

Identifying the objectives of a policy prior to analyzing its effects is not only a good research practice but also a requirement when analyzing government projects. For example, the Office of Management and Budget (2023) publishes "Circular A-94" to provide federal agencies with guidance for performing cost-benefit and cost-effectiveness analyses. The circular explicitly states: "The rationale for the Government projects being examined should be clearly stated in the analysis" (p. 5). Therefore, I foundationally refer to Executive Order 14057 to discern the attributes to include in my objective hierarchy. In doing so, I assess that the president's objective is to combat the negative effects of climate change. In particular, Executive Order 14057 specifies the goal of achieving: "a carbon pollution-free electricity sector by 2035 and net-zero emissions economy-wide by no later than 2050" (p. 1). However, the president's order also includes goals to reduce federal building emissions, increase use of clean construction materials, develop climate resilient infrastructure, and cultivate a sustainability-focused workforce.

Thus, it appears the president's ZEV initiative is one part of a multi-pronged approach to improve climate conditions. ZEVs seem to be of particular interest because vehicles powered by internal combustion engines produce carbon dioxide emissions, which have adverse effects on human health and the environment. For example, a report by the American Lung Association (2023) estimated that the president's ZEV policy could result in "89,300 fewer premature deaths, 2.2 million fewer asthma attacks, and 10.7 million fewer lost workdays" (p. 2). Additionally, a report by the U.S. Energy Information Administration (2023), states greenhouse gases like carbon dioxide "produce an increase in the average surface temperature of the earth over time. Rising temperatures may produce changes in precipitation patterns, storm severity, and sea level" (para. 4). Based on these reports, ZEVs would serve a role that benefits public health and protects the environment.

1. Light-Duty Vehicles

Based on the president's objectives, the term "light-duty" carries precise meaning, but it is not defined in the Executive Order. However, a presidential memorandum authored by Young et al. (2021) provides the following definition: "a vehicle weighing 8,500 pounds gross vehicle weight rating or less, certified for use on all public roads and highways" (p. 14). Notably, the required timeline for ZEV transition distinguishes between light-duty vehicles, which must be zero-emission by 2027, and medium/heavy-duty vehicles that have until 2035 to achieve zero-emissions. As shown in Figure 5, a GAO report found 69% of the federal fleet is comprised of light-duty vehicles.

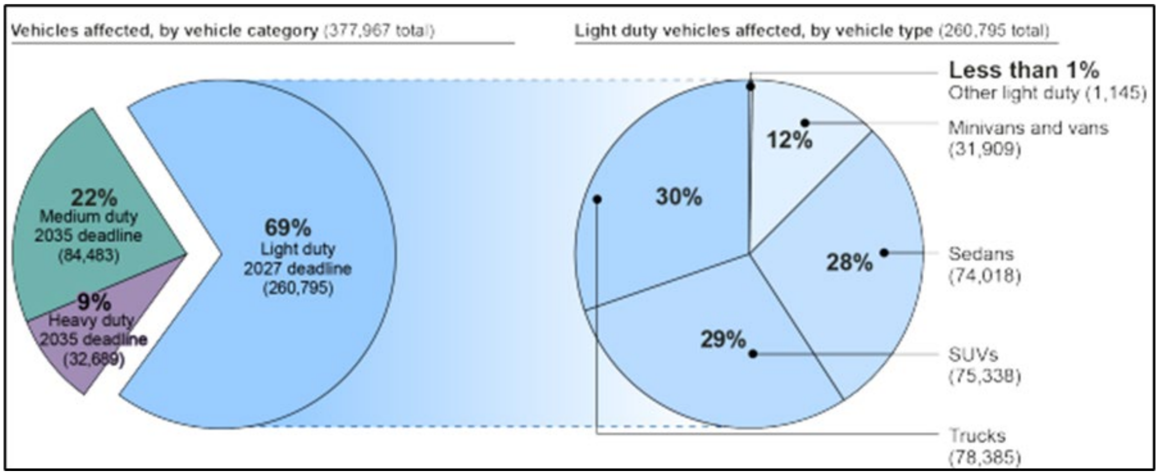


Figure 5. Composition of the Federal Government's Fleet by Vehicle Type. Source: Latham (2023).

2. ZEVs

Furthermore, the memorandum by Young et al. defines ZEV as “a vehicle that when operating produces zero tailpipe exhaust emissions of any criteria pollutant (or precursor pollutant) or greenhouse gas” (p. 15). However, the memorandum also provides a carveout, which states “For the purposes of meeting this requirement, plug-in hybrid vehicles may be considered ZEVs” (p. 4). This is noteworthy because this stipulation effectively provides leeway for some emission-producing vehicles despite the insistence placed on *zero* emissions. By including the plug-in hybrid variant, the ZEV category expands from two to three types of vehicles that are available in today’s automotive market. In particular, the only types of vehicles that meet the president’s ZEV definition are: Battery Electric Vehicles (BEVs), Fuel Cell Electric Vehicles (FCEVs), and Plug-in Hybrid Electric Vehicles (PHEVs). Each vehicle has unique characteristics that are important for agencies to consider when assessing their transition to a ZEV fleet.

According to the Department of Energy (2023), “BEVs have an electric motor instead of an internal combustion engine. The vehicle uses a large traction battery pack to power the electric motor and must be plugged in to a wall outlet or charging equipment” (para. 1). The Department of Energy also states: “Because [a BEV] runs on electricity, the vehicle emits no exhaust from a tailpipe and does not contain the typical liquid fuel components, such as a fuel pump, fuel line, or fuel tank” (para. 1).

Similar to BEVs, FCEVs are also powered by an electric motor but “produce electricity using a fuel cell powered by hydrogen, rather than drawing electricity from only a battery” (Department of Energy, 2023-a, para. 1). However, the Department of Energy (2023-b) assesses that FCEV availability and the hydrogen infrastructure needed to power them is extremely limited with only “59 retail hydrogen stations available nationwide, mostly concentrated in the state of California” (para. 2). Therefore, vehicle manufacturers are only offering FCEVs to consumers who live in regions where hydrogen stations exist (Department of Energy, 2023-c).

PHEVs are a unique addition to the president’s ZEV category because PHEVs possess both an internal combustion engine *and* an electric motor. The Department of

Energy (2023-a) states a PHEV "typically runs on electric power until the battery is nearly depleted, and then the car automatically switches over" to the internal combustion engine (para. 1). Therefore, PHEVs do in fact produce tailpipe emissions but can be driven for an extended period of time using only electric.

Similar to PHEVs, Hybrid Electric Vehicles (HEVs) also possess both an internal combustion engine and an electric motor but HEVs always rely on the *simultaneous* use of both engines for power (Department of Energy, 2023-a). HEVs often provide improved fuel economy and less tailpipe emissions relative to a gasoline-powered vehicle, but an HEV cannot operate without the use of its internal combustion engine and is therefore not an authorized ZEV for purposes of complying with the president's executive order.

3. Exemptions to the ZEV Requirement

While President Biden appears resolute in his direction to adopt ZEVs throughout government, his order articulates a narrow opportunity for exemption. Specifically, Section 602 of Executive Order 14057 states: "The head of an agency may exempt particular agency activities and related personnel, resources, and facilities from the provisions of this order when it is in the interest of national security, to protect intelligence sources and methods from unauthorized disclosure, or where necessary to protect undercover law enforcement operations from unauthorized disclosure." Section 602 goes on to list a limited set of justifications for ZEV exemption and concludes in Subsection (c) by stating "The head of an agency may … request for an exemption … for any reason not otherwise addressed." Thus, while an exemption to the ZEV mandate is possible, any attempt by the Marine Corps to obtain one would require a compelling justification be submitted to and approved by the Secretary of Defense.

D. ZEVS FOR LAW ENFORCEMENT USE

One of many areas that may help the Marine Corps assess the feasibility of adopting ZEVs for military police use is to consider the experiences of civilian law enforcement agencies that have pursued similar initiatives. In fact, many civilian law enforcement agencies have recently taken steps toward police fleet electrification, which have yielded a variety of insights that the Marine Corps can learn from. Based on my review of several law enforcement vehicle studies, the following key issues emerged: the performance characteristics of police vehicles, the availability of "pursuit-rated" ZEVs, upfitting compatibility, and the fleet's total cost of ownership.

1. The Performance Characteristics of Police Vehicles

The fundamental question concerning a law enforcement agency's transition is whether ZEVs will be able to withstand the demanding nature of police patrol operations. According to Thomas (2023), "Police vehicles age much more rapidly than most civilian vehicles. Not only are they driven more aggressively with rapid acceleration, stops, swerving and more, but they also are regularly left on when an officer is on duty." For these reasons, auto manufacturers "adjust a standard vehicle" to make it more suitable for police use (Grimes, 2023-a, para. 5). When vehicles receive these police-specific adjustments, the vehicle is commonly referred to as "pursuit-rated." However, there is not a widely accepted technical definition or formal process for determining if a vehicle is pursuit-rated. That said, the Michigan State Police department is internationally recognized for its role in evaluating vehicles for police use.

In fact, the Michigan State Police "began testing patrol cars in the 1950s" (Darlington et al., 2023, p. 5). The state-level law enforcement agency has seemingly adopted this responsibility due to their close proximity to the "three largest car manufacturers in the United States:" General Motors, Stellantis, and Ford Motor Company (Blessing et al., 2022, para. 1). Michigan State Police work closely with these three manufacturers to test law enforcement vehicles on an annual basis and announce their findings in a publicly accessible "Police Vehicle Evaluation" report. In the report for model year 2024 vehicles, Darlington et al. (2023) state "there is no sanctioning body, or specific performance criteria, to determine if the vehicle meets a specific designation" (p. 5). Instead, Michigan State Police provide insight by evaluating each vehicle on a common set of standards and encourage law enforcement agencies to consider their findings in the context of their agency's individualized need.

Moreover, Darlington et al. state that the term "pursuit-rated" simply refers to vehicles that were "modified from a civilian vehicle to perform better under the rigors of police use" (p. 5). The authors explain that pursuit-rated "vehicles are engineered to repetitively stop in a shorter distance, accelerate faster, and handle better than the base platform." To achieve this, the authors note that auto manufacturers typically make "modifications to engines, cooling systems, transmissions and shifting parameters, brakes, tires, [and] stability control programming" (p. 5). In addition to mechanical changes, manufacturers also make police-specific adjustments to the interior of these vehicles. For example, a government sales manager for General Motors said their company "spend [s] a lot of time and effort to ensure the ergonomics are right… [that] the vehicle will be comfortable for the officers, easy to get in/out, easy for them to get detainees in/out … police-specific seats designed for duty belts and … switches and ports are placed to ensure easy access to lights and equipment" (Grimes, 2023-a, Sec. "GM Vehicles Built to Withstand Tough Demands").

Thus, while pursuit-rated standards are important, they also tend to vary in scope and substance by auto manufacturer and differ in priority based on the operational requirements of each law enforcement agency. For example, the Fremont Police department in California experimented with a 2014 Tesla Model S85 and said that the "results provided confidence in the ability to deploy an EV (with similar range) for a standard 11-hour patrol shift" (Washington, 2020, p. 10). In this report, Washington stated that the vehicle was driven between 40 and 70 miles per day and consumed approximately 50% of the vehicle's battery. As a result, Washington stated that the vehicle "met or exceeded performance and operational objectives" and "withstood the rigors of police use." However, the results reported by Washington are *not* entirely compelling for a few reasons.

While Washington's report does provide a list of benefits and challenges related to the vehicle's deployment, the report does not specify any performance or operational objectives that the vehicle was evaluated against. Washington essentially states that the vehicle met or exceeded expectations without defining what the expectations were, much less how the vehicle fared in contrast with the existing Fremont police fleet. Furthermore, Washington states that the Tesla demonstrated "superior performance when compared to gas-powered police vehicles" but only offers the following support: an enhanced feeling of safety and control when responding to emergency calls for service, a reduction in anxiety and stress when responding to emergency calls for service due to fewer engine noises, and improved radio communication due to the lack of background engine noise (p. 10). While these points are interesting and relevant, they lack equitable comparison with Fremont's current fleet and seem to represent subjective observations for which the report lays out no clear metrics for evaluating. Even if these findings were undeniable, the report does not specify just *how effective* the vehicle was in meeting the desired standards. A comprehensive cost-effectiveness analysis would avoid this pitfall.

In another study, the City of Brookhaven, Georgia also experimented with the 2015 Tesla Model S. Unlike Washington's evaluation, Brookhaven compared the Tesla to a sample of three different gasoline-powered police vehicles. Additionally, the city states that "the vehicle was assessed by the driving instructors at the Georgia Public Safety Training Center on a closed-course track prior to placing in patrol service to ensure the vehicle could be safely driven in emergency operations mode" (City of Brookhaven, 2020, p. 6). The vehicle was then placed into service for ninety-four 12-hour shifts between Aug. 9, 2019, and Mar. 10, 2020, during which the vehicle accumulated 9,535 miles. As a result, Brookhaven Police identified several advantages and disadvantages. Similar to Washington's findings, Brookhaven found the vehicle was "superb in speed and handling," and did not demonstrate "a lack of battery life for a full 12-hour patrol shift" (p. 9). Brookhaven also stated the vehicle was "driven an average of 92 miles per day … without any change in the daily patrol routine" (p. 7). This mileage translated to the vehicle starting a shift with about 85% charge and ending shift with about 49% of its charge remaining.

However, while Brookhaven praises the vehicle's speed, maneuverability, and battery efficiency, it also cautioned that "the increased maneuvering executed by a police officer compared to that of an average driver, and the additional weight of equipment and energy required to run lights and sirens and other police ancillary equipment take a higher toll on the battery, reducing the range from that advertised by Tesla" (p. 6). This finding is consistent with what Fremont Police experienced when their Tesla ran out of power during a high-speed pursuit: "when cars accelerate at speeds such as … going over 110 miles per hour, the car charge starts to drain down faster” (Ortiz, 2019, para. 18). Additionally, the City of Brookhaven (2020) identified issues with the vehicle’s ergonomics such as “the inability to transport passengers in the backseat” due to the confined space and “discomfort of the driver’s seat for a larger officer wearing full police gear” (p. 12). For these reasons, Brookhaven’s conclusion was different than Washington’s stating: “The Tesla Model S is a good option for some police purposes, though not an ideal choice for patrol operations” (p. 2). As a result, the City of Brookhaven recommended the adoption of electric vehicles for “administrative purposes” only, while waiting for the production of EVs that are “more suitable for police patrol purposes” (p. 11).

Despite the comprehensiveness of Brookhaven’s report, the City’s police department only compared its sample of gasoline vehicles to its experimental Tesla in terms of life cycle costs and energy efficiency. While the Brookhaven report provides analysis of the Tesla’s performance on patrol, it makes no comparison of those characteristics to its gasoline fleet. Thus, it is difficult for readers to conclude which vehicle is truly superior. Another drawback common to the Fremont and Brookhaven studies is that both agencies tested the same make and model vehicle, which was only distinguishable by one model year (2014 and 2015 respectively). Although both agencies modified their experimental vehicles for police use (by installing lights, sirens, and other police equipment), neither vehicle was manufactured to meet any police-specific standards.

While these studies shed meaningful light on the performance of ZEVs under police use, they also reflect an extremely limited view of ZEV suitability for widespread law enforcement adoption including use by the Marine Corps. Given the limited breadth of these studies, it is not surprising that Fremont’s police force deemed the EV suitable in meeting its needs and Brookhaven deemed the same EV unsuitable. These conflicting viewpoints underscore the need for the Marine Corps to clearly define its own law enforcement vehicle requirements and assess a ZEV’s compliance with those requirements.

2. The Availability of Pursuit-rated ZEVs

Despite the aforementioned police vehicle performance standards, some agencies have noted a separate concern for the *availability* of pursuit-rated ZEVs. In an “Electric

Vehicle Feasibility Study," published by Brown et. al. (2021), the authors listed the "availability of police rated patrol vehicles" as a challenge (p. 18). Similarly, the Brookhaven (2020) study assessed: "The transition to an all-electric fleet is certainly applicable" but ultimately not recommended as "the EV market does not have an all-electric platform presently suitable for police patrol operations" (p. 2). In a third study titled "Electric Vehicles Save Money for Government Fleets," the authors intentionally excluded police vehicles because "municipal fleet managers raised questions about whether currently *available* electric options would meet the performance needs of first responders" (T. Dutzik, email to author, Nov. 9, 2023).

These concerns for vehicle availability are not unique to civilian agencies. In an after-action report published by the U.S. Army's Installation Management Command, Calbillo (2023) stated "there are no pursuit-rated vehicle options offered" and recommended the DOD "issue blanket exemption to electrification mandate … until industry meets [law enforcement] mission requirements" (p. 1). Relatedly, in its "Plan to Reduce Greenhouse Gas Emissions," the DOD (2023-b), stated that it is working "to obtain special-purpose pursuit-rated law enforcement ZEVs as appropriate to potentially fill the Department's requirement for more than 3,500 law enforcement vehicles by 2026" (p. 6). These findings indicate that the lack of pursuit-rated ZEVs is a concern for the DOD, but one that it is actively working to resolve.

One sign of progress seems to have emerged in August 2022 when Chevrolet unveiled "the nation's first purpose-built pursuit-rated electric vehicle" (Grimes, 2023-b, para. 1). According to Chevrolet's Pressroom (2022), the 2024 Chevrolet Blazer Police Pursuit Vehicle (PPV) "begins production in the first quarter of 2024" and "is designed to meet or exceed the demands of the nationally recognized Michigan State Police annual vehicle testing." However, in its FY-2024 ZEV Fact Sheet, the General Services Administration (GSA), listed the Chevrolet Blazer PPV as available for lease in a quantity restricted to 40. In other words, while Chevrolet may be starting to produce the first-ever pursuit-rated ZEV, the GSA can only procure a maximum of 40 Blazer PPVs across all of the federal agencies that it services.

Therefore, the supply of zero-emission pursuit-rated vehicles appears to be severely limited, but increasing the availability of these types of vehicles appears to be a priority initiative across the automotive industry, the law enforcement community, and the DOD. Nonetheless, the 2024 Chevrolet Blazer PPV represents the first potential opportunity for Marine Corps law enforcement to evaluate the utility of ZEVs by experimenting with a vehicle that is purpose-built for law enforcement rather than having to experiment with a makeshift police vehicle like Fremont and Brookhaven.

3. Patrol Vehicle Equipment

As the Blazer PPV marks a major step forward, its creation seems to mitigate only one of many concerns pertaining to law enforcement's use of ZEVs. Adding necessary police equipment to a ZEV is also questionable. In addition to the pursuit standards described earlier, patrol vehicles typically require aftermarket equipment be installed such as "decals, window tint, lights, sirens, radios, computer, prisoner transport screens, etc." (Brookhaven, 2020, p. 3). The process of installing police equipment to a vehicle is commonly referred to as "upfitting" or "outfitting" and is usually performed by a vendor that is separate from the auto manufacturer. Therefore, close collaboration between the law enforcement agency, the auto manufacturer, and the upfitter is required to ensure the aftermarket equipment meets the agency's need and does not interfere with the vehicle's mechanical functions. According to the City of Brookhaven (2020), one of the reasons the city deemed the Tesla unsuitable for patrol operations was due to "the difficulty and time required to outfit [the Tesla] … compared to the ease of using the same vendors who are accustomed to quickly outfit … the models Brookhaven has predominantly used" (p. 12).

A related issue experienced by Brookhaven is that "outfitting the car took longer than expected … due to the proprietary issues and the newness of the vehicle" (p. 2). In total, "approximately five months" had elapsed between the time the vehicle was delivered and the time it was ready for service (p. 2). In the Fremont study, Washington (2020) stated that police-specific customizations and equipment installation took 12 months (p. 3). Moreover, the U.S. Army's report by Calbillo (2023), stated "the required amperage to operate lightbars and mobile radios that are standard on most [law enforcement] upfit options exceeds the available amperage offered on any existing [electric vehicle] options" (p. 1). Calbillo's report indicates an unsatisfactory attempt by the U.S. Army's to upfit a standard EV with aftermarket police equipment.

Nevertheless, upfitting reportedly impacts a vehicle's gross weight and its demand for electricity, which seems to exacerbate the complexity involved in the vehicle's overall design. While purpose-built police vehicles such as the Blazer PPV are specifically designed to maximize upfit compatibility, there seems to remain a heightened level of difficulty involved in installing police equipment on ZEVs relative to the more familiar gasoline-powered vehicles. Perhaps this complexity represents the start of a learning curve that can be remedied as ZEV production increases, but for the near-term these considerations seem to hamper the production of patrol-capable ZEVs.

4. Total Cost of Ownership

Based on the ZEV considerations noted above, there appear to be some factors that will reduce the cost of owning a ZEV fleet while other factors will increase ZEV-fleet ownerships costs. Therefore, in the Marine Corps' financial analysis of this transition, it is important to consider both direct *and* indirect costs involved in attaining ZEV-fleet compliance. Likewise, it is appropriate to contrast the cost of a hypothetical ZEV fleet to the cost of Camp Pendleton's current gasoline-powered fleet. To date however, the unfamiliar nature of a zero-emission police fleet has either precluded an effective cost analysis, even by agencies like Fremont and Brookhaven that have studied the issue closely, or has resulted in ambiguous cost estimates that may not transfer in kind to the Marine Corps.

For example, in the study by Dutzik et al., the authors stated that police vehicles were excluded from the study because "reliable, up-to-date data on current pricing, performance and total cost of ownership were harder to come by than for the mass-market light-duty vehicles that were the focus of the report" (T. Dutzik, email to author, Nov. 9, 2023). The exclusion of police vehicles from the Dutzik et al. study seems rational, but underscores two prominent themes that have come from my research. One theme is the important distinction between the performance requirements of police vehicles compared to vehicles driven for administrative business or private use. Secondly, there is a recurring observation by researchers that data pertaining to the use of ZEVs for law enforcement purposes are limited. Likewise, using cost data that pertains to standard EVs, which is more commonly available, is unlikely to be an equitable reference for projecting the cost of zero-emission police fleets.

However, the law enforcement agencies that have attempted to determine ZEV-fleet ownership costs make only a small number of contributions that are valuable to the Marine Corps. For example, Washington (2020) compared the cost of the Ford Explorer PPV (gasoline-powered) to the Tesla Model S and determined: “The total cost of ownership over a five-year period was calculated for the Tesla Model S 85 at $132,758 and the Ford Utility Interceptor at $115,740” (p. 11). Based on these estimates, Fremont Police would realize a savings of approximately $3,404 per year per vehicle. However, Washington does not account for the cost to develop charging infrastructure in his analysis, but asserts that “23 dual port level 2 chargers and 1 direct current fast charger are projected to be needed at the Fremont Police Department complex to accommodate long-term fleet vehicle electrification” (p. 14). As previously noted by the GAO (2023), the installation of EV charging equipment is a costly endeavor, which I would expect to far surpass the $3,404 annual savings. This infrastructure development cost is significant and should indeed be included in the financial analysis of a ZEV transition.

In a similarly problematic fashion, the City of Brookhaven (2020) estimated the cost of its experimental Tesla and compared it to two types of gasoline-powered vehicles used by its police department (sedans and SUVs). More specifically, the authors refer to the Ford Taurus and Chevrolet Impala as “gas-powered police sedan” and the Explorer as “gas-powered police SUV” (p. 10). As shown in Figure 6, the City of Brookhaven concluded “total lifetime costs for a Tesla to remain in the fleet for six years are less than total lifetime costs for a gas-powered SUV that remains in the fleet for only five years, at $51,928 and $52,064 respectively” (p. 11).

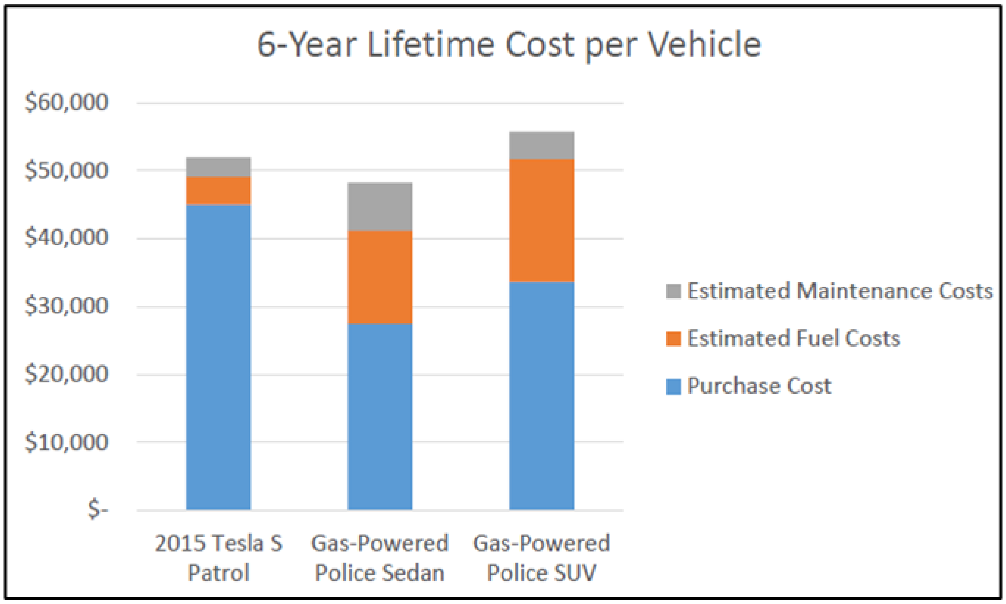


Figure 6. Cost of Brookhaven's Police Vehicles. Source: City of Brookhaven (2020).

While these results indicate a cost-savings in favor of the Tesla, this conclusion is incomplete for at least two reasons. First, the city's cost-comparison uses two different time horizons (five years and six years), but does not seem to accurately denote this distinction in its chart (see Figure 6). Furthermore, the city declares this "savings" without providing ample context. The true monetary difference can be better understood by finding the equivalent annual cost. I calculate this by taking the amounts reported by Brookhaven and dividing them by the noted lifespans to determine each vehicle's cost per year.

- Gas-powered police SUV: ($52,064 / 5 years) = $10,412 per year
- Tesla: ($51,928 / 6 years) = $8,655 per year
- Net savings: ($10,412 – $8,655) = $1,758 per year per vehicle.

Based on this calculation, the author can in fact attribute a $1,758 savings to each Tesla. This represents such a trivial difference that to claim a savings would be unfair especially given the many uncertainties involved in life cycle costs. Likewise, Brookhaven does not consider these costs in light of the vehicle's effectiveness. Doing so would help decision makers better understand what capability is gained or lost relative to the cost difference.

However, Brookhaven treats cost and effectiveness as separate and distinct components of its analysis thereby diminishing the usefulness of the cost estimate.

Secondly, the City of Brookhaven disregards the cost of installing charging infrastructure, stating: "The City has already installed 13 EV charging ports across the city for community use, thus there is no upfront charger infrastructure cost for City fleet conversion to EVs" (p. 9). This may be a fair exclusion in light of the study only experimenting with one vehicle. However, this is not a realistic assessment for widespread adoption of ZEVs throughout the city's entire police department, which operates over 100 vehicles (p. 3). It would seem problematic to expect all municipal police vehicles to share the 13 communal charging ports that are spread out across the city.

Of related concern, the City of Brookhaven offers no analysis as to the different types of charging infrastructure that its police department may need to invest in. For example, the study by Brown et al. (2021) determined that level 2 charging stations would be suitable for its county-government fleet *except for police vehicles* … which would require faster, level 3 charging stations, citing "their need for minimal charge time and the potential for heavier loads on their onboard battery systems" (p. 15). In my analysis, I will analyze the type, quantity, and cost of different charging infrastructure to support a ZEV fleet as doing so is integral to assessing the total cost of the ZEV alternative.

E. LITERATURE REVIEW SUMMARY

Based on a review of the relevant literature, I assess that law enforcement vehicles have unique engineering specifications that vary by automobile manufacturer. These unique performance features have made the production of police-worthy ZEVs more difficult. Likewise, affixing aftermarket police equipment to a ZEV exacerbates the complexity due to the increased demand for electricity and the effect of additional weight on the vehicle's battery. Furthermore, the cost of transitioning to a ZEV fleet varies widely by agency location and mission and each transition requires individualized analysis. However, the 2024 Chevrolet Blazer PPV is the first pursuit-rated ZEV ever developed and provides a valuable experimentation opportunity to the Marine Corps. As such, it is timely and necessary for the Marine Corps to conduct its own cost-effectiveness analysis.

IV. COST ANALYSIS

This chapter outlines the cost analysis portion of my research where I determined that a ZEV fleet is *financially* more expensive than the current gasoline-powered fleet. The cost differential is largely attributable to the infrastructure development costs needed to sustain ZEV operations. However, this cost estimate shifts in favor of the ZEV fleet when the social cost of carbon is considered. I perform this analysis by comparing the predominant vehicle in the current patrol fleet (Dodge Durango PPV) to the first pursuit-rated ZEV (Chevrolet Blazer PPV). For ease of distinction, I sometimes refer to the current gasoline-powered fleet as the "status quo" and the ZEV fleet as "the alternative" course of action. To estimate the total cost of each fleet, I rely on the fleet's recent utilization data provided to me from Marine Corps Installations Command and cost data from the GSA.

A. DATA SOURCE AND METHODOLOGY

As introduced in Chapter II, the Camp Pendleton PMO currently uses a fleet of 22 gasoline-powered vehicles to perform its patrol mission. On Sept. 26, 2023, I obtained two reports from Marine Corps Installations Command (2023) related to these vehicles. These reports were accessed via the "GSA Fleet Drive-thru" database (S. Seaman, email to author, Nov. 16, 2023). In reviewing the data, I determined all 22 patrol vehicles are assigned to the Camp Pendleton PMO under a lease program managed by the GSA. Therefore, I obtained publicly available cost data from the GSA's website to estimate the direct costs to procure, operate, and maintain the current fleet and the alternative ZEV fleet.

In evaluating the cost of each fleet, I include all direct costs, meaning the monetary costs that pertain to procurement, operations, and maintenance. I also assess one indirect cost: the social cost of carbon. Furthermore, my cost estimate is based on leasing a Dodge Durango PPV that accumulates the average mileage and average maintenance expense as determined by the fleet's recent utilization data. However, it is important to note that the current patrol fleet includes vehicles other than the Durango and therefore the cost that I estimate would vary based on the specific make, model, and equipment of each vehicle. That said, my cost estimate reflects the most prevalent vehicle in the status quo fleet.

B. STATUS QUO: GASOLINE-POWERED FLEET

1. Description of the Status Quo

Using the vehicle data provided by Marine Corps Installations Command, I created Table 1 to depict the basic characteristics of the current patrol fleet.

Table 1. Basic Vehicle Data for Camp Pendleton's Gasoline-Powered Fleet. Adapted from S. Seaman, email to author, (2023).

ID	Vehicle Type	Make	Model	Model Year	Date Assigned	Months Owned	Miles Accumulated
1	LD SUV 4x4	Ford	Explorer	2023	8/18/2023	1	126
2	LD Pickup 4x4	Chevrolet	K1500	2023	7/13/2023	3	163
3	LD SUV 4x4	Dodge	Durango	2023	6/29/2023	3	1,454
4	LD SUV 4x4	Dodge	Durango	2023	6/29/2023	3	9,386
5	LD SUV 4x4	Ford	Explorer	2023	6/29/2023	3	4,473
6	LD SUV 4x4	Ford	Explorer	2023	6/29/2023	3	8,483
7	LD SUV 4x4	Ford	Explorer	2022	5/23/2023	4	8,167
8	LD SUV 4x4	Dodge	Durango	2021	9/23/2022	12	44,377
9	LD SUV 4x4	Dodge	Durango	2022	8/4/2022	14	46,258
10	LD SUV 4x4	Dodge	Durango	2021	3/17/2022	19	60,055
11	LD SUV 4x4	Dodge	Durango	2021	3/16/2022	19	78,107
12	LD SUV 4x4	Dodge	Durango	2021	3/16/2022	19	85,575
13	LD SUV 4x4	Dodge	Durango	2021	3/8/2022	19	53,529
14	LD SUV 4x4	Dodge	Durango	2020	1/13/2022	21	50,020
15	LD SUV 4x4	Dodge	Durango	2020	12/23/2021	21	84,758
16	LD SUV 4x4	Dodge	Durango	2020	11/23/2021	22	65,294
17	LD SUV 4x4	Dodge	Durango	2020	11/18/2021	23	80,760
18	LD Pickup 4x4	Ford	F150	2020	9/23/2020	37	70,208
19	LD SUV 4x4	Dodge	Durango	2020	9/8/2020	37	143,529
20	LD Pickup 4x2	Chevrolet	C1500	2020	7/30/2020	38	104,853
21	Sedan	Ford	Taurus	2018	5/18/2020	41	129,450
22	Sedan	Dodge	Charger	2019	5/11/2020	41	116,331

Based on the information shown in Table 2, the following key takeaways are apparent: all vehicles in the fleet are powered by internal combustion engines, 13 of 22 vehicles in the fleet are Durango PPVs, and the average patrol vehicle has been in the fleet for 18 months and accumulated 56,607 miles.

To understand the workload of this fleet, I calculated the miles accrued by each vehicle since the time it was assigned to the Camp Pendleton PMO. My calculation assumes each vehicle was received by the PMO with exactly "25 miles on the odometer" (S. Seaman, email to author, Oct. 20, 2023). As shown in Table 2, the average patrol vehicle drives approximately 2,691 miles per month or 90 miles per day (2,691 miles / 30 days).

Table 2. Mileage Data for Camp Pendleton's Gasoline-Powered Fleet. Adapted from S. Seaman, email to author, (2023).

ID	Date Assigned	Months Owned	Accumulated Mileage (-25 mi)	Average Miles Per Month
1	8/18/2023	1	101	78
2	7/13/2023	3	138	55
3	6/29/2023	3	1,429	482
4	6/29/2023	3	9,361	3,155
5	6/29/2023	3	4,448	1,499
6	6/29/2023	3	8,458	2,851
7	5/23/2023	4	8,142	1,939
8	9/23/2022	12	44,352	3,616
9	8/4/2022	14	46,233	3,318
10	3/17/2022	19	60,030	3,227
11	3/16/2022	19	78,082	4,190
12	3/16/2022	19	85,550	4,591
13	3/8/2022	19	53,504	2,831
14	1/13/2022	21	49,995	2,415
15	12/23/2021	21	84,733	3,959
16	11/23/2021	22	65,269	2,914
17	11/18/2021	23	80,735	3,578
18	9/23/2020	37	70,183	1,918
19	9/8/2020	37	143,504	3,868
20	7/30/2020	38	104,828	2,728
21	5/18/2020	41	129,425	3,167
22	5/11/2020	41	116,306	2,830

This mileage estimate is relevant to cost because the Marine Corps incurs a mileage expense based on the amount of miles each vehicle accrues. This mileage estimate is also used in my effectiveness to evaluate the demand that a vehicle must be able to handle relative to the fuel efficiency of the Durango and battery efficiency of the Blazer.

2. Cost to Procure, Operate, and Maintain the Status Quo

In estimating the direct cost that the Marine Corps incurs to employ the gasoline-powered fleet, I identified four elements of cost that pertain: monthly rate (lease payment), mileage rate (fuel and routine maintenance), agency incurred expenses (beyond routine maintenance), and optional equipment rate (lease payment for upfitted police equipment).

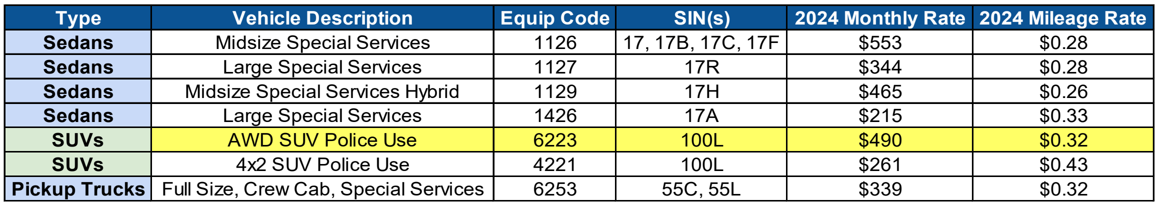
a. Monthly Rate (Lease Payment): $490

According to the GSA Fleet Customer Leasing Guide (2020), every leased vehicle is assigned a monthly rate, which allows the GSA to recover "all fixed costs, including vehicle acquisition costs, overhead, depreciation, and replacement costs" (p. 20). These rates are "evaluated and adjusted at least annually" to account for changes in the economic environment such as inflation and changes in operating expenses (p. 20). To communicate rates, the GSA (2024-a) publishes a vehicle rate bulletin to their website. This bulletin identifies vehicles by an equipment code and a federal standard identification number for which the Durango PPV is "6223" and "100L." As shown in Table 3, the GSA's FY-24 Vehicle Rate Bulletin states that the monthly rate for a Dodge Durango PPV is $490.

b. Monthly Mileage Rate (Fuel and Routine Maintenance): $861

In addition to the monthly lease rate, the GSA (2020) bills a mileage rate to recover "variable costs for fuel and general maintenance and repairs" (p. 20). As shown in Table 3, the GSA's FY-24 Vehicle Rate Bulletin establishes the mileage rate for the Durango PPV is $0.32. In other words, for every mile a Durango accumulates, the Marine Corps incurs a $0.32 expense. Therefore, I estimate that the Camp Pendleton patrol fleet incurs a monthly mileage expense of approximately: $861 ($0.32 * 2,691 miles) per vehicle.

Table 3. The GSA’s FY-24 Vehicle Rate Bulletin for Police-Use Vehicles. Source: GSA (2024-a).



Type	Vehicle Description	Equip Code	SIN(s)	2024 Monthly Rate	2024 Mileage Rate
Sedans	Midsize Special Services	1126	17, 17B, 17C, 17F	$553	$0.28
Sedans	Large Special Services	1127	17R	$344	$0.28
Sedans	Midsize Special Services Hybrid	1129	17H	$465	$0.26
Sedans	Large Special Services	1426	17A	$215	$0.33
SUVs	AWD SUV Police Use	6223	100L	$490	$0.32
SUVs	4x2 SUV Police Use	4221	100L	$261	$0.43
Pickup Trucks	Full Size, Crew Cab, Special Services	6253	55C, 55L	$339	$0.32

c. Agency Incurred Expenses (Beyond Routine Maintenance): $271

While the GSA recovers routine maintenance costs through the mileage rate, the Marine Corps is financially responsible for all other maintenance expenses such as excessive wear and tear and repairs emanating from vehicle collisions. The GSA refers to these beyond routine maintenance matters as “agency incurred expenses” (AIE). As stated in its Customer Leasing Guide, the GSA “retains the right to issue an AIE for any expenses not covered by its rates, as well as any abuse, neglect, or other damages which result in diminished vehicle value upon resale” (p. 22). As shown in Table 4, I analyzed the patrol fleet’s recent utilization data to determine the AIEs incurred by each vehicle.

Table 4. AIE Summary for Camp Pendleton’s Gasoline-Powered Fleet. Adapted from S. Seaman, email to author, (2023).

ID	Months Owned	Average miles per month	Total AIE (induction to 9/26/23)	Average Monthly AIE
1	1	78	$0	$0
2	3	55	$340	$136
3	3	482	$0	$0
4	3	3,155	$0	$0
5	3	1,499	$0	$0
6	3	2,851	$6,087	$2,052
7	4	1,939	$0	$0
8	12	3,616	$998	$81
9	14	3,318	$787	$56
10	19	3,227	$1,450	$78
11	19	4,190	$13,602	$730

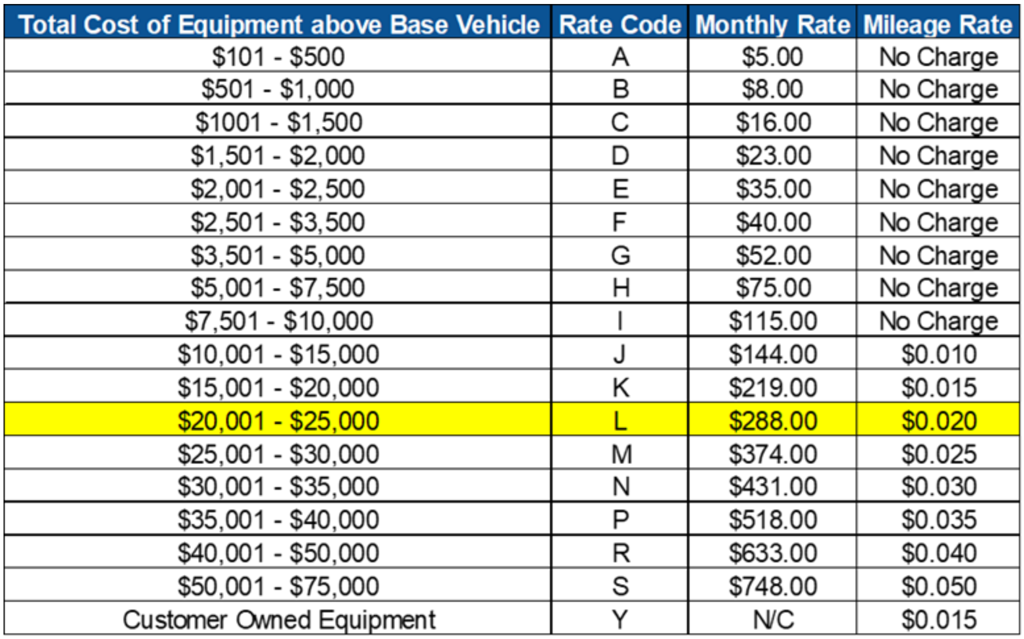
ID	Months Owned	Average miles per month	Total AIE (induction to 9/26/23)	Average Monthly AIE
12	19	4,591	$18,909	$1,015
13	19	2,831	$4,632	$245
14	21	2,415	$7,182	$347
15	21	3,959	$5,428	$254
16	22	2,914	$6,932	$309
17	23	3,578	$6,404	$284
18	37	1,918	$817	$22
19	37	3,868	$4,827	$130
20	38	2,728	$1,867	$49
21	41	3,167	$4,651	$114
22	41	2,830	$2,430	$59

The findings shown in Table 4 are based on a report that queried all 22 vehicles, starting when the oldest vehicle was inducted into the fleet and ending on Sept. 26, 2023, when the report was generated. This report shows 17 of 22 vehicles were subject to AIEs for amounts that ranged from $340 to $18,909. Thus, I assess an average monthly AIE of $271 per vehicle. Of note, the five vehicles (IDs: 1, 3, 4, 5, 7) that did not incur any AIE were in the fleet for fewer than three months at the time this report was generated. Additionally, the vehicle with the largest AIE (ID: 12) also has the highest average monthly mileage, suggesting a positive correlation between mileage and maintenance expenses.

d. Optional Equipment Rate (Upfitting): $342

As described earlier, an expense that is unique to patrol vehicles is the aftermarket equipment installed to aid in performing police duties. Since vehicles are leased, this equipment is typically leased as well and recovered by the GSA through an increase to the mileage rate and the addition of an “optional equipment rate.” By cross-referencing vehicle data shown in Table 1 and GSA’s FY-24 rate bulletin, I determined that the total cost of police equipment for each Durango PPV is between $20,001 and $25,000.

Table 5. The GSA's FY-24 Vehicle Rate Bulletin for Optional Equipment. Source: GSA (2024-a).



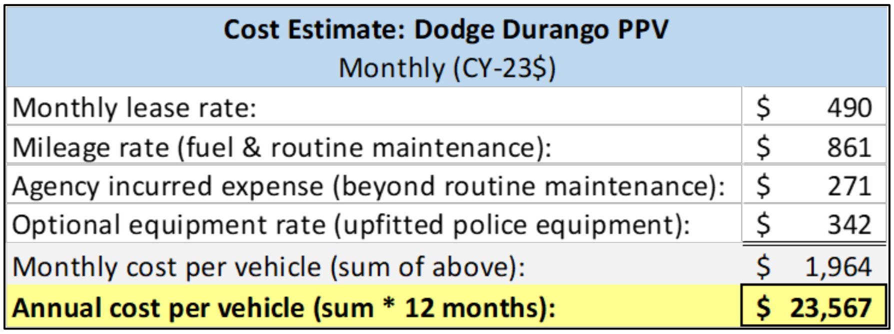
Total Cost of Equipment above Base Vehicle	Rate Code	Monthly Rate	Mileage Rate
$101 - $500	A	$5.00	No Charge
$501 - $1,000	B	$8.00	No Charge
$1001 - $1,500	C	$16.00	No Charge
$1,501 - $2,000	D	$23.00	No Charge
$2,001 - $2,500	E	$35.00	No Charge
$2,501 - $3,500	F	$40.00	No Charge
$3,501 - $5,000	G	$52.00	No Charge
$5,001 - $7,500	H	$75.00	No Charge
$7,501 - $10,000	I	$115.00	No Charge
$10,001 - $15,000	J	$144.00	$0.010
$15,001 - $20,000	K	$219.00	$0.015
$20,001 - $25,000	L	$288.00	$0.020
$25,001 - $30,000	M	$374.00	$0.025
$30,001 - $35,000	N	$431.00	$0.030
$35,001 - $40,000	P	$518.00	$0.035
$40,001 - $50,000	R	$633.00	$0.040
$50,001 - $75,000	S	$748.00	$0.050
Customer Owned Equipment	Y	N/C	$0.015

As shown in Table 5, this results in a monthly cost of $288 per vehicle and an additional $0.02 per mile. Thus, the average monthly cost for equipment is $342 ($288 + $54 [$0.02 * 2,691 miles]). For reference, this portion of the GSA bulletin is highlighted in Table 5.

3. Cost Summary for the Status Quo

Up to this point, I analyzed vehicle utilization data from Marine Corps Installations Command and the GSA's FY-24 Vehicle Rate Bulletin to estimate the cost of the gasoline-powered patrol fleet. As summarized in Table 6, I estimate that the Camp Pendleton PMO incurs an annual expense of $23,567 for each Durango PPV that it has in its fleet. As shown in Table 6, this cost estimate is based on Camp Pendleton leasing a Durango PPV that accumulates the average mileage as shown in Table 2 and the average AIE as shown in Table 4. Therefore, if all 22 of Camp Pendleton's patrol vehicles were in fact Durango PPVs with $20,001 to $25,000 of upfitted police equipment, the annual cost to operate and maintain them would be $518,480 ($23,567 * 22 vehicles), as highlighted in yellow.

Table 6. Cost Estimate for Camp Pendleton's Gasoline-Powered Patrol Fleet



Cost Estimate: Dodge Durango PPV Monthly (CY-23$)	
Monthly lease rate:	$ 490
Mileage rate (fuel & routine maintenance):	$ 861
Agency incurred expense (beyond routine maintenance):	$ 271
Optional equipment rate (upfitted police equipment):	$ 342
Monthly cost per vehicle (sum of above):	$ 1,964
Annual cost per vehicle (sum * 12 months):	**$ 23,567**

C. ALTERNATIVE COURSE OF ACTION: ZEV FLEET

1. Description of the ZEV Fleet

In the alternative course of action, I assume that the Camp Pendleton PMO replaces all 22 gasoline-powered patrol vehicles with 22 Chevrolet Blazer PPVs. I evaluate the cost of the Blazer in much the same way as the Durango. However, there are two expenses that pertain to the ZEV fleet that do not pertain to the status quo: the cost of electric vehicle charging infrastructure and the cost of electricity for vehicle charging. In theory, an equitable comparison may consider the cost of Camp Pendleton's gasoline infrastructure. However, I disregard these costs because experts consider them "sunk costs," which pertain to foregone investment decisions that have no bearing on whether to adopt the alternative.

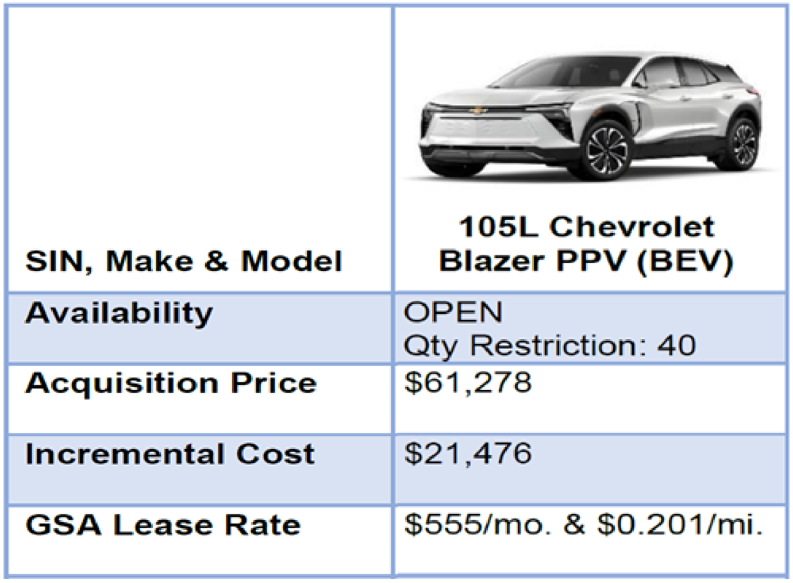
According to Cellini and Kee (2010), "sunk costs are defined as investments previously made in a program or project, such as original research and development costs, as compared to ongoing costs." Cellini and Kee explain that when "recommending future action on a program or project, sunk costs should be ignored, because they have no impact on the marginal costs and benefits of the continuation of the project or program" (p. 505). Similarly, Brealey et al. (2020) state "sunk costs are like spilled milk: They are past and irreversible outflows. Because sunk costs are bygones, they cannot be affected by the decision to accept or reject the project, and so they should be ignored" (p. 140).

Additionally, the fuel facilities that Camp Pendleton's patrol vehicles currently use are functionally and financially distinct from how ZEV operations would conceivably occur. In effect, Camp Pendleton's patrol vehicles currently refuel at government fuel facilities or commercial gas stations (S. Ansbigian, email to author, Aug. 24, 2023). In either case, the PMO is spared the operating expenses that pertain to these facilities and merely acts as a customer who pays for the fuel it consumes. This fuel cost is accounted for via GSA's mileage rate previously described. Conversely, amid a transition to ZEVs, my research assumes the PMO would need its own dedicated charging infrastructure as a total reliance on communal charging ports would impede readiness and potentially degrade the PMO's law enforcement mission. Thus, to fully support a ZEV fleet, the PMO would need its own charging-station for which electricity costs would be its direct responsibility.

2. Cost to Procure, Operate, and Maintain the Alternative

To estimate the cost for Camp Pendleton to employ the Blazer PPV, I assess seven cost elements that pertain. Four elements closely follow the status quo: the monthly rate, mileage rate, AIE, and equipment rate. The mileage rate differs in that fuel costs are no longer a component of the rate. However, as noted earlier, fuel costs would be replaced by the cost of electricity. Additionally, the Marine Corps would be responsible for an upfront per-vehicle procurement cost designed to offset the lease payment and the cost to install charging infrastructure. As shown in Table 7, the GSA's ZEV Fact Sheet (2023), stipulates the applicable Blazer procurement costs that I use in my cost estimate.

Table 7. Pricing for the 2024 Chevrolet Blazer PPV. Source: GSA (2023).



SIN, Make & Model	105L Chevrolet Blazer PPV (BEV)
Availability	OPEN Qty Restriction: 40
Acquisition Price	$61,278
Incremental Cost	$21,476
GSA Lease Rate	$555/mo. & $0.201/mi.

a. *Monthly Rate (Lease Payment): $555*

As shown in Table 7, the monthly lease rate for a Blazer PPV is $555. This figure represents an increase of $65 or 13% relative to the monthly rate for the Durango. However, this rate assumes the $21,476 incremental cost shown in Table 7 is paid upfront. I will further explain the basis for this cost in the section titled "Incremental Cost per Vehicle."

b. *Monthly Mileage Rate (Routine Maintenance): $541*

Also shown in Table 7 is the Blazer PPV's mileage rate ($0.20 per mile). This figure represents a decrease of 37% or a $0.12 per mile relative to the mileage rate of the Durango. This reduction is attributable to the Blazer not having a fuel expense and the anticipation that routine maintenance will cost less than the Durango. Therefore, I estimate the monthly mileage cost for one Blazer to be $541 ($0.201 * 2,691 miles). This amounts to $320 less than the mileage rate of the Durango, but this ignores electricity consumption costs.

c. *Cost of Electricity: $188*

To estimate the cost of vehicle charging, I apply the Federal Energy Management Program's (2020) "methodology to estimate electricity consumption" in kilowatt hours (kWh), expressed by the following equation:

- Electricity Consumed = Annual Distance Driven * BEV Efficiency / 100

Using the mileage factor given by Table 2, I estimate the annual distance accrued by one patrol vehicle is 32,292 miles (2,691 miles * 12 months). Additionally, the Department of Energy (2024) states the BEV efficiency of the 2024 Chevrolet Blazer BEV is 35 kWh per 100 miles. In other words, to drive the Blazer 100 miles requires 35 kWhs of energy. Thus, the annual electricity consumption for one Blazer PPV is approximately 11,302 kWhs (32,292 miles * 35 kWh / 100).

According to Camp Pendleton's Energy Manager, the installation's cost per kWh is $0.20 (S. Seaman, email to author, Jan. 11, 2024). Therefore, I expect the annual electricity cost of one Blazer PPV to be approximately $2,260 (11,302 kWh * $0.20) or $188 per month. This estimate assumes that this amount of energy output is possible given Camp Pendleton's current electrical infrastructure and does not account for any upgrades or improvements that may be needed to support this draw for electrical power.

d. *Agency Incurred Expenses (beyond Routine Maintenance): $271*

Since the Blazer PPV is the only currently available pursuit-rated ZEV and has not been fully implemented by any law enforcement agency, there are no historical data to estimate AIEs. Additionally, any anticipated reduction in cost for *routine* maintenance is already accounted for in the reduced mileage rate previously shown in Table 7. However, I conservatively assume *beyond routine* maintenance will be equal to the Durango's AIE as the factors causing an AIE have little to do with the *type* of vehicle and more to do with the likelihood of a collision, excessive wear, and other such occurrences. Therefore, I hold the AIE estimate from the status quo constant in this course of action. If this estimate were flawed, I would expect it to be underestimated as "electric vehicles have slightly higher repair costs" relative to gasoline-powered vehicles (Rapier & St. John, 2024, para 10").

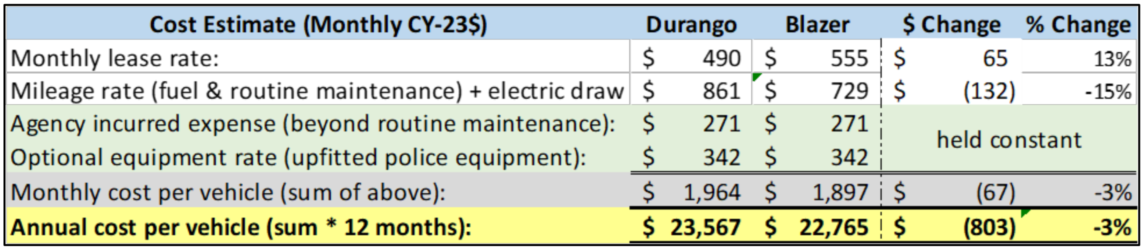
e. Optional Equipment Rate: $342

For reasons similar to the AIE estimate, I also hold the equipment rate constant. At present, there is no historical basis to estimate the cost of upfitting the Blazer PPV and the exact price will vary depending on the equipment options that an agency chooses. However, I would expect the Durango upfit costs to be analogous. As shown in Table 5, the GSA charges a monthly rate and mileage rate for optional equipment based on the equipment's total cost. As such, I assume equipment costs for the Blazer will fall within the same range as the Durango and this cost is also constant. If this estimate were flawed, I would expect it to be underestimated due to the complexity of ZEV upfitting as described in Chapter III.

3. Cost Summary for the ZEV Fleet

Prior to analyzing the incremental costs that pertain to the ZEV fleet, it is informative to compare both cost estimates up to this point. As shown in Table 8, the ZEV fleet offers an annual savings of $803 per vehicle (highlighted in yellow). However, this is only a net change of 3% relative to the status quo. Due to the various uncertainties involved in patrol vehicle operations and maintenance, I view this as a negligible cost differential.

Table 8. Cost Estimate for the Durango and Blazer PPVs (without Incremental Costs)



Cost Estimate (Monthly CY-23$)	**Durango**	**Blazer**	**$ Change**	**% Change**
Monthly lease rate:	$ 490	$ 555	$ 65	13%
Mileage rate (fuel & routine maintenance) + electric draw	$ 861	$ 729	$ (132)	-15%
Agency incurred expense (beyond routine maintenance):	$ 271	$ 271	held constant	
Optional equipment rate (upfitted police equipment):	$ 342	$ 342		
Monthly cost per vehicle (sum of above):	$ 1,964	$ 1,897	$ (67)	-3%
Annual cost per vehicle (sum * 12 months):	**$ 23,567**	**$ 22,765**	**$ (803)**	**-3%**

The change in mileage rate and the cost of electricity for charging is also notable. Initially, a savings stems from the lower ZEV mileage rate ($0.32 → $0.02) as fuel costs are eliminated. However, when the cost of electricity is combined with the ZEV mileage rate, the savings is only $132 per month. Thus, the savings that are realized from eliminating fuel costs are merely replaced by the cost of electricity for charging ($861 vs. $729).

a. Incremental Cost per Vehicle: $21,476

The GSA's Customer Leasing Guide (2020) essentially states that when a ZEV is more expensive than the gasoline-vehicle it replaces, the price differential shall be paid as an upfront cost (p. 62). This payment is part of the government's acquisition strategy to keep lease payments within close range of the status quo. In this case, I treat the Durango PPV as the "gasoline-powered equivalent" to the Blazer PPV. As such, GSA's (2024-b) Auto Choice database shows the Durango PPV has a base price of $38,313. Alternatively, the same GSA database gives a base price for the Blazer PPV of $61,278. Expectedly, the incremental cost shown in Table 7 is *roughly* the difference between the two base prices ($61,278 – $38,313). Thus, to replace the current patrol fleet with 22 Blazer PPVs, the Marine Corps would incur $472,472 ($21,476 * 22 vehicles) in procurement costs.

b. Incremental Costs for Charging Infrastructure: $200,000-720,000

The final element of cost pertains to charging infrastructure and is arguably the most difficult element to estimate. As noted earlier by the GAO, there is a high degree of variability in ZEV charging infrastructure costs and agencies may not know the true cost until they have a professional site assessment. Further compounding the difficulty of this estimate are the varying capabilities offered by different types of chargers. According to Moloughney (2021), "there are three levels of EV charging … the higher the level of charging, the faster the charging process, as more power is delivered to the vehicle" (para 4). In this case, I use costs recommended by the Office of the Secretary of Defense (OSD) for Level 2 and 3 chargers. However, according to Marine Corps Installations Command:

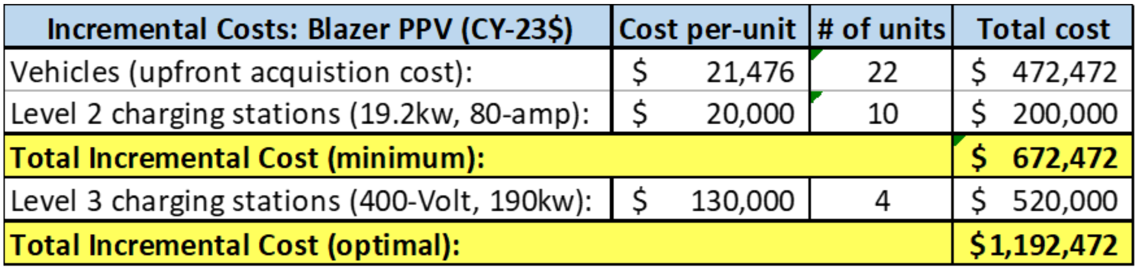
> [OSD] acknowledged all the variables that could affect the cost to install EV charging equipment. Even professional EV assessments are using similar installation costs. As we get into more and more planning to install charging facilities, we're discovering more and more issues upstream in the electric distribution system (transformers, switches, gates, etc.) that obviously affect costs. We're still using the initial cost estimate factors to begin our planning and adjusting as we learn the total infrastructure requirements. (S. Seaman, email to author, Jan. 12, 2024)

Nonetheless, OSD (2023) estimates that the average per-unit cost for a Level 2 charger is $20,000 and a Level 3 charger is $130,000. In Chapter V, I detail my assessment for Camp Pendleton PMO needing a minimum of ten Level 2 chargers to maintain its current level of operational capability. However, my analysis finds that the procurement of an additional four Level 3 chargers would be optimal.

c. *Cost Summary of Incremental Costs for ZEV Fleet*

Given OSD's estimates, Table 9 depicts the incremental costs that the Marine Corps would incur when procuring 22 Blazer PPVs. The first yellow highlight reflects the cost of procuring the minimum necessary charging equipment and the second yellow highlight reflects the cost of procuring four additional Level 3 chargers. The basis for this mix of charging infrastructure will be further explained in the section titled "Range Analysis."

Table 9. Incremental Cost Estimate for the ZEV Fleet



Incremental Costs: Blazer PPV (CY-23$)	Cost per-unit	# of units	Total cost
Vehicles (upfront acquistion cost):	$ 21,476	22	$ 472,472
Level 2 charging stations (19.2kw, 80-amp):	$ 20,000	10	$ 200,000
Total Incremental Cost (minimum):			**$ 672,472**
Level 3 charging stations (400-Volt, 190kw):	$ 130,000	4	$ 520,000
Total Incremental Cost (optimal):			**$1,192,472**

D. LIFE CYCLE COST COMPARISON AND INFLATION

Given the near-term cost estimates shown in Tables 8 and 9, I evaluate these costs over the life cycle of each fleet. In this case, I consider the life cycle seven years to coincide with the GSA's lease term for SUVs (S. Seaman, email to author, Sept. 26, 2023). In doing so, I analyze the cost of both fleets from FY-24 to FY-30 and adjust for inflation based on the previous ten years of inflation data. According to the U.S. Bureau of Labor Statistics (2023), the average annual rate of inflation from 2013–2023 was 2.7%. I round up to 3% and apply this factor year-over-year. I expect this inflation factor will take effect in the form of the GSA raising rates on an annual basis to compensate for changes in the cost of labor, repair parts, and other economic factors impacting the cost to maintain either fleet.

As shown in Figure 7, my cost estimate finds that, over a seven-year period, the operations and maintenance costs for the ZEV fleet is slightly less than the current gasoline-powered fleet ($3.84-million vs. $3.97-million). However, the ZEV fleet is in fact more expensive when incremental costs are factored into the estimate.

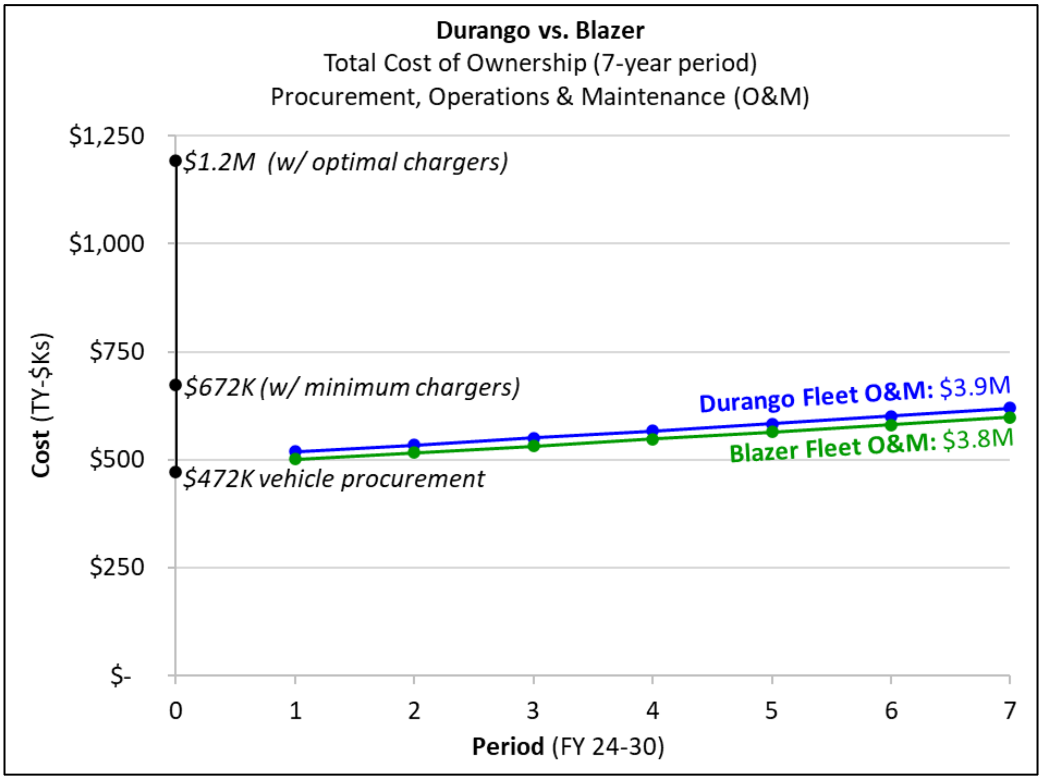


Figure 7. Total Cost of Fleet Ownership (7-Year Period), Adjusted for Inflation

As shown in Figure 7, I expect the ZEV fleet will cost approximately:

- $472-thousand in upfront vehicle procurement costs
- + $200-thousand for the minimum necessary charging capability or…
- + $720-thousand for the optimal charging capability

Therefore, after accounting for the savings in operations and maintenance costs as well as the incremental costs, I expect the ZEV fleet will be approximately:

- $537-thousand more expensive with minimum charging capability or…
  (($3,837,512 + $472,472 + $200,000) – $3,972,835)
- $1-million more expensive with the optimal charging capability
  (($3,837,512 + $472,472 + $720,000) – $3,972,835).

E. THE SOCIAL COST OF CARBON

Before I transition to an analysis of vehicle effectiveness, it is necessary to consider the social cost of carbon. The social cost of carbon "is an estimate, in dollars, of the economic damages that would result from emitting one additional ton of greenhouse gases into the atmosphere" (Rennert & Kingdon, 2019, para. 1). The underlying ideas used to formulate this cost are: "changes in net agricultural productivity, human health, property damages from increased flood risk and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning" (U.S. Environmental Protection Agency [EPA], 2017, para. 2). This metric is often used by "policymakers who are weighing regulatory proposals that may increase or curb carbon emissions" (Asdourian & Wessel, 2023, para. 2). In essence, "if a policy to prevent one ton of carbon emissions costs less than the [social cost of carbon], then the benefits of the policy outweigh the costs and it pays for itself in the long run" (Asdourian and Wessel, 2023).

Thus, the social cost of carbon is a useful tool in economic analysis, but one drawback is that its value varies widely across political administrations. For example, under President Obama, "White House economists calculated the social cost of carbon at $42 a ton … The Trump administration lowered it to less than $5 a ton" (Davenport, 2023, para. 6). More recently, President Biden's EPA "asserts that each ton of carbon dioxide emitted into the atmosphere costs society $190" (Prest, 2023, para. 1). As shown in Figure 8, I applied these costs to the carbon footprint of each fleet to estimate how each administration would value the social cost of carbon over each fleet's seven-year life cycle.

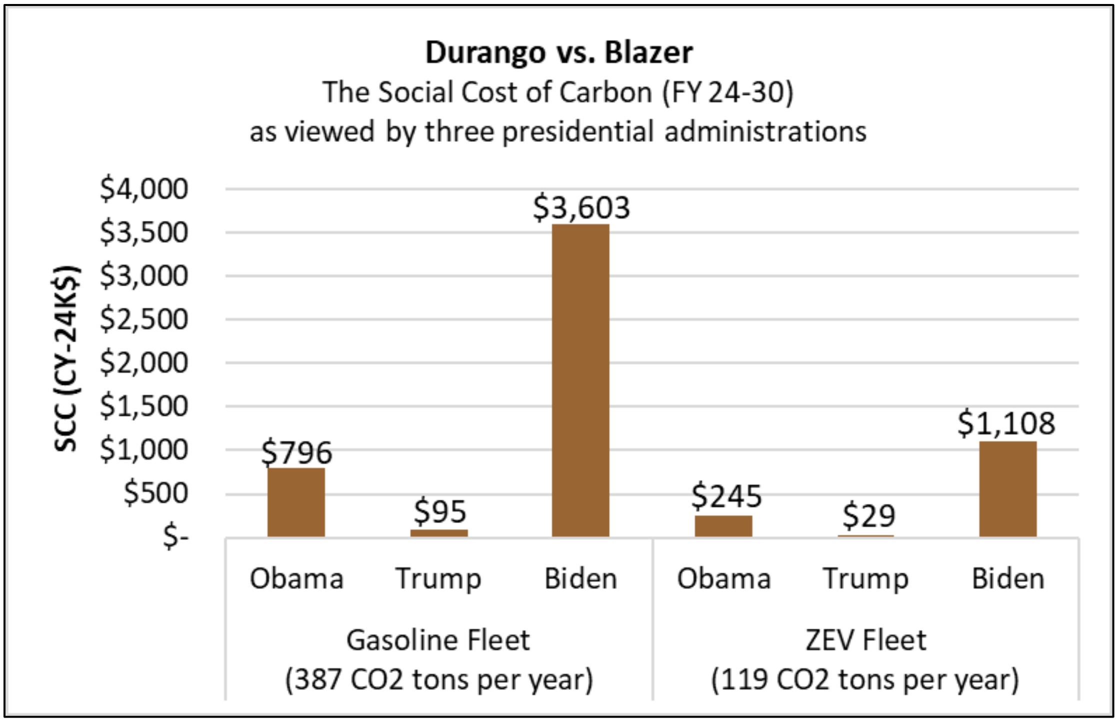


Figure 8. Each Fleet's Social Cost of Carbon per The Last Three Presidential Administration

To calculate the carbon footprint of each fleet, I referred to the manufacturer's specification guide for each vehicle and the EPA's (2023) "Greenhouse Gas Equivalencies Calculator." According to the manufacturer's specification guide, the Durango PPV has a 24.6-gallon fuel tank and a fuel economy of 18 city miles per gallon (Stellantis, 2024). This means a full tank of gasoline provides the Durango 443 miles of range (18 mpg * 24.6). Thus, for a Durango to travel the average 2,691 miles per month, it must completely refuel six times (2,691 / 443 miles). This results in one vehicle consuming 1,794 gallons of gasoline per year (24.6 gallons * 6 refuels * 12 months) and the 22-vehicle fleet consuming 39,468 gallons per year. According to the EPA (2023), consuming this amount of gasoline is equivalent to emitting 387 tons of carbon dioxide per year (2,709 tons over seven years).

For the alternative, I applied the Blazer PPV's electricity consumption calculated in Chapter IV (11,302 kWhs each year). As such, a fleet of 22 Blazer PPVs would demand 248,644 kWhs (11,302 kWh * 22 vehicles). According to the EPA (2023), consuming this amount of electricity is equivalent to emitting 119 tons of carbon dioxide into the atmosphere each year (833 tons over seven years). Thus, a transition from the status quo to the alternative fleet results in an annual reduction of 268 tons of carbon (387 – 119 tons). Finally, to arrive at the values shown in Figure 8, I multiplied the seven-year carbon tonnage for each fleet by each administration's social cost of carbon ($42, $5, $190). As a result, I find that the transition from the gasoline-powered fleet to the ZEV fleet would indirectly reduce fleet ownership cost by the following amounts based on each administration's assessed social cost of carbon:

- President Obama: $551-thousand ($796-thousand – $244-thousand)
- President Trump: $66-thousand ($95-thousand – $29-thousand)
- President Biden: $2.5-million ($3.6-million – $1.1-million)

It is important to emphasize that these are *indirect* social costs would not manifest in the form of a real monetary savings for the Marine Corps. Instead, these "savings" would take place in the form of less-tangible social and environmental benefits that are equivalent to the stated monetary values.

V. EFFECTIVENESS ANALYSIS

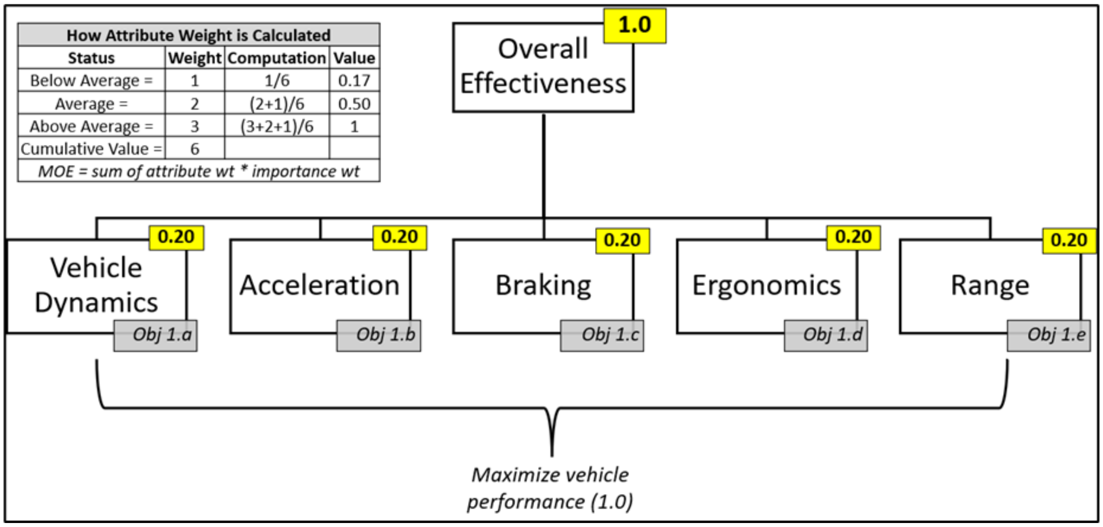
Having established cost estimates for the status quo and the alternative, I now compare the *effectiveness* of each vehicle. In particular, I compare five areas of vehicle performance including: dynamics, acceleration, braking, ergonomics, and range. As a result, I conclude that the Blazer PPV is 40% more effective than the status quo. In this portion of the analysis, I intentionally omit the environmental impacts of either vehicle because the established difference between the two is that the Blazer is a ZEV with a low carbon footprint and the Durango is gasoline vehicle with a relatively higher carbon footprint. If environmental factors were included, I would expect the resulting measures of effectiveness to skew in favor of the Blazer. Therefore, my analysis sets this variable aside to hone in on each vehicle's performance and ability to withstand the rigors of police use.

A. DATA SOURCE AND METHODOLOGY

As discussed in my literature review, the Michigan State Police are highly regarded for their annual evaluation of police vehicles. During their evaluation of model year 2024 police vehicles, the Michigan State Police Vehicle Testing Team assessed twelve vehicles including the Durango and Blazer PPVs. As such, I rely on these test results for four of the five attributes included in my analysis: vehicle dynamics, acceleration, braking, and ergonomics. To apply these results, I first determine the average test result among all twelve vehicles for each attribute and then compare that to the performance of the Durango and Blazer. I use that result to assign each outcome a numeric weight with respect to the vehicle's performance around the average (at, above, or below).

The fifth attribute I evaluate is the range of each vehicle, which for the Blazer, is directly tied to my charging infrastructure analysis. Here, I apply Little's Law to determine the minimum amount of charging time necessary to sustain the current pace of patrol. Little's Law is a foundational concept in queuing theory (the mathematical study of waiting in lines, or queues), coined by John D. Little in 1961. The law asserts that "the average number of items in a queuing system, equals the average arrival rate of items to the system, multiplied by the average waiting time of an item in the system" (Little, 2011, p. 536). By applying the principles of this law, I am able to determine the type and quantity of charging infrastructure needed for the Blazer PPV to meet the operational demand currently performed by the Durango patrol fleet.

I begin this process by establishing an objective hierarchy and assigning weights to decision make preferences as described by Wall and MacKenzie (2015). My hierarchy takes the approach that all individual attributes hold equal importance and therefore I assign the same amount of nominal weight to all objectives (see Figure 9).



How Attribute Weight is Calculated			
Status	**Weight**	**Computation**	**Value**
Below Average =	1	1/6	0.17
Average =	2	(2+1)/6	0.50
Above Average =	3	(3+2+1)/6	1
Cumulative Value =	6		
*MOE = sum of attribute wt * importance wt*			

Figure 9. Objective Hierarchy

The chart shown in Figure 9 explains the process by which weights are aggregated to calculate the overall measure of effectiveness. In essence, each attribute will result in an average, above average, or below average rating—each of which carries a nominal weight: 0.17 (below average), 0.50 (average), 1 (above average). The attribute weight that each vehicle achieves is then multiplied by the established importance weight (0.20) and then all resulting weights are summed to arrive at an overall measure of effectiveness.

B. PERFORMANCE

This section draws upon the Michigan State Police vehicle evaluation report authored by Darlington et al. (2023). It is important to note that the Michigan State Police tested all vehicles *without* any upfit equipment attached. The testing team states "this is the best way to ensure all the vehicles are tested on an equal basis" but warns that once police equipment is added, "overall performance may be somewhat lower" (p. 4). It is also important to note that two different Durango PPVs were included in the Darlington et al. evaluation, one with a 5.7-liter engine and one with a 3.6-liter engine. For my analysis, I only refer to the performance of the 3.6-liter engine because this is the only type of Durango that the Camp Pendleton PMO has in its fleet.

1. Vehicle Dynamics

According to the Darlington et al. report, dynamics are assessed on a two-mile racing track with hills, curves, and corners. The track is designed to simulate the conditions that police officers would likely face when responding to emergencies. To establish a score, the authors state "each vehicle is driven a total of 32 timed laps, using four separate drivers, each driving an eight-lap series. The final score for the vehicle is the combined average (from the four drivers) of the five fastest laps for each driver during the eight-lap series." As shown in Figure 10, the average time across the twelve vehicles was 99 seconds.

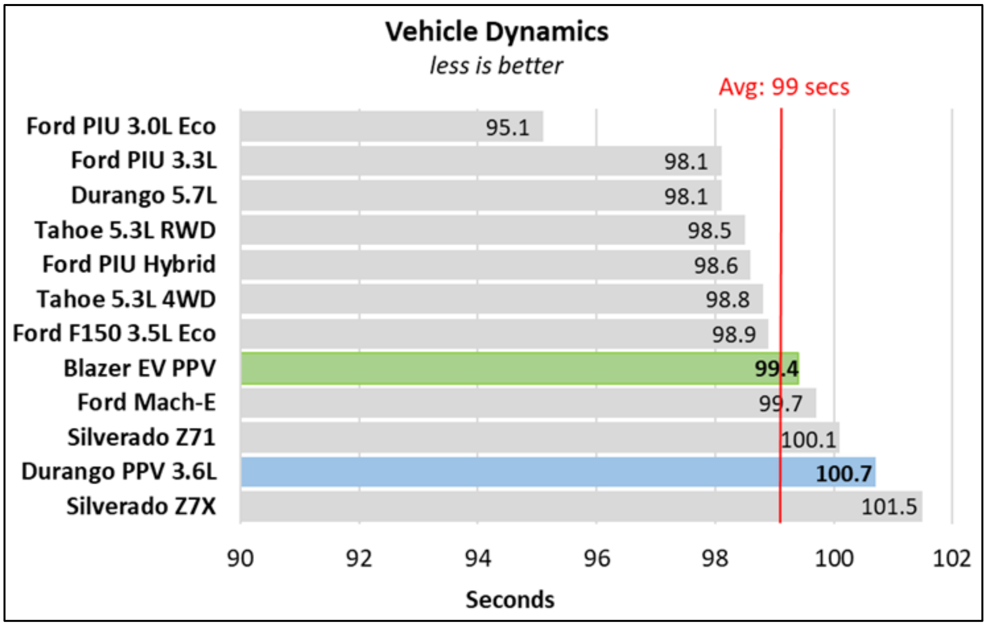


Figure 10. Test Results for Vehicle Dynamics. Adapted from Darlington et al. (2023).

As shown in Figure 10, the Blazer finished the vehicle dynamics test in an average time of 99.4 seconds and the Durango finished in a below average time of 100.7 seconds.

2. Acceleration

To determine acceleration, Michigan State Police used global positioning technology to assess how long each vehicle takes to reach speeds of 60, 80, and 100 miles per hour (mph). The test methodology disclosed by Darlington et al. (2023) states "each vehicle is driven through four acceleration sequences, two northbound and two southbound, to allow for wind direction. The four resulting times for each target speed are averaged and the average times are used to derive scores for acceleration" (p. 40). As a result, the Blazer PPV had the second-fastest acceleration time in all three distance categories compared to all vehicles in the sample. Since this result was consistent throughout all acceleration testing (0-60mph, 0–80mph, and 0–100mph), I only applied the results of the 0–60 mph test to my analysis (see Figure 11).

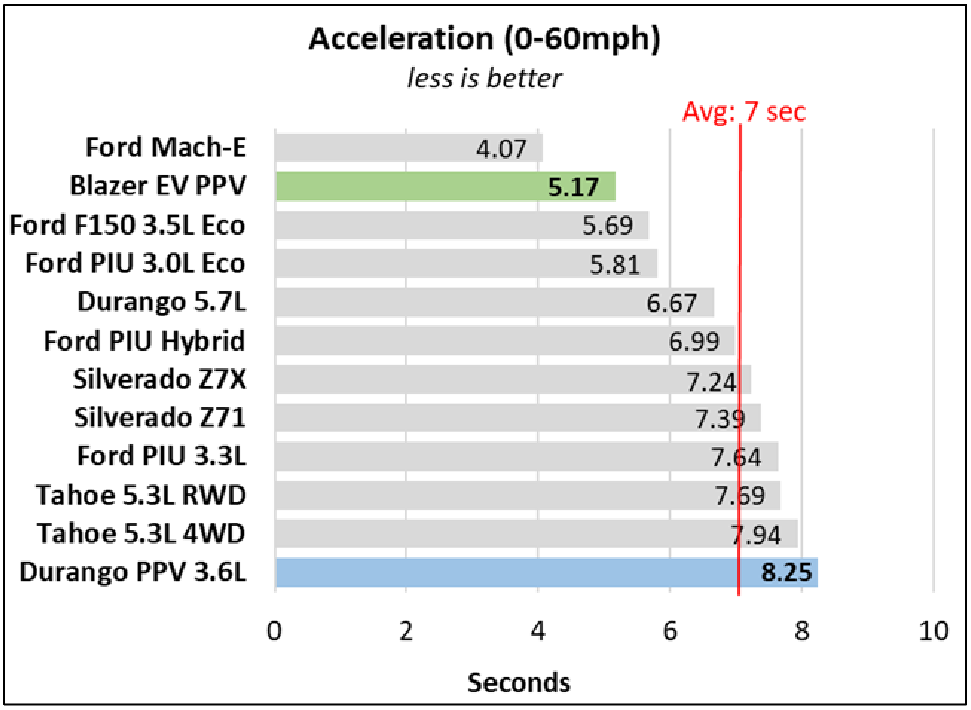
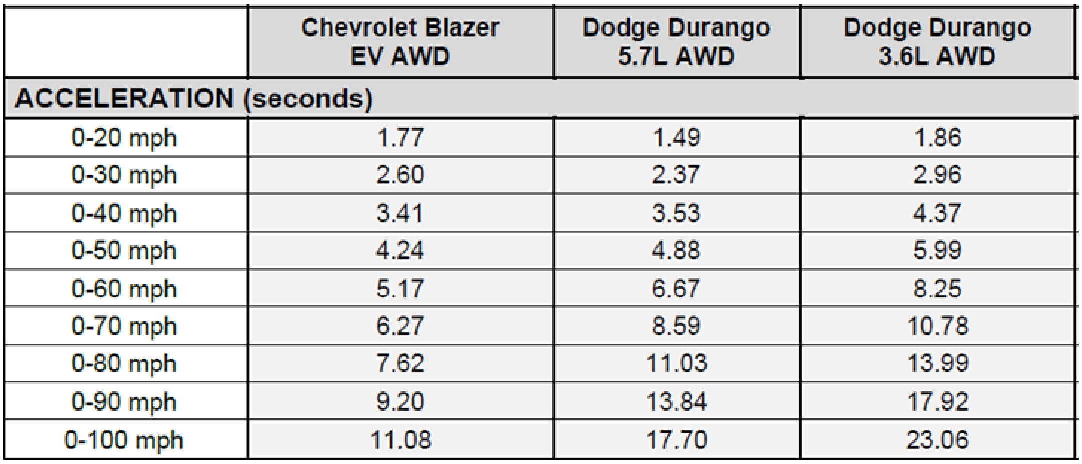


Figure 11. Test Results for Vehicle Acceleration. Adapted from Darlington et al. (2023).

As shown in Figure 11, the average 0–60 mph acceleration time across the twelve-vehicle sample was 7 seconds. Therefore, I consider the Blazer above average (5.7 seconds) and the Durango below average (8.25 seconds). For added context, Table 10 depicts the progressive acceleration times of the Blazer and both types of Durango PPVs. In effect, the very last line of this table shows that the Blazer can reach 100 mph in less than half of the time, it would take the 3.6-liter engine Durango.

Table 10. Acceleration Times for the Blazer and Durango. Source: Darlington et al. (2023).



	Chevrolet Blazer EV AWD	Dodge Durango 5.7L AWD	Dodge Durango 3.6L AWD
ACCELERATION (seconds)			
0-20 mph	1.77	1.49	1.86
0-30 mph	2.60	2.37	2.96
0-40 mph	3.41	3.53	4.37
0-50 mph	4.24	4.88	5.99
0-60 mph	5.17	6.67	8.25
0-70 mph	6.27	8.59	10.78
0-80 mph	7.62	11.03	13.99
0-90 mph	9.20	13.84	17.92
0-100 mph	11.08	17.70	23.06

3. Braking

According to the Darlington et al. report, brake testing was conducted by driving each vehicle at a rate of 60 mph and then forcing the vehicle to a complete stop to measure the deceleration rate. The test methodology disclosed in the report states that the vehicle begins in a southerly direction and "is stopped five times at pre-determined points on the roadway. The vehicle is then turned around and stops an additional five times again at pre-determined points on the roadway in a northerly direction" (p. 56). The vehicle's stopping distance is measured in feet using a standardized deceleration rate formula. As shown in Figure 12, the average stopping distance from a speed of 60 mph was 136.8 feet. The Blazer's stopping distance was 135 feet and the Durango's was 137 feet.

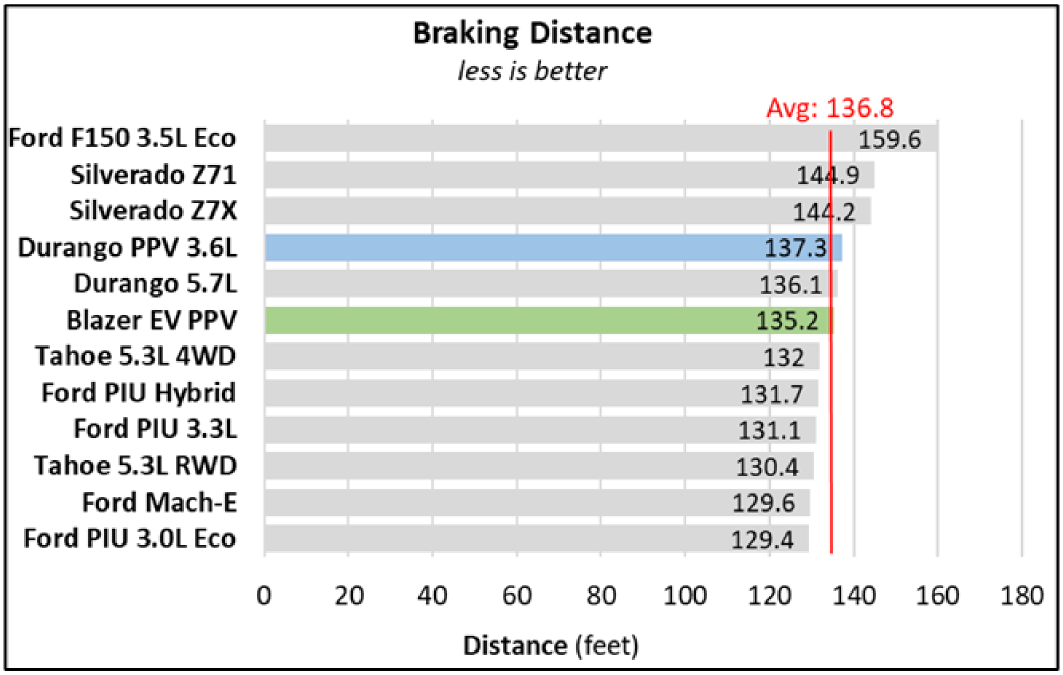


Figure 12. Test Results for Vehicle Braking. Adapted from Darlington et al. (2023).

As shown in Figure 12, the Blazer stopping distance was above average (< 136 feet) and the Durango's stopping distance fell below average (≥137 feet).

4. Ergonomics

The final metric evaluated by Michigan State Police pertains to the vehicle's ability to "provide a suitable environment for the patrol officer in the performance of his/her assigned tasks." In this case, the vehicle testing team was comprised of five police officers that "individually and independently compare [d] and score [d] each test vehicle ... based on comfort, convenience, instrumentation and visibility" (p. 70). The scores were based on a scale from 1–10, with "10" being the best possible result and "1" being the worst possible score. As shown in Figure 13, the average ergonomics rating across the twelve vehicles was 7.89 points. Therefore, the Blazer PPV fell within the average range (7 to 7.9) by a small margin (7.87 points) and the Durango PPV was rated above average with a score of 8.2 points.

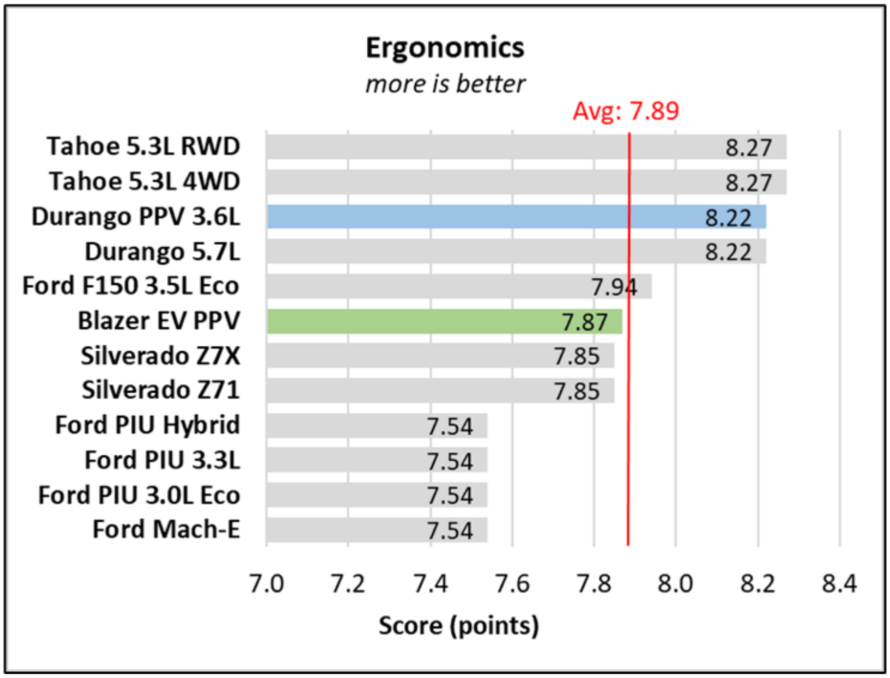


Figure 13. Test Results for Vehicle Ergonomics. Adapted from Darlington et al. (2023)

5. Range Analysis

As stated in my cost analysis, I assess the Camp Pendleton PMO would require at least ten Level 2 chargers to support a fleet of 14 Blazer PPVs. To determine this, I referred back to the average daily miles a patrol vehicle accumulates at Camp Pendleton (90 miles). I consider this mileage factor a key indicator of the patrol mission. By converting this to an hourly rate, I assess that a patrol vehicle must be able to complete its daily mission at an average pace of 4 mph (90 miles / 24 hours), which I refer to as “the pace of patrol.” To be clear, I do not suggest that a vehicle must remain continuously active at a speed of 4 mph nor that a vehicle could simply drive 90 mph for one hour and consider their daily mission complete. Rather, the historical data indicates that the PMO needs to maintain a state of vehicle readiness (be it battery charge or fuel level) that allows it to cover 90 miles, over a 24-hour period, at an average pace of 4 mph or less. A higher speed would be detrimental as it would indicate that the vehicle needs to patrol more quickly to accommodate an increased amount of down-time (to recharge or refuel).

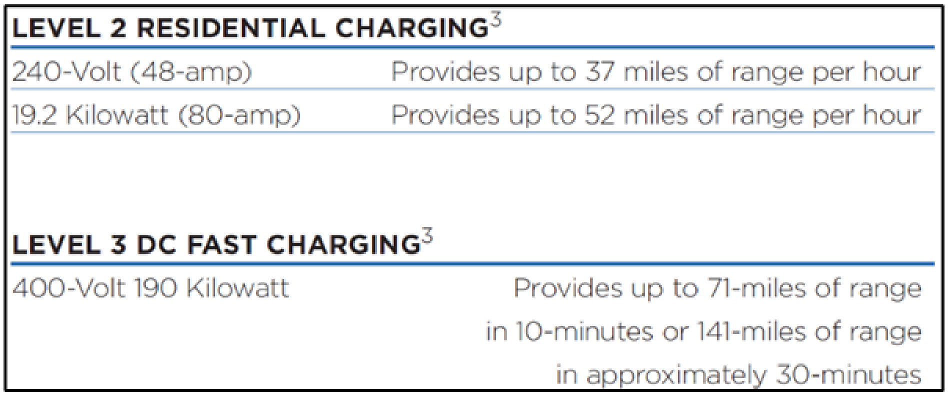
a. Range of the Durango

Before analyzing how the Blazer PPV would respond to this demand, I assess how the Durango currently manages it. As previously stated, a Durango PPV with a full tank of gasoline can travel 443 miles. Given a daily mission of 90 miles, a full tank can endure for 4.9 days (443-mile tank / 90 miles per day) or 118 hours. This requires six tanks of gasoline each month (2,691 / 443 miles). I also estimate that it takes 30 minutes to fuel a Durango. This includes filling the tank from empty to full and any transit time involved in getting to and from the fuel facility. Based on these parameters, each Durango spends approximately three hours per month refueling (0.5 hours * 6 refuels), leaving 717 hours to patrol. Therefore, on an average day, 90-miles of patrol can in fact be accomplished at a pace of 4 mph (717 hours / 30 days = 23.9 hours), (90 miles / 23.9 hours = 4 mph). Thus, from a status of fuel standpoint, the Durango is available to patrol 99% of the time (23.9/24 hours). Going forward, I use this metric as a benchmark and interpret any scenario that allows for 95% or more vehicle up-time to be *optimal*, anything greater than 90% to be *acceptable*, and anything less than 90% to be an *impediment* to the PMO’s mission.

b. Range of the Blazer

With respect to the alternative, the manufacturer’s specification guide states that the Blazer PPV has a range of 250 miles on a full battery (General Motors, 2023, p. 12). Table 11 provides an excerpt from the manufacturer’s guide, which outlines the efficiency of three different chargers relative to the Blazer’s battery power.

Table 11. Blazer PPV Charging Options. Source: General Motors (2023).



LEVEL 2 RESIDENTIAL CHARGING[3]

240-Volt (48-amp)	Provides up to 37 miles of range per hour
19.2 Kilowatt (80-amp)	Provides up to 52 miles of range per hour

LEVEL 3 DC FAST CHARGING[3]

400-Volt 190 Kilowatt	Provides up to 71-miles of range in 10-minutes or 141-miles of range in approximately 30-minutes

Given the charge times shown in Table 11, it would take about: 7 hours to fully charge a Blazer using a 240-Volt charger (250/37 miles), 5 hours using a 19.2-kw charger (250/52), and less than one hour using a Level 3 charger.

Given these parameters, I use Little's Law to determine the effect of chargers on vehicle up-time. For example, with a 240-Volt charger, the Blazer would need to charge once every 2.8 days (250-mile range / 90-mile patrols) or 11 times per month (30/2.8 days). Given the average service time for a 240-Volt charger is 7 hours, charging would consume a total of 77 hours per month. This means 21.4 hours per day are available for patrol ((720-77 hours) / 30 days) and approximately 2.6 hours of charging are needed each day.

Relative to the daily 90-mile mission, this allows for a pace of 4 mph (90 miles / 21.4 hours), but a patrol availability of 89% ((720-77) / 720 hours). Based on the benchmark established by the status quo, a 240-Volt charger falls just shy of the acceptable threshold. However, as shown in Figure 14, I continue to apply this formula to assess the Level 2 (19.2-kw) charger and Level 3 (190-kw) charger until I find the optimal type and quantity that meets the 90% threshold and the 4-mph pace of patrol. The minimum charging infrastructure I identified is depicted in the figure by a blue dotted line while the optimal mix entails additional Level 3 chargers and is shown as highlighted in yellow.

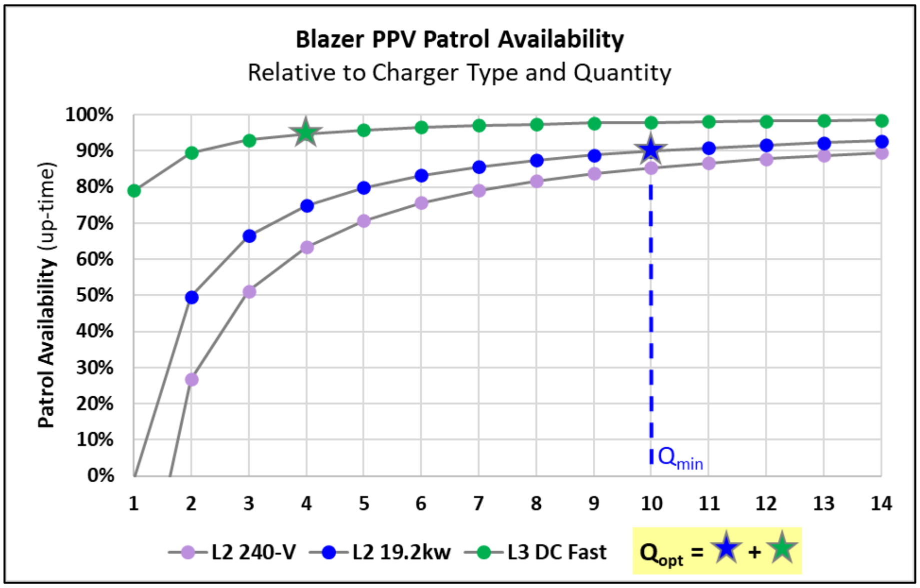


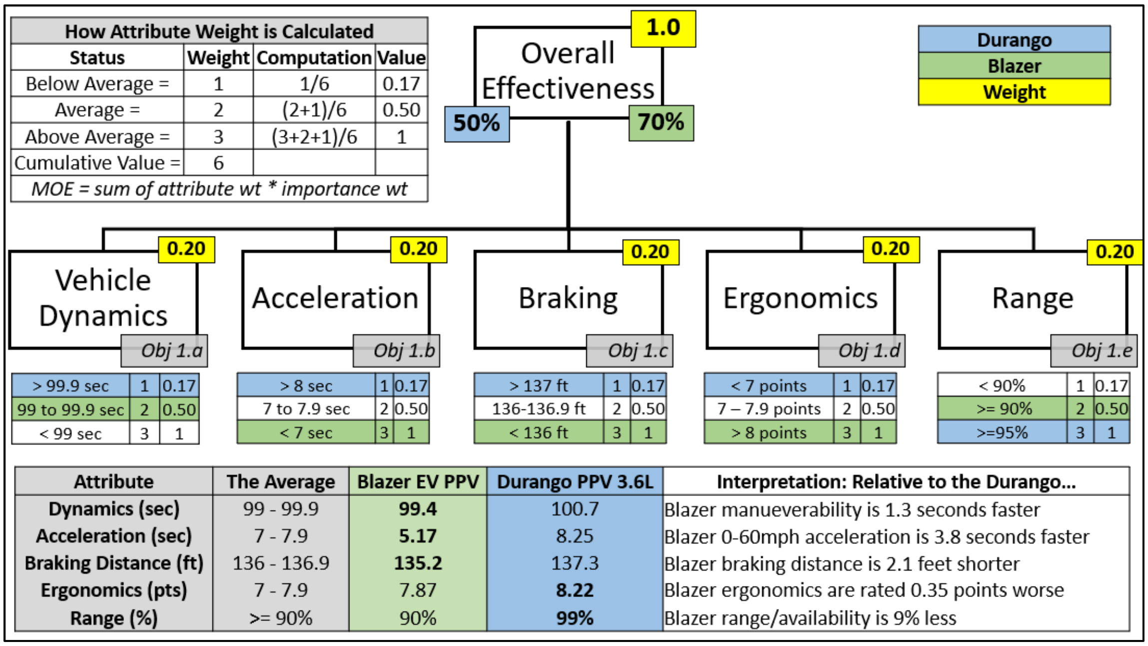
Figure 14. Patrol Vehicle Availability by Type and Quantity of Chargers

As shown in Figure 14, I assess that a patrol shift comprised of 14 Blazer PPVs can sustain 90% patrol availability if these vehicles have dedicated access to at least ten Level 2 (19.2kw) chargers. This type and quantity of charging infrastructure places the Blazer PPV in the average patrol availability range with respect to my pre-established measures of effectiveness. However, I assess that the addition of four Level 3 chargers would allow the Camp Pendleton PMO to have an up-time greater than 95% (above average). While ten Level 2 chargers may be adequate, it is important to consider the potential ramifications of having only the minimum required capability to support the organization's law enforcement mission. Given that the organization operates at all hours of the day and is devoted to installation security, it would be prudent to have an abundant and redundant means of keeping vehicles charged.

For example, a disruption to just one charger could have far-reaching implications on the PMO's ability to respond to emergencies. Additionally, while at least 14 vehicles are normally placed on patrol at any given time, there are a total of 22 vehicles that rotate in and out of the patrol fleet and will inevitably compete for charger availability. These additional vehicles could also be called upon to reinforce the standard patrol fleet during any number of contingencies including regularly scheduled special events that require an increased patrol presence or less-predictable events such as sudden elevations in the local threat level. Moreover, the addition of four Level 3 chargers would not only achieve a one-to-one ratio of vehicles to chargers for the standard 14-vehicle patrol shift but would also allow the organization to maintain the desired 4-mph pace of patrol for all 22 vehicles, if and when necessary.

C. SUMMARY OF COST-EFFECTIVENESS ANALYSIS

In Figure 15, I summarize each vehicle's overall measure of effectiveness and conclude that the ZEV is 40% (or 20 percentage points) more effective than the status quo. In effect, I find that the Chevrolet Blazer PPV is superior to the Dodge Durango PPV in three of the five evaluated areas of effectiveness including: vehicle dynamics, acceleration, and braking distance. Conversely, the Durango outperformed the Blazer in two of the five evaluated areas including: ergonomics and range. As such, the chart in the upper left corner of Figure 15 outlines the calculations I used to arrive at each vehicle's measure of effectiveness. The figure also provides a summary interpretation of vehicle performance.



How Attribute Weight is Calculated			
Status	Weight	Computation	Value
Below Average =	1	1/6	0.17
Average =	2	(2+1)/6	0.50
Above Average =	3	(3+2+1)/6	1
Cumulative Value =	6		
*MOE = sum of attribute wt * importance wt*			

Obj 1.a		
> 99.9 sec	1	0.17
99 to 99.9 sec	2	0.50
< 99 sec	3	1

Obj 1.b		
> 8 sec	1	0.17
7 to 7.9 sec	2	0.50
< 7 sec	3	1

Obj 1.c		
> 137 ft	1	0.17
136-136.9 ft	2	0.50
< 136 ft	3	1

Obj 1.d		
< 7 points	1	0.17
7 – 7.9 points	2	0.50
> 8 points	3	1

Obj 1.e		
< 90%	1	0.17
>= 90%	2	0.50
>=95%	3	1

Attribute	The Average	Blazer EV PPV	Durango PPV 3.6L	Interpretation: Relative to the Durango…
Dynamics (sec)	99 - 99.9	**99.4**	100.7	Blazer manueverability is 1.3 seconds faster
Acceleration (sec)	7 - 7.9	**5.17**	8.25	Blazer 0-60mph acceleration is 3.8 seconds faster
Braking Distance (ft)	136 - 136.9	**135.2**	137.3	Blazer braking distance is 2.1 feet shorter
Ergonomics (pts)	7 - 7.9	7.87	**8.22**	Blazer ergonomics are rated 0.35 points worse
Range (%)	>= 90%	90%	**99%**	Blazer range/availability is 9% less

Figure 15. Summary of Effectiveness Analysis

With the results of my effectiveness analysis complete in Figure 15, I return to my cost estimate as shown in Figure 7 for a final assessment of each fleet's cost-effectiveness. In essence, my analysis finds that transitioning from a fleet of 22 gasoline-powered Durango PPVs to a zero-emission fleet of 22 Blazer PPVs will cost at least $537,149 more than the status quo over the next seven years (14% increase in direct costs), but this will provide the Camp Pendleton PMO with a patrol vehicle that has a 70% effectiveness rating (a 40% increase relative to the status quo). Furthermore, if the optimal charging infrastructure is procured, the cost differential will increase from $537-thousand to nearly $1.2-million (27% increase in direct costs) and the Blazer's overall measure of effectiveness will increase from 70% to 80%. Figure 16 provides a more comprehensive view of the cost-effectiveness tradeoffs including the two potential options for ZEV charging infrastructure and the effect that the social cost of carbon has on each fleet's life cycle cost.

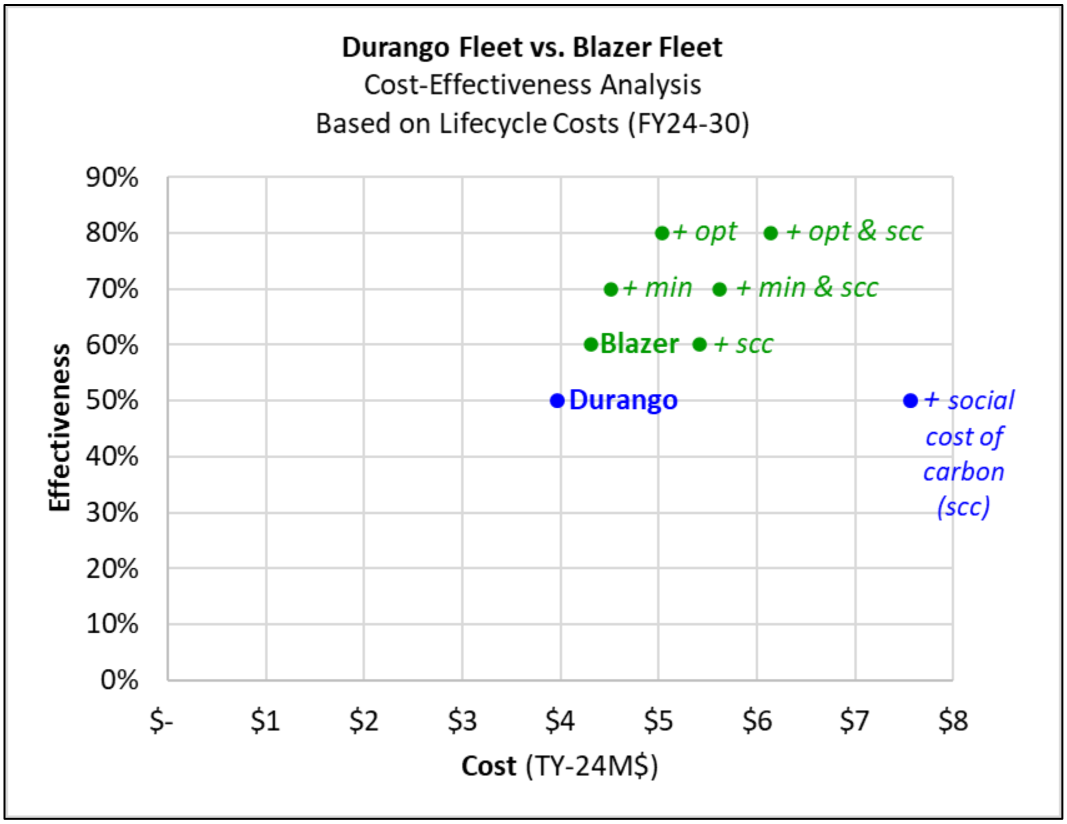


Figure 16. Summary of Cost-Effectiveness Analysis

Figure 16 depicts the cost-effectiveness relationship of each fleet scenario spanning FY-24 to FY-30, with and without the EPA's most recently assessed social cost of carbon ($190 per ton). The tradeoffs involved in each course of action are summarized as follows:

- To procure, operate, and maintain a fleet of 22 Durango PPVs costs about $4-million ($7.6-million after accounting for the social cost of carbon) in exchange for a vehicle that is 50% "effective." As given by Figure 15, this effectiveness rating provides the Camp Pendleton PMO with a vehicle that is suitable for patrol and superior to the Blazer in terms of ergonomics and range/availability due to the minimal time needed for the vehicle to refuel. However, this vehicle is otherwise not *as effective* as the Blazer PPV and it carries a higher social cost of carbon ($3.6-million over seven years).

- To procure, operate, and maintain a fleet of 22 Blazer PPVs would cost about $4.3-million ($5.4-million after accounting for the social cost of carbon) in exchange for a vehicle that is 60% effective. However, this effectiveness rating is skewed high because it reflects a scenario where the PMO only has the ZEVs and no organic charging equipment dedicated to sustaining them. In this scenario, the PMO would benefit from a vehicle that outperforms the Durango in dynamics, acceleration, and braking, but range/availability would be significantly impeded as the PMO would need to arrange and rely on an external means of support for re-charging.

- If the minimum necessary charging equipment were procured and placed in direct support of the PMO, it would raise the Blazer fleet's total cost to $4.5-million ($5.6-million after accounting for the social cost of carbon), and effectiveness would increase to 70%. This effectiveness rating entails the same superior level of dynamics, acceleration, and braking described earlier, but also boosts the vehicle's range/availability as the PMO would have its own charging capability. Specifically, this scenario equips the PMO with ten Level 2 chargers, which allows a typical shift (14 vehicles) to maintain 90% patrol availability. This is still less than the Durango's 99% availability, but it satisfies the PMO's current workload.

- If the optimal mix of charging equipment were installed, it would raise the Blazer fleet's total cost to $5-million ($6.1-million after accounting for the social cost of carbon), and increase effectiveness to 80%. In this scenario, dynamics, acceleration, and braking remain superior features and range/availability increases to 95% as the PMO's organic charging capability, would have greater speed and capacity relative to the minimum charging equipment. Specifically, this scenario adds four Level 3 chargers to the minimum mix of ten Level 2 chargers, which allows the 14 Blazers to be on patrol 95% of the time and allows 90% availability and the 4-mph pace of patrol to be maintained across the entire 22 vehicle fleet.

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VI. CONCLUSION

This chapter summarizes the key findings of my research and provides recommendations to the Marine Corps regarding the integration of ZEVs for military police patrol. I also highlight several related areas of importance that arose in the course of my studies, but fell outside the direct scope of my research questions. I raise these topics as recommendations to future researchers who may be better postured to explore these issues in greater depth. Furthermore, while my research is largely focused on the Camp Pendleton PMO, I believe it provides a conceptual framework that other civilian and military law enforcement entities can easily replicate to assess feasibility of their own transition to a zero-emission patrol fleet.

A. FINDINGS AND RECOMMENDATIONS

Subject to the assumptions I make in this thesis, I conclude that the Camp Pendleton PMO's transition to a zero-emission patrol fleet is feasible, but more costly than the gasoline-based status quo. Furthermore, I recommend my assessment be tested with a small quantity of Blazer PPVs before the Marine Corps commits to full-scale implementation.

1. Patrol Vehicle Effectiveness

From a vehicle performance standpoint, I determined that the Blazer PPV was superior to the Durango in three of five evaluated areas including: vehicle dynamics, acceleration, and braking. The Durango was superior to the Blazer in terms of ergonomics and range. Specifically, the Durango's ergonomics were rated about one-third of a point higher than the Blazer. Additionally, my analysis of each vehicle's range efficiency indicates that the Durango fleet is available for patrol 99% of the time compared to 90% of the time for 14 Blazers supported by ten Level 2 chargers. The Blazer's patrol availability could be boosted to 95% if an additional four Level 3 chargers were installed. In quantitative terms, this evaluation of vehicle performance resulted in the Durango attaining a 50% measure of effectiveness and the Blazer attaining 70% effectiveness with the minimum charging capability, or 80% if the additional Level 3 chargers were procured.

2. Patrol Vehicle Cost

My cost estimate finds that the Blazer's increase in effectiveness is accompanied by a greater monetary cost relative to the current gasoline-powered fleet. Specifically, leasing 22 Blazers PPVs for seven years and procuring the minimum necessary charging capability would cost approximately $4.5-million whereas leasing 22 Durangos over the same seven-year period would cost approximately $3.9-million. In other words, to lease 22 Blazers, which are each 40% more effective than the Durangos, would cost the Marine Corps 14% more money (+$537-thousand). If the additional Level 3 chargers were installed as recommended, the Blazer fleet's effectiveness would increase 10 percentage points and the seven-year cost would be 27% greater than the status quo (+$1.2-million). As my research describes, the largest cost drivers pertain to charging infrastructure development and the per-vehicle procurement costs. Aside from these initial investments however, operations and maintenance costs for the Blazer are expected to be less than the Durango. However, these savings are so negligible (3% over a seven-year lease term) that they are unlikely to offset the upfront investment in charging infrastructure and vehicles.

This cost differential is also exacerbated by the high degree of uncertainty that surrounds the future cost of ZEVs and the longevity of charging infrastructure. For example, my analysis only projects seven years into the future. However, in year 8 these ZEVs would be due for replacement at which time the Marine Corps may, depending on the nation's ZEV market performance, incur a new set of per-vehicle procurement costs (the future value of $472,472). In addition, charging infrastructure may, at some point in the future, require extensive maintenance or warrant costly improvements based on advancements in charging technology and general dilapidation. For example, research by Sowder (2023) states that "EV technology is relatively new, so the industry can only estimate the lifespan of chargers to be approximately 10 years." Based on this assessment, the ZEV course of action is likely to entail a long-term, periodic cost to replace or overhaul charging infrastructure, which my cost estimate does not take into account.

Furthermore, it is important to restate that a fundamental difference between the two vehicles is that the Blazer complies with the president's ZEV mandate while the Durango does not. As such, if one were to briefly set aside the difference in direct costs, the Blazer would be the logical choice considering it is both ZEV-compliant and offers better performance. That said, the Blazer's higher cost prompts the project's decision makers to decide whether the 40% increase in performance is *worth* the 14% or 27% increase in cost. However, as shown in Table 12, the cost estimate flips in favor of the ZEV fleet after including the Environmental Protection Agency's most recent assessment on the social cost or carbon ($190 per ton).

Table 12. Life cycle Cost Estimates with and without Social Cost of Carbon

FY-24 to FY-30 (TY$)	Direct Cost	Social Cost	Total
Durango Fleet	$ 3,972,835	$ 3,602,970	$ 7,575,805
Blazer Fleet + Min. Chargers	$ 4,509,984	$ 1,107,890	$ 5,617,874
Blazer Fleet + Opt. Chargers	$ 5,029,984	$ 1,107,890	$ 6,137,874

In essence, Table 12 shows that over a seven-year period, the Durango fleet would cause nearly $3.6-million in social costs as a result of its carbon footprint compared to $1.1-million for the ZEV fleet. Thus, the gasoline-powered fleet is slightly less expensive when the social cost of carbon is *excluded* from the estimate, but significantly more expensive when the social cost is *included* in the estimate.

Nonetheless, these cost-effectiveness metrics outline a key decision point for Marine Corps officials charged with the project's implementation. Such consideration is especially necessary as my analysis looks at the cost of the ZEV transition in isolation of competing budgetary requirements. For example, a 14% or 27% increase in direct costs may seem financially possible, but may not be fiscally responsible when reconciled in the context of the service's broader budgetary constraints and priorities. In the event, decision makers deem the cost difference untenable, this would be grounds to pursue other pathways such as reducing cost in exchange for less effectiveness, exploring alternative vehicles, or requesting a ZEV exemption pursuant to Section 602 of Executive Order 14057.

3. The Proposed Way Forward

Furthermore, to best determine the viability of the ZEV fleet, the PMO should commence a limited-scale implementation period. This goal can be accomplished by leasing a small quantity of Blazer PPVs (10% to 20% of the fleet). While not entirely necessary, I recommend these vehicles do not immediately replace their gasoline-powered equivalents and instead serve as temporary additions to the existing fleet. This way, the PMO can retain access to a tried and tested vehicle as it learns to integrate the new one. A gradual approach should be taken to minimize the friction inherent when implementing any new system. For example, implementation can entail the small quantity of Blazers following-in-trace of a gasoline-powered patrol unit for a set period of time. This step will posture the Blazers to mimic the existing fleet while operators adapt to how the vehicle withstands the typical workload. As institutional knowledge matures, the Blazers can take on a more permanent role and the gasoline-powered vehicles can be phased out. Should the trial period deem the Blazer unsuitable, the Marine Corps should have recourse to reassign these vehicles either to a smaller PMO or other federal law enforcement agency whose patrol demand is significantly less than Camp Pendleton's.

During this trial period, the PMO should make use of Camp Pendleton's existing charging infrastructure while ZEV patrol operations are being closely monitored. This shared charging arrangement should not serve as the long-term solution, but doing so temporarily will allow for hands-on ZEV application to inform supporting infrastructure requirements. The PMO can use my charging infrastructure assessment as a baseline in need of validation while it obtains a specialized site assessment to determine the full extent and cost of its supporting infrastructure needs. In doing so, the distribution of chargers should be carefully considered. For example, it may be prudent to centralize all charging to the PMO headquarters, but consideration should be given to strategically dispersing charging points throughout the installation so patrol units can remain in or near their assigned zones and not be overly constrained by having only one location to re-charge. In effect, the PMO should start small, but start soon, and make use of a trial period to validate feasibility and inform the organization's logistical support requirements.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

The following topics were notable issues that I identified in the course of my studies, but I did not address in depth due to the fact they lay outside the direct scope of my research. However, future researchers should explore these topics so that the Marine Corps' transition to ZEVs can be more efficient and effective.

1. Supply Chain Vulnerabilities due to China Dominated EV Market

According to the International Energy Agency (2022), "China produces three-quarters of all lithium-ion batteries and is home to 70% of production capacity for cathodes and 85% for anodes (both are key components of batteries)" (p.6). The same report holds that, "the U.S. has an even smaller role in the global EV battery supply chain, with only 10% of EV production and 7% of battery production capacity" (p. 7). Given this disparity and the competitive relations between the U.S. and China, it is important to assess the extent to which the government's transition to ZEVs bolsters the nation's energy security and the extent to which it makes the U.S. more vulnerable to a dependence upon China.

2. Humanitarian Concerns for EV Production

According to a report by the Rocky Mountain Institute, "the upstream portion of the EV battery supply chain (mining) is linked to human rights abuses, such as the use of child and forced labor. Many mines lack basic worker safety measures — endangering workers' lives — and extraction often comes with an environmental cost" (Carreon, 2023, sec. "Addressing human rights and environmental abuses"). Moreover, the Department of Labor (2022) published a report asserting that "Chinese companies use cobalt tainted with child labor to manufacture battery components," which are used to produce much of the world's EVs among other electronic technologies (p. 50). In the foreword of this report, the Secretary of Labor states, "eliminating egregious labor abuse requires all of us—governments, businesses, unions, workers, and civil society—to play our part" (p. III) To that end, research should further assess whether sufficient safeguards are in place to ensure the federal government does not consume or inadvertently enable the consumption of EV products manufactured under inhumane or unethical labor conditions.

3. Recuperability of ZEVs after a Collision or Mechanical Failure

According to a report by Greenfield (2023), EV "repairs following a collision can cost thousands of dollars more than their gas-powered counterparts, because the fixes tend to require more replacement parts, the vehicles are more complicated and fewer skilled technicians exist to do such repairs" (para. 1). Additionally, a report by Krumlauf (2023), found that "in 2022, EVs required two full weeks of additional cycle time and nearly eight more days between the last estimate being sent and the vehicle going into the shop to begin repairs. And, once the EV was in the shop, it required an average of 5.8 more days to complete the repairs" (para. 3). Considering the extraordinary demand placed on patrol vehicles, how reliable and responsive is the Marine Corps' *beyond routine* maintenance cycle for ZEVs that experience a collision or otherwise require a major repair?

4. Resilience of ZEV Support Infrastructure

In a study authored by Sayed et al. (2021), the authors argued that the "rapid deployment [of EVs] has contributed to the EV ecosystem's lack of proper security measures, raising multiple questions related to the power grid security and vulnerability" (p. 1). Additionally, the Department of Energy sanctioned a study by Sandia National Laboratories, in which Johnson et. al. (2022) stated "there is currently no comprehensive EVSE [electric vehicle supply equipment] cybersecurity approach and limited best practices have been adopted by the EV/EVSE industry" (p. 3). As the Marine Corps and other government agencies move towards ZEV adoption, greater attention must be given to the potential security vulnerabilities and ramifications that may correspond. Thus, future research should examine the extent to which the increased reliance on electricity for transportation impacts the organization's energy resilience in light of nefarious actors that may seek to target the nation's electrical infrastructure.

5. Alternative Types of Vehicles for Military Installation Security

Finally, emerging technology has given way to a host of new types of vehicles that have not been sufficiently considered for military police use. For example, Roque (2023) reported on the Electric Military Concept Vehicle built by General Motors and featured at the 2023 Modern Day Marine convention. Roque explains that the General Motors vehicle “has a 300-mile driving range,” can charge for a “100-mile drive in 12 minutes,” has a “brake system more apt for off-road maneuver,” and can tote a “46-inch gun ring and swing side side-arm mount” (para. 4). Similarly, Hutchinson (2019) reported that “The Army has been exploring smart technology, including using autonomous vehicles to patrol bases.” While systems like these are often considered for expeditionary operations, the Marine Corps should also consider the integration of certain tactical and autonomous vehicles for the installation security mission. In light of such technological advancements and the expanding threats that military bases must confront, perhaps it is time to completely rethink the conventional “pursuit-rated” police fleet that PMO’s have grown accustomed to.

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