



Addressing Ballistic Glass Delamination in the Marine Corps Tactical Vehicle Fleet

Implications for Resourcing and Readiness

Ellen M. Pint, Joslyn Fleming, Gene Germanovich, Luke Muggy



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Preface

Over the course of operations in Afghanistan and Iraq, the U.S. Marine Corps identified a need for ballistic glass to be installed on the windshields and side-door windows of forward-deployed tactical vehicles to protect against bullets and other projectiles fired by insurgents. This requirement was satisfied with an Urgent Universal Need Statement and subsequent fielding to most up-armored vehicles. Although the glass proved reliable from a ballistics perspective, delamination—a physical process whereby material splits apart into layers—impaired driver visibility due to spots, bubbles, and discoloration. In recent years, this type of degradation to ballistic glass has been occurring at a rapid pace, affecting equipment readiness and resulting in an unplanned cost burden on operational forces and depots.

In this report, the authors estimate the effects of delaminated ballistic glass on future sustainment costs and availability of Marine Corps tactical vehicles under various repair and replacement scenarios using a simulation model. Based on the model's results, the authors identify steps the Marine Corps can take to mitigate risks associated with ballistic glass delamination.

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Summary

Over the course of operations in Afghanistan and Iraq, the U.S. Marine Corps identified a need for ballistic glass to be installed on the windshields and side-door windows of forward-deployed tactical vehicles to protect against bullets and other projectiles fired by insurgents. This requirement was satisfied with an Urgent Universal Need Statement, a U.S. Department of Defense process for rapidly fielding capabilities to counter an immediate operational threat. Although the glass proved reliable from a ballistics perspective, delamination—a physical process whereby layers of protective material split apart due to the intrusion of moisture and dirt—impaired driver visibility with spots, bubbles, and discoloration.

Ballistic glass delamination occurs throughout the Marine Corps' fleet of armored tactical vehicles and affects equipment availability, reducing the effectiveness and operational readiness of these vehicles. As a result of the rapid introduction of ballistic glass in the mid- to late-2000s and subsequent delamination, operational forces and depots continue to incur an unplanned cost burden. Potentially more problematic, some units opt to continue operating vehicles with delaminated windshields or store them for emergencies to save money or focus maintenance resources on other priorities. There are currently no deadlining criteria in Marine Corps maintenance manuals requiring units to report that windshields have experienced delamination. Therefore, Marine Corps program managers and senior leaders remain unaware of the extent of the problem across the fleet and thus cannot accurately budget for sustainment.

As part of this research, we collected data on the extent of delamination in a sample of tactical vehicles assigned to Marine Expeditionary Forces (MEFs) and constructed a simulation model to estimate the effects of delamination on future sustainment costs and availability of Marine Corps tactical vehicles under various repair and replacement scenarios. Based on the model's results, we identified steps the Marine Corps can take to mitigate the risks associated with ballistic glass delamination.

Ballistic Glass Delamination

In a rush to manufacture as many windshields as possible in support of the war effort, contracts prioritized speed of manufacture and ballistic protection. The product specifications for ballistic glass included some environmental testing, such as exposure to high and low temperatures, humidity, and solar radiation, but not a service life requirement. While the glass met ballistic requirements, and environmental testing requirements increased over time, the current vehicle fleet is still experiencing significant delamination in its ballistic windshields. Although the exact chemical-mechanical cause of delamination remains under investigation, scientists suspect that a combination of incompatible materials, improper assembly techniques, and exposure to heat and moisture after production are among the contributing factors.¹ Figure S.1 shows an example of ballistic glass delamination on the windshield of a High Mobility Multipurpose Wheeled Vehicle (HMMWV). The delaminated area is the cloudy portion.

After initial procurements were completed, supply management of ballistic glass was transferred to the Defense Logistics Agency (DLA), which purchases and stocks these items based on specifications provided by customers in the Marine Corps and other services. Marine Corps customers purchase ballistic glass windshields and side-

¹ U.S. Department of the Army, *Transparent Armor Delamination*, Warren, Mich.: U.S. Army Research, Development, and Engineering Command, Tank Automotive Research, Development and Engineering Center, August 8, 2016, p. 2.

Figure S.1
Example of a Delaminated Windshield



SOURCE: Photo by Robert Hayden. Used with permission.

RAND RR2285-S.1

door windows from DLA to replace delaminated glass, typically while a vehicle is in a depot for unrelated scheduled maintenance or undergoing field-level maintenance. The Marine Corps intends for future contracts to include more-stringent requirements for resistance to delamination, which is the topic of several ongoing studies.² In the meantime, program managers and senior leaders are seeking to understand the extent of the problem, ramifications for sustainment costs and risks, and mitigation options.

Research Approach

This study's research objectives were to measure the effects of ballistic glass delamination in Marine Corps vehicles on operational risks and budgets, forecast future costs for replacement and sustainment, and identify steps the Marine Corps can take to mitigate the risks associ-

² Interview with managers at Marine Corps Program Executive Office Land Systems (PEO LS), January 18, 2017.

ated with ballistic glass delamination.³ RAND researchers undertook four tasks to achieve these objectives:

1. determine the population of vehicles potentially affected by delamination of ballistic glass
2. determine the number and types of vehicles that meet PEO LS delamination criteria⁴
3. develop a model to forecast replacement and sustainment costs and vehicle availability
4. identify potential mitigation steps.

Data Collection

To estimate the population of vehicles affected by delamination of ballistic glass and transparency problems, the research team examined historical trends on replacements of ballistic glass using supply and maintenance databases and collected data from a sample of more than 1,000 vehicles located at three Marine Corps installations. Researchers examined vehicles from 43 units to ensure that the sample included a mix of air, ground, logistics, and MEF headquarters equipment. The data collection focused on the vehicle windshields to determine if the driver's and codriver's vision would be blocked or impaired due to delamination, posing a safety risk. For a subset of these vehicles, we also collected information on the serial numbers and manufacture dates of the windshields to assess the speed of delamination.

The principal limitation of the data collection approach is that the sample focused on the vehicles located in the unit motor pools at the

³ This study uses the term *ballistic glass*; some organizations and studies use the term *transparent armor*. The most common term for glass without ballistic protection is *automotive glass*.

⁴ According to PEO LS guidelines, if there is any delamination present in the wiped area of the windshield (i.e., the area the windshield wiper traverses), the windshield is considered delaminated and should be replaced. Currently, delamination guidelines have not yet been developed for side or rear windows. PEO LS, *Not Mission Capable (NMC) Criteria for Transparent Armor on Light, Medium, MRAP and Heavy Tactical Vehicles: DRAFT—1E LEVEL OF RISK*, Quantico, Va., January 30, 2017.

time of collection. If vehicles were being used in support of missions (e.g., assigned to a deployed Marine Expeditionary Unit [MEU]) or training events, they were not inspected. It is possible that the vehicles in the best state (i.e., with little to no delamination) were not present at the time of inspection, which may have resulted in a higher rate of delamination being observed. Also, since the focus of this study was on the windshields, data on side windows were not collected.

Modeling Scenarios

After the data collection phase, researchers developed a simulation model to compare four scenarios representing the status quo and three mitigation options over a ten-year period.

- **Scenario 1: Status Quo** modeled the current state of operations in the Marine Corps. In this scenario, we assumed that units and depots replaced windshields at the average pace over the last five years.
- **Scenario 2: Replace Immediately** modeled the effects of replacing delaminated windshields as soon as significant delamination is observed.
- **Scenario 3: Repair** modeled the effects of establishing a repair facility to relaminate the ballistic glass rather than replace it. This scenario is based on the use of emerging technology that is being developed under a Marine Corps contract.
- **Scenario 4: Automotive Glass** modeled the option of replacing some delaminated ballistic glass with automotive glass in garrison, while continuing to use ballistic glass in prepositioned stocks and other vehicles deployed with MEUs.

Key modeling assumptions included the rate at which the windshields delaminated after being replaced and the size of the repair facility. Based on interviews with subject-matter experts, our baseline assumption was that windshields showed full delamination (as defined by PEO LS criteria) in an average of four years. We conducted sensitivity analysis on varying the delamination timeline from three years up

to six years.⁵ We also examined variations in repair costs and in the size of repair facilities to ensure that they would meet steady-state demands to replace delaminated windshields.

After analyzing the four original scenarios, we considered two additional scenarios recommended by the sponsor and study advisory committee. The first, Scenario 5, is a hybrid of Scenarios 2 and 3 and models establishing a repair facility with a capacity of 5,000 windshields per year that would focus on *repairing* higher-cost windshields (for Logistics Vehicle System Replacements [LVSRs], Medium Tactical Vehicle Replacements [MTVRs], and Mine-Resistant Ambush Protected vehicles) and *replacing* lower-cost HMMWV windshields until the repair technology can be evaluated for further expansion.⁶ Scenario 6 incorporates a projected fielding schedule for Joint Light Tactical Vehicles (JLTVs), which are planned to replace a portion of the armored HMMWV fleet during the ten-year horizon of the model.

Model Results

Table S.1 compares the modeling results for the original four scenarios and the two additional scenarios, including the number of windshields replaced, sustainment costs over the ten-year modeling horizon, and vehicle availability at the end of year ten.

Scenario 1 represents the status quo and assumes that the Marine Corps continues to operate at current replacement rates. Under this assumption, the availability of vehicles for training and deployment continues to fall because further delamination outpaces windshield replacement rates. Replacing all windshields with delamination in the wiped area would cost approximately \$272 million over ten years, but

⁵ For the purpose of this study, the average rate of delamination is estimated at four years. Environmental testing requirements for ballistic glass have been increasing over time, but we did not have sufficient data on manufacture dates to detect an increase in the life span of the glass. Therefore, if new technology increases the life span of ballistic glass beyond six years, the results of this study should be revisited.

⁶ Repairing the most-expensive windshields increases the cost savings at a given fixed cost and throughput for the repair facility.

Table S.1
Comparison of Costs and Vehicle Availability

Scenario	Number of Windshields Replaced over Ten Years	Ten-Year Costs (\$ millions)	Vehicle Availability in Year Ten ^a
1. Status Quo	30,800	\$79.0	3,522 (22%)
2. Replace Immediately	81,000	\$272.1	15,820 (100%)
3. Repair 1,000 per year	Insufficient capacity, must decide how to allocate		
3a. Repair 3,000 per year	30,000	\$50.8 ^b	6,653 (42%)
3b. Repair 5,000 per year	50,000	\$82.8 ^b	8,973 (57%)
3c. Repair 8,000 per year	72,900	\$122.1 ^b	14,563 (92%)
4. Automotive Glass	50,600	\$113.2	5,453 (34%)
Ballistic portion	26,900	\$108.6	5,453 (100%)
Automotive portion	23,700	\$4.6	10,367 (100%) ^c
5. Hybrid	80,800	\$153.7 ^b	15,820 (100%)
6a. JLTV (replace immediately)	73,900	\$294.4	15,820 (100%)
6b. JLTV (repair 5,000 per year)	50,000	\$93.6 ^b	8,173 (52%)
6c. JLTV (repair 8,000 per year)	69,400	\$139.5 ^b	13,976 (88%)

NOTE: Costs are in fiscal year (FY) 2017 dollars. There is an approximate total of 16,000 tactical vehicles in the model, with a total of 32,000 left and right windshield panels.

^a Number of vehicles that do not have significant delamination in either windshield, based on PEO LS criteria. Percentage is determined by dividing the number of vehicles by the current vehicle inventory.

^b Excludes fixed costs of repair facility, estimated at \$7.8 million for 5,000 windshields per year.

^c Vehicles are available for training, but not for deployment if ballistic glass is required.

would fix the vehicle availability issues. However, DLA does not have sufficient inventory to meet a potential short-term surge of windshield replacements in the first year of Scenario 2, so the Marine Corps may need to ramp up replacements over time. The proposed repair technology is still in development, but if it can be operated reliably, it would

be less costly than replacement. For example, a new LVSR windshield panel costs about \$7,200, but, based on current estimates, the windshield could be repaired at a cost of \$3,600. The repair facility would also need to have enough capacity to meet steady-state demands. Using automotive glass improves vehicle availability for training but could be problematic if a large-scale contingency occurs.⁷ However, the Marine Corps prioritizes having vehicles at a high state of readiness to be able to deploy, making this scenario counter to its culture.

Scenario 5 appears promising because it would allow for time to test the repair technology while reducing reliance on DLA to acquire inventories of ballistic glass. Scenario 6 reduces windshield replacements and costs initially, but as the JLTV windshields begin to delaminate, costs increase because the JLTV windshields are more expensive than HMMWV windshields.

Findings and Recommendations

The Marine Corps has approximately 16,000 tactical vehicles that currently require ballistic glass. Based on our field data collection, a significant proportion of these vehicles have delamination in the wiped areas of their windshields, particularly the HMMWV and MTRV fleets. An analysis of a limited sample of windshield manufacture dates indicates that half or more windshields manufactured in 2012 or earlier are delaminated, which is roughly consistent with an average time to delamination of four years. However, it may be possible to refine this estimate using maintenance data on the vehicle serial numbers in the data collection sample.

The benefits and risks of the three most-promising mitigation options that achieve high rates of vehicle availability are summarized in Table S.2. Senior leaders should weigh these benefits and risks when choosing the best course of action.

⁷ The model assumes that automotive glass does not delaminate and does not need to be replaced after it is initially installed. It could be susceptible to rock strikes and other types of damage but is relatively inexpensive to replace. For example, an LVSR automotive glass windshield panel costs approximately \$100.

Table S.2
Benefits and Risks of Replace, Repair, and Hybrid Scenarios

Scenario	Benefits and Risks
2. Replace Immediately	• Benefits: high vehicle availability, assuming sufficient ballistic glass is in stock • Risks: highest-cost option; could take time for DLA to acquire increased inventories
3. Repair	• Benefits: lower-cost approach to achieve high vehicle availability • Risks: technology is in development; may be difficult to scale up or may delaminate faster than newly manufactured glass
5. Hybrid	• Benefits: allows time to test repair technology while improving vehicle availability; less reliance on DLA to acquire inventories • Risks: higher costs than Scenario 3 if repair technology is effective

Additional Mitigation Steps

The Marine Corps should continue to develop and implement improved specifications and environmental testing requirements for newly manufactured glass to improve its life span. The Army also has large, armored tactical vehicle fleets and should support continued research into better manufacturing technology. A significant improvement in the life span of ballistic glass (in the range of eight to ten years) could reduce future costs after the initial backlog of delaminated glass is replaced. Some marginal improvement in the life span of ballistic glass might also be possible if operators and maintainers covered windshields when vehicles are not in use to reduce sun exposure.

Second, the Marine Corps should consider how much of the tactical vehicle fleet—particularly HMMWVs, LVSRs, and MTRVs—should be armored for future operations. Does the need for armored tactical vehicles for operations in Iraq and Afghanistan reflect a permanent change, or will fewer of these vehicles be needed in the future?

Third, the Marine Corps should adopt maintenance procedures that specify deadlining criteria for ballistic glass delamination and ensure the reporting and collection of relevant data to inform future resource allocation decisions. Additional data collection could better inform the average time to delamination. The Marine Corps could use Global Combat Support System–Marine Corps maintenance data to

determine when ballistic glass was last installed for the vehicle serial numbers included in this study. The Marine Corps could also use the same data collection approach to inspect additional vehicles, or conduct follow-up analysis on the vehicles included in this study. Data collection and modeling could also be extended to side-door windows, gunners' turrets, and engineering equipment. These steps would improve forecasts of future ballistic glass sustainment costs and vehicle availability.

Acknowledgments

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Abbreviations

ATPD	Armor Transparent Purchase Description
DLA	Defense Logistics Agency
FY	fiscal year
GCSS-MC	Global Combat Support System–Marine Corps
HMMWV	High Mobility Multipurpose Wheeled Vehicle
JLTV	Joint Light Tactical Vehicle
LVSF	Logistics Vehicle System Replacement
MAK	Marine Armor Kit
MAP-K	Marine Expeditionary Unit Augmentation Program–Kuwait
M-ATV	Mine-Resistant Ambush Protected All-Terrain Vehicle
MCPN	Marine Corps Prepositioning Program–Norway
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MPS	Maritime Prepositioning Squadron
MRAP	Mine-Resistant Ambush Protected
MTVR	Medium Tactical Vehicle Replacement

NIIN	National Item Identification Number
OAD	Operations Analysis Directorate
PEO LS	Program Executive Office Land Systems
RTAA	Ready to Accept Armor
SME	subject-matter expert
TAM	Table of Authorized Material
TAMCN	Table of Authorized Material Control Number
TLCM-OST	Total Life Cycle Management Operational Support Tool
UUNS	Urgent Universal Need Statement

Introduction

Over the course of operations in Afghanistan and Iraq, the U.S. Marine Corps identified a need for ballistic glass to be installed on the windshields and side-door windows of forward-deployed tactical vehicles to protect against bullets and other projectiles fired by insurgents. This requirement was satisfied with an Urgent Universal Need Statement (UUNS), a U.S. Department of Defense process for rapidly fielding capabilities to counter an immediate operational threat. Although the glass proved reliable from a ballistics perspective, delamination—a physical process whereby the layers of protective material split apart due to the intrusion of moisture and dirt—impaired driver visibility with cloudiness, bubbles, spots, whiteness, discoloration, and visual distortion.

Ballistic glass delamination is occurring throughout the Marine Corps' fleet of armored tactical vehicles, affecting equipment availability and reducing the effectiveness and operational readiness of these vehicles. Maintenance systems, interviews with drivers and maintainers, and an examination of a sample of vehicles as part of this study indicate that delamination most commonly occurs four to five years after a windshield's manufacture date, and in some cases as quickly as one year after manufacture. As a result of the rapid deployment of ballistic glass in the mid- to late-2000s and subsequent delamination, operational forces and depots continue to incur an unplanned cost burden. Potentially more problematic, some units opt to continue operating vehicles with delaminated windshields or store them for emergencies to save money or focus maintenance resources on other

priorities. Since there are currently no deadlining criteria in Marine Corps maintenance manuals requiring units to report that windshields have experienced delamination, Marine Corps program managers and senior leaders remain unaware of the extent of the problem across the fleet and thus cannot accurately budget for sustainment.

The Army experienced the same operational need, also relied on the UUNS approach, and now faces a similar delamination problem across its fleet of armored tactical vehicles.¹ For example, a 2016 Army document indicates that

[t]ransparent armor delamination has become a significant area of interest since many program offices are having transparent armor replaced during vehicle refurbishment. Reports of operational life vary significantly, and little or no field data, especially that is statistically significant, is available on [transparent armor's] lifespan.²

Why Delamination Occurs

The U.S. military used rapid acquisition processes to procure a range of equipment that proved critical in Afghanistan and Iraq, particularly for force protection against a highly adaptive adversary. Unlike most peacetime procurements, the speed at which equipment was fielded to the theater was paramount. In the case of ballistic glass, the Marine Corps relied on several companies to manufacture thousands of windshields in a matter of months. Contracts incentivized speed of delivery and ballistic protection—other considerations, such as service life

¹ This study examines the budgetary impact of ballistic glass delamination for the Marine Corps, but findings and recommendations may be applicable to the Army as well.

² U.S. Department of the Army, *Transparent Armor Delamination*, Warren, Mich.: U.S. Army Research, Development, and Engineering Command, Tank Automotive Research, Development and Engineering Center, August 8, 2016, p. 2. This study uses the term *ballistic glass*; some organizations and studies use the term *transparent armor*. The most common term for glass without ballistic protection is *automotive glass*.

or environmental testing for resistance to delamination, were either unstated or secondary.³

Ballistic glass typically consists of several layers of glass with polymer interlayers bonded to a polycarbonate liner that prevents glass shards and other debris from entering the crew area. Manufacturers use a type of coating to seal the peripheral edges of the ballistic glass, and in turn apply an adhesive substance to bond the glass to a steel frame that attaches to the vehicle. Caulk or gaskets are applied to seal any gaps between the frame and glass.⁴ An example of ballistic glass composition is shown in Figure 1.1. Although the exact chemical-mechanical cause of delamination (or separation between the layers of glass and polymers) remains under investigation, scientists suspect that the combination of inadequate peripheral sealing, the substances used for bonding and caulking, and exposure to heat and moisture after production are among the contributing factors.⁵ Figure 1.2 shows an example of delamination on the ballistic glass windshield of a High Mobility Multipurpose Wheeled Vehicle (HMMWV). The delaminated area appears cloudy in the photograph. Figure 1.3 shows the driver's view through a delaminated windshield. Based on our discussions with Marine Corps personnel, delamination may affect visibility differently at night than it does during the day because night vision goggles use near-infrared and thermal infrared to produce images.⁶

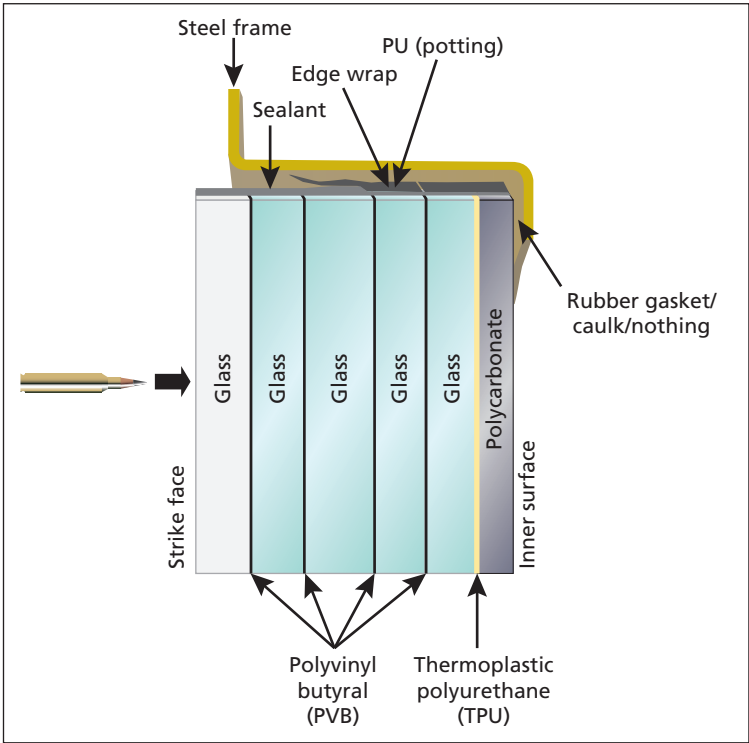
³ Interview with managers at Marine Corps Program Executive Office Land Systems (PEO LS), January 18, 2017.

⁴ Marriner H. Merrill, James P. Thomas, and William R. Pogue III, "Repair Methods for Delaminated Transparent Armor," Washington, D.C.: Naval Research Laboratory, NRL/MR/6350--14-9501, January 21, 2014, p. 2.

⁵ U.S. Department of the Army, 2016, p. 2; Timothy Talladay, "Root Cause Investigation of Delamination in Tactical Vehicle Transparent Armor: Interim Report," Warren, Mich.: U.S. Army Tank Automotive Research, Development, and Engineering Center, October 2014.

⁶ According to the product specification for ballistic glass, its optical properties are measured by integrated luminous (photopic) transmittance for daytime transparency, and by night vision goggles weighted spectral transmission for nighttime transparency. Delamination may affect these optical properties differently. See U.S. Army Tank Automotive Research, Development, and Engineering Center, "Purchase Description: Transparent Armor," Warren, Mich., ATPD-2352T, May 8, 2013.

Figure 1.1
Example of Ballistic Glass Composition



SOURCE: Adapted from Merrill, Thomas, and Pogue, 2014, p. 3.

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After the initial procurements of ballistic glass were completed, responsibility for supply management was transferred to the Defense Logistics Agency (DLA), which purchases and stocks ballistic glass based on specifications provided by the Marine Corps and other services. For example, the Marine Corps validated a need for ballistic glass as part of add-on armor kits for Medium Tactical Vehicle Replacements (MTVRs) in April 2004.⁷ In supply system data, we observe

⁷ U.S. Government Accountability Office, *Defense Logistics: Lack of a Synchronized Approach Between the Marine Corps and Army Affected the Timely Production and Installation of Marine Corps Truck Armor*, Washington, D.C., GAO-06-274, June 22, 2006. The report also pro-

Figure 1.2
Example of a Delaminated Windshield



SOURCE: Photo by Robert Hayden. Used with permission.

RAND RR2285-1.2

DLA beginning to issue ballistic glass for MTRVs in fiscal year (FY) 2011. Marine Corps customers purchase ballistic glass from DLA to replace delaminated windshields, typically while a vehicle is in a depot for unrelated scheduled maintenance or is undergoing field-level maintenance.

The Army first developed a specification for testing ballistic glass—Armor Transparent Purchase Description (ATPD) 2352—in 2008. The Army formerly used commercial specifications, but they were not sufficient to protect vehicles from ammunition heavier than handguns and small-caliber rifle rounds.⁸ The Army specifications, which have also been adopted by the Marine Corps, were further revised in April 2010 (ATPD-2352R) and May 2013 (ATPD-2352T).⁹

vides a description of the UUNS process. The Marine Corps later validated a requirement in October 2004 to install integrated armor on MTRVs by May 2006.

⁸ Anthony M. Dolan, “Ballistic Transparent Armor Testing Using a Multi-Hit Rifle Pattern,” thesis, Flint, Mich.: Kettering University, December 2007.

⁹ Environmental testing required by ATPD-2352T included exposure to low temperatures (–54°C for 24 hours), high temperatures (three cycles up to 63°C), humidity (five cycles from 30°C to 60°C at 95-percent humidity), thermal shock (five cycles from 30°C to 60°C with a transfer time of 5 minutes and a stabilization period of 18 hours at each extreme), solar radiation (1,120 W/m² for 56 24-hour cycles), abrasion on interior and exterior sur-

Figure 1.3
Interior View Through a Delaminated Windshield



SOURCE: Photo by Robert Hayden. Used with permission.

RAND RR2285-1.3

The Marine Corps intends for future product specifications to include more-stringent environmental testing requirements to reduce the speed of delamination, which is the topic of several ongoing studies. The Army is currently conducting its own studies to establish increased testing for resistance to delamination that will be included in an update to ATPD-2352T. Guidance will be communicated to manufacturers and updated within the specification, but currently no update

faces, and chemicals (e.g., nonabrasive soap, kerosene, alcohol, ammonium hydroxide, and cleaning solvent on the interior and diesel or jet fuel, gasoline, hydraulic fluid, antifreeze, liquid detergent, grease, and lubricant oil on the exterior). Following each test, the glass must have met requirements for maximum allowable defects (including delamination, bond separation, cracking, crazing, or clouding) and optical requirements (luminous transmittance, night vision goggles weighted transmittance, haze, optical deviation, and optical distortion). See U.S. Army Tank Automotive Research, Development, and Engineering Center, May 8, 2013.

has been agreed upon. DLA has expressed the desire for any forthcoming specification to apply to both the Marine Corps and the Army.¹⁰ In the meantime, program managers and senior leaders are seeking to understand the extent of the problem and its fiscal ramifications.

Research Objectives and Tasks

This study's research objectives were to measure the effects of ballistic glass delamination in Marine Corps vehicles on operational risks and budgets; forecast future costs for replacement and sustainment; and identify steps the Marine Corps can take to mitigate the risks associated with ballistic glass delamination. RAND researchers undertook four tasks to achieve these objectives:

1. determine the population of vehicles potentially affected by delamination of ballistic glass
2. determine the number and types of vehicles that meet PEO LS delamination criteria¹¹
3. develop a model to forecast replacement and sustainment costs and vehicle availability
4. identify potential mitigation steps.

The research team reviewed prior studies of ballistic glass delamination and other related documents and conducted interviews with several subject-matter experts in PEO LS, Marine Corps Installations and Logistics, and Marine Corps Logistics Command to obtain background information about the problem.¹² To determine the popula-

¹⁰ Interview with managers at PEO LS, January 18, 2017.

¹¹ According to PEO LS guidelines, if there is any delamination present in the wiped area of the windshield (i.e., the area the windshield wiper traverses), the windshield is considered delaminated and should be replaced. Currently, delamination guidelines have not yet been developed for side or rear windows. PEO LS, *Not Mission Capable (NMC) Criteria for Transparent Armor on Light, Medium, MRAP and Heavy Tactical Vehicles: DRAFT—1E LEVEL OF RISK*, Quantico, Va., January 30, 2017.

¹² A copy of our interview protocol is provided in Appendix A.

tion of vehicles potentially affected by delamination of ballistic glass, the research team examined Marine Corps logistics databases to identify the number of armored tactical vehicles assigned to each Marine Expeditionary Force (MEF), as well as to other units and locations. We also examined historical trends in the replacement of ballistic glass using supply and maintenance databases. However, these data did not provide an accurate picture of current fleet status and future demands because ballistic glass may be replaced due to cracks and other damage, or units may choose not to replace delaminated glass due to cost and the lack of deadlining criteria. Therefore, we examined the windshields of a sample of more than 1,000 vehicles (out of a total population of approximately 16,000 armored tactical vehicles) located at three Marine Corps installations and recorded data on the extent of delamination. We used these data to establish the initial condition of the tactical vehicle fleets in a simulation model to estimate sustainment costs and vehicle availability over a ten-year period, from FY 2018 through FY 2028. The simulation model was originally designed to assess four scenarios, including the status quo and three potential mitigation options. The mitigation options included replacing windshields as soon as significant delamination was found, establishing facilities to repair delaminated glass, and replacing some delaminated glass with automotive glass. After the initial results were obtained, we analyzed two additional scenarios. The first additional scenario involved replacing the less-expensive HMMWV windshields and focusing the repair facilities on the more-expensive windshields of the other tactical vehicles. The second additional scenario incorporated an estimated fielding schedule for the Joint Light Tactical Vehicle (JLTV), which is planned to replace some armored HMMWVs.

Organization of This Report

The remainder of this report presents the results of our research. Chapter Two provides information on the size of the tactical vehicle fleet with ballistic glass installed and the historical replacement rates and costs of ballistic glass. Chapter Three quantifies the impact of delamination

on the Marine Corps tactical vehicle fleet based on data collected for this study. Chapter Four details the modeling approach, while Chapter Five presents the results from the six scenarios examined, as well as sensitivity analyses on the speed of delamination, the relative costs of repairing and replacing windshields, and the size of the repair facility needed. Chapter Six concludes with findings, mitigation steps, recommendations, and broader implications for future rapid acquisitions. Appendix A provides the interview protocol for subject-matter experts. Appendix B describes the data collection methodology in more depth, and Appendix C provides the results of the simulation model for each of the six scenarios considered.

Historical Trends in Ballistic Glass Replacement

In this chapter, we describe the population of vehicles examined for ballistic glass delamination and review historical trends in ballistic glass requisitions, costs, and supply availability.

Population of Armored Tactical Vehicles

The Table of Authorized Material (TAM) provides guidance on supply classes and contains all equipment authorized for use by the Marine Corps. The TAM groups commodities into five categories, lettered from “A” to “E.” This study focused on ballistic windshields installed on motor transport vehicles, designated as “D” TAM commodities.¹ The D TAM commodities are further divided into nonarmored, armor-accepting, and armored categories. *Nonarmored* vehicles offer the least amount of protection and cannot be outfitted with armor kits. *Armor-accepting* vehicles may be outfitted with armor. For example, the HMMWV comes in a Marine Armor Kit (MAK) configuration and the MTVR comes in a Ready-to-Accept-Armor (RTAA) status. *Armored* vehicles, as implied by the label, are outfitted with armor.

This study examined armored vehicles in the D TAM category. Nonarmored vehicles have automotive glass, and the armor-accepting

¹ As part of this study, we also gathered some information on armored engineering equipment in B TAMs, but we found very few engineering vehicles (or, in some cases, detachable armored cabs) on our installation visits, and so could not assess the extent of delamination in a representative sample. Therefore, we excluded the B TAMs from our model.

vehicles are being phased out of the Marine Corps inventory. Therefore, only armored vehicles were included in this study. A list of all vehicles included in the analysis is provided in Table 2.1. In addition to HMMWVs and MTRVs, the Mine-Resistant Ambush Protected (MRAP) vehicle (Cougar), the MRAP All-Terrain Vehicle (M-ATV), and the Logistics Vehicle System Replacement (LVSR) are included in this study.

High Mobility Multipurpose Wheeled Vehicle

The HMMWV is the service's most employed light tactical vehicle. The four-wheel drive HMMWV comes in variants for command and control, limited troop transport, light cargo transport, and towed weapons primary movement and is used as a weapons platform. The armored HMMWVs are installed with an integrated armor package commonly referred to as the *underbody*. Additional armor and fragmentation kits are field-installable and removable to provide flexibility for missions that do not require heavy protection.²

Logistics Vehicle System Replacement

The LVSR is the Marine Corps' heavy fleet vehicle, a ten-by-ten truck tasked with the transportation of bulk liquids, ammunition, standardized containers, break bulk cargo, palletized cargo, and bridging equipment. Variants include a cargo truck, wrecker, and tractor. Armor packages for the LVSR may be factory-installed ("A" kits) or outfitted by field maintenance activities ("B" kits).

Cougar Mine-Resistant Ambush Protected Vehicle

The MRAP Cougar family of vehicles performs a variety of tasks, including route clearance, explosive ordnance detection, and movement of troops. The MRAP's armor package offers protection against mines, improvised explosive devices, rocket-propelled grenades, explosively formed projectiles, and small arms fire.

² Except where otherwise noted, vehicle descriptions are based on Headquarters, United States Marine Corps, *Principal Technical Characteristics of U.S. Marine Corps Motor Transportation Equipment*, TM 11240-ODA, Washington, D.C., March 2010.

Table 2.1
Marine Corps Armored Vehicles in the D TAM Category

Nomenclature	Variant	Vehicle Type	TAMCN	Number of Vehicles
Truck, Utility: Expanded Capacity Armament Carrier	M1114	HMMWV	D0030	3,774
Truck, Utility, ECV, TOW Carrier, Armored	M1167A1	HMMWV	D0032	445
Truck, Utility: Expanded Capacity, Enhanced, Fully Armored (2-door)	M1152A1	HMMWV	D0033	1,419
Truck, Utility: Expanded Capacity, Command and Control/GP, Fully Armored (4-door)	M1165A1	HMMWV	D0034	1,636
Truck, Ambulance, 4-Litter, Armored, 2 1/4 ton	M997A2	HMMWV	D1001	488
LVSR, Armored Cargo Variant	MKR18	LVSR	D0052	456
LVSR, Armored Tractor Variant	MKR16	LVSR	D0053	81
LVSR, Armored Wrecker Variant	MKR15	LVSR	D0054	61
M-ATV	N/A	M-ATV	D0036	549
Cougar CAT II A2 ISS	N/A	MRAP	D0023	233
Cougar CAT I A1	N/A	MRAP	D0025	1,126
Cougar CAT II A1	N/A	MRAP	D0027	6
Truck, Armored, Cargo 7 ton	AMK23	MTVR	D0003	2,826
Truck, Armored, XLWB Cargo, 7 ton	AMK27	MTVR	D0005	515
Truck, Armored, Dump 7 ton	AMK29	MTVR	D0007	297
Truck, Armored, Tractor, 7 ton	AMK31	MTVR	D0013	292
Truck, Armored, Wrecker, 7 ton	AMK36	MTVR	D0015	338
HIMARS, Armored Re-supply Vehicle	AMK37	MTVR	D1063	103

SOURCE: Data are from the Total Life Cycle Management Operational Support Tool (TLCM-OST) as of March 2017.

NOTE: TAMCN = Table of Authorized Material Control Number. TOW = tube-launched, optically tracked, wire-guided [missile]. ECV = expanded capacity vehicle. GP = general purpose [vehicle]. N/A = not applicable. CAT = category. ISS = Independent Suspension System. XLWB = extra long wheel base. HIMARS = high mobility artillery rocket system.

Mine-Resistant Ambush Protected All-Terrain Vehicle

The M-ATV is a lighter version of the MRAP designed for use in Afghanistan, where combat operations involved unpaved roads and small mountain villages that were not well suited for heavier, less maneuverable MRAPs. The M-ATV is primarily made of fiberglass and lighter metals, but the crew cab is designed with the same blast-proof features as the MRAP, such as a V-shaped hull and blast-proof metal and windows.³

Medium Tactical Vehicle Replacement

The MTRV makes up the bulk of the Marine Corps medium automotive fleet. This seven-ton, off-road-capable truck provides functions such as transportation of personnel and cargo, maintenance, towing, and engineering. Variants include the cargo truck (with standard or extended wheel base configurations), dump truck, wrecker, and tractor. Approximately half of the MTRV fleet is armored.⁴ MTRV armored trucks are outfitted with the MTRV Armor System, which provides complete 360-degree protection, as well as overhead and underbody protection for the crew compartment.

Table 2.2 summarizes the mix of armored Marine Corps D TAM vehicles at I MEF, II MEF, III MEF, prepositioning sites, and other locations (e.g., headquarters). Our simulation model initially assumed that the vehicle quantities in Table 2.2 will remain constant over the next ten years. We also examined a scenario with a hypothetical fielding schedule for 5,500 JLTVs replacing some armored HMMWVs. However, as the Marine Corps continues to review its tactical vehicle portfolio, senior leaders are likely to make additional changes to the mix of vehicles to better meet the future operating environment. Part of this calculus will include determining what percentage of the fleet will be armored and to what standard. Several key considerations include

³ Mike Mount, "Pentagon Hopes New M-ATV Is 'Life-Saver,'" CNN, November 4, 2009.

⁴ PEO LS, *Program Executive Officer Land Systems: 2013–2014 Program Overview*, Washington, D.C., 2014.

- the expected transition from 24,000 HMMWVs (including armored, MAK, and unarmored variants) to a mix of HMMWVs and JLTVs and the requisite decisions regarding armor and ballistic glass. The Marine Corps currently expects to field 5,500 JLTVs, but this number may increase as part of force modernization.⁵ The JLTV-HMMWV mix (and the proportion of the JLTV-HMMWV fleet that needs to be armored) will influence the quantity and cost of ballistic glass replacements.
- the effects of the MTVR's future on ballistic glass requirements. Although the original MTVR design was not well-suited for combat, operations in Afghanistan and Iraq dictated extensive deployment and up-armoring. Approximately half of the current MTVR fleet is armored, but this may change if the Marine Corps elects to use this vehicle for garrison missions.
- the fact that MRAP requirements have changed several times since the drawdown of most marines from Afghanistan and Iraq. The current plan is to sustain 2,510 vehicles through 2030.⁶ The Marine Corps is pursuing a strategy of wartime equipment sets whereby vehicles are kept at several locations (at different states of readiness) but are not used for routine training.

Table 2.2
Location of Armored Marine Corps D TAM Vehicles

Vehicle	I MEF	II MEF	III MEF	Prepositioned	Other	Total
HMMWV	1,454	1,316	877	1,480	2,635	7,762
LVSr	366	328	195	256	546	1,691
M-ATV	44	19	2	231	253	549
MRAP	45	50	0	139	1,131	1,365
MTVR	838	706	532	1,070	1,225	4,371

SOURCE: Data are from TLMC-OST as of March 2017, supplemented by clarifying information from I MEF and II MEF personnel. More-detailed information on the organizations included in the "Prepositioned" and "Other" categories is provided in Appendix B.

⁵ Headquarters, United States Marine Corps, *United States Marine Corps Ground Combat and Tactical Vehicle Strategy*, Washington, D.C., October 17, 2014.

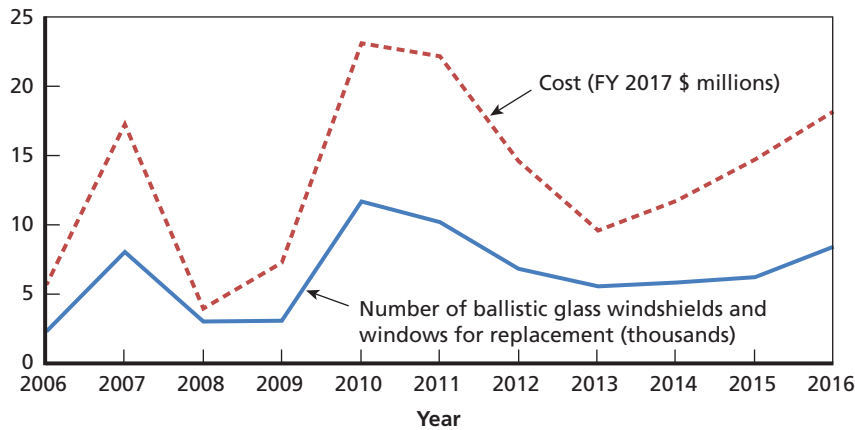
⁶ Headquarters, United States Marine Corps, 2014.

Supply Analysis

We examined Marine Corps and DLA supply and maintenance system data to identify trends in ballistic glass replacements and costs for windshields and side windows for the five vehicle types (HMMWV, LVSF, M-ATV, MRAP, and MTRV) from FY 2006 through FY 2016. Figure 2.1 shows the total quantities and costs of ballistic glass replacements, with quantities in thousands (blue line) and costs in millions of dollars (red dashed line). Quantities and costs have fluctuated widely over this period, depending on the use of the vehicles in operations, depot overhaul programs that replaced delaminated glass, and the availability of funding (for example, budgets were constrained in FY 2013 due to sequestration).

A breakdown of costs by vehicle type for FY 2010 through FY 2016 is shown in Table 2.3, along with the weighted average unit price of the replacement glass for each vehicle. These costs are driven both by the number of replacements and the cost of the ballistic glass components by National Item Identification Number (NIIN). The HMMWV

Figure 2.1
Marine Corps Demands and Costs for Ballistic Glass Replacements



SOURCE: Authors' compilation using DLA data and Global Combat Support System–Marine Corps (GCSS-MC) data as of March 2017.

Table 2.3
Ballistic Glass Costs, by Vehicle Type

Vehicle	2010 (\$ millions)	2011 (\$ millions)	2012 (\$ millions)	2013 (\$ millions)	2014 (\$ millions)	2015 (\$ millions)	2016 (\$ millions)	Weighted Average Unit Price (\$)
HMMWV	6.55	6.59	4.43	2.32	1.51	1.79	2.01	820
LVSr	0.22	1.50	2.67	0.84	0.51	2.19	1.90	8,214
M-ATV	0.59	1.83	1.63	0.86	1.22	0.48	2.68	4,279
MRAP	2.52	2.10	2.54	2.36	6.14	5.98	8.09	2,514
MTVR	13.18	10.07	3.34	3.29	2.40	4.31	3.53	4,251
Total	23.05	22.10	14.60	9.67	11.77	14.76	18.21	

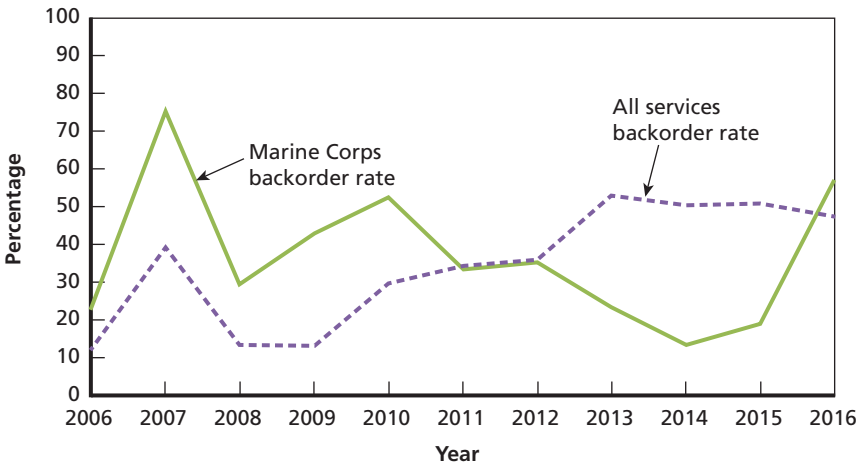
SOURCE: Data are from DLA and GCSS-MC as of March 2017.

NOTE: Costs are in FY 2017 dollars. Numbers may not sum exactly due to rounding.

NIINs are the least expensive, while those on the LVSR are the most expensive, on average. The cost of each NIIN is related to its size and the ballistic protection requirements for the vehicle. As Table 2.3 indicates, in earlier years, the HMMWV and MTVR accounted for most of the Marine Corps’ ballistic glass replacement costs. In later years, costs shifted away from HMMWVs toward MRAPs and M-ATVs, which were going through depot overhaul programs.

We also examined backorder rates for the same group of ballistic glass NIINs over the period from FY 2006 to FY 2016, shown in Figure 2.2.⁷ The backorder rate for Marine Corps requisitions is shown in green, in comparison with the average rate for all services, shown in the dashed purple line. The backorder rate depends both on DLA inventories and the priority of the requisitions, and has varied widely over this period. In recent years, the overall backorder rate for ballistic glass has been close to 50 percent, with the Marine Corps seeing some-

Figure 2.2
Backorder Rates for Ballistic Glass



SOURCE: Authors’ compilation using DLA data as of March 2017.

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⁷ A *backorder rate* measures the percentage of orders that cannot be filled when the order is placed.

what better performance in 2013–2015, but jumping above the overall average in 2016.

For the simulation model, we focused on the specific set of windshield NIINs that are currently in use by the Marine Corps. These windshields are listed in Table 2.4, along with their prices, recent demand rates, and average DLA and Marine Corps inventories for FY 2017. The HMMWV M1114 variant uses a different set of windshields than other armored variants, so we separated these two groups of vehicles in the model.

Based on the guidance of the study advisory committee, we did not use historical demand rates to forecast future replacement rates for ballistic glass due to delamination. First, some ballistic glass is replaced for reasons other than delamination, such as cracks or other damage,

Table 2.4
Vehicle Windshields Used in the Simulation Model

Vehicle	Position	FY 2017 Price	Average Annual Demand Rates, FY 2012–2016	DLA Inventory (FY 2017 average)	Marine Corps Inventory (FY 2017 average)
HMMWV Armored ^a	Driver	573.61	678	2,097	12
	Passenger	563.13	793	2,039	59
HMMWV M1114	Driver	1,152.13	219	6	0
	Passenger	1,152.13	296	1,019	9
LVSF	Both sides ^b	7,164.11	143	1	11
M-ATV	Driver	3,270.42	75	173	460
	Passenger	3,236.57	86	355	450
MRAP	Both sides ^b	6,223.15	301	54	12
MTVR	Driver	5,748.23	288	114	102
	Passenger	5,739.85	268	126	66

SOURCE: Data are from DLA and GCSS-MC as of March 2017.

^a The A1 variants of armored HMMWVs used different windshield NIINs than other M1151, M1152, and M1165 variants, but the prices were similar, so this table reflects combined demands and inventories.

^b The left and right windshields are interchangeable and possess the same NIIN.

particularly if the vehicles are being used in operations. Second, operational units may not be replacing some delaminated glass due to the cost, and because deadlining criteria have not been widely established that would require replacement. Therefore, we used field data collection to assess the current state of delamination in the vehicle fleets owned by I MEF, II MEF, and III MEF and establish the initial condition of the vehicles in the simulation model. We discuss our data collection methodology and results in the next chapter.

Current Extent of Delamination

Marine Corps maintenance databases do not accurately track delamination occurring on tactical vehicle windshields. Maintenance procedures that state deadlining criteria and establish reporting requirements have not been established across the Marine Corps. Many units do not record cases of delaminated windshields, accepting operational risk in order to save funds and, in some cases, to preserve the appearance of equipment readiness. To overcome this data limitation, the research team conducted in-person visual inspections of a sample of more than 1,000 tactical vehicles. Researchers visited three Marine Corps installations and provided data collection instructions to III MEF personnel. Data were collected from a total of 43 units at these locations.

This chapter documents the results of the vehicle assessment and provides details on delamination trends by geographic location and vehicle type. The data collection design is summarized here. Appendix B provides additional documentation.

Data Collection Design

Site Selection

Marine Corps tactical vehicles examined in this study—the HMMWV, M-ATV, MRAP, LVSF, and MTVR—are used by both the operational forces and the supporting establishment. Table 2.2 summarizes the current inventory of armored vehicles across Marine Corps commands and organizations. In aggregate, most vehicles are located at one of the three MEFs: I MEF in Camp Pendleton, California; II MEF

in Camp Lejeune, North Carolina; and III MEF in Okinawa, Japan. Other locations include deployed units and organizations, reserve component units, prepositioned stocks, depots, training locations, and headquarters. The study team elected to collect data from the three MEFs in order to inspect a statistically meaningful number of vehicles during the time allotted for this project. The other benefit of selecting the MEFs as inspection sites is that they reflect different climate and storage conditions (e.g., Okinawa frequently experiences typhoons). A pilot test also included one headquarters unit in Quantico, Virginia, at which time the data collection approach was finalized.

The sample included vehicles from air, ground, logistics, and MEF headquarters units, such as communications and reconnaissance battalions. Including a wide array of units helped to ensure that the sample accounted for differences in how the vehicles may be operated, maintained, or stored. The list of units participating in this survey is found in Appendix B.

Sample Size

Due to the large size of the vehicle fleet and number of locations, inspecting every vehicle was neither plausible nor necessary. Researchers established a goal of inspecting 10 percent of each vehicle type at each of the three MEFs (e.g., 10 percent of the HMMWVs located at I MEF). Because of the small numbers of M-ATVs and MRAPs assigned to the MEFs, the research team aimed to collect more than a 10-percent sample to provide a better basis for extrapolation.¹

The sample size goals and number of vehicles inspected are shown in Table 3.1. We initially included HMMWV MAK and MTRV RTAA variants in the sample design, but, in practice, these vehicles did not have ballistic glass installed. Therefore, we ended up with greater-than-10-percent samples of the armored HMMWVs and MTRVs.

¹ The standard errors of the estimated proportions of vehicles meeting the PEO LS delamination criteria in either windshield can be calculated using the formula $EQ1$, where $VARIABLE$ is the sample proportion and n is the sample size. For example, if 75 percent of the HMMWVs observed at I MEF meet the delamination criteria, the standard error would be ± 2.78 percent. See Pennsylvania State University, Eberly College of Science, "Lesson 10.2: Confidence Intervals for a Population Proportion," 2017.

Table 3.1
Number of Vehicles Inspected, by MEF

Vehicle	I MEF Goal	I MEF Actual	II MEF Goal	II MEF Actual	III MEF Goal	III MEF Actual	Total Goal	Total Actual	Percentage of MEF Armored Fleet Inspected
HMMWV	224	242	192	193	138	82	554	517	14.2
LVSr	42	45	33	22	20	3	95	70	7.9
M-ATV	9	22	2	4	0	0	11	26	40.0
MRAP	6	16	4	5	0	0	10	21	23.6
MTVR	171	198	145	149	103	61	419	408	19.7

SOURCE: TlCM-OST data as of March 2017 and study sample design and data collection.

Data collected in Okinawa fell short of the design goal due to low on-hand quantities within the motor pool. A large population of III MEF vehicles were either deployed or in use for training.

Limitations

Due to time and availability, vehicles were only inspected at the MEFs, which constituted about half of the Marine Corps' entire vehicle fleet. To mitigate this limitation, we used interviews with subject-matter experts (SMEs) to enhance our understanding of the conditions of the rest of the fleet. SMEs associated with the prepositioned fleet provided the insight that when vehicles are placed onto maritime prepositioning ships or into storage at the Marine Expeditionary Unit (MEU) Augmentation Program in Kuwait, they have little to no delamination. Additionally, those vehicles stored in the caves in Marine Corps Prepositioning Program–Norway (MCPN) show near-zero signs of delamination. However, we assume that their windshields can begin to delaminate after they are placed into storage.² While no vehicles were inspected in the “other” fleet,³ a pilot test was done at one of the units in that group. This group of vehicles contains units with a wide variety of missions and locations. Despite these limitations, the data collection methodology is well documented and easily replicable if further inspection of Marine Corps vehicles is desired. We recommend that periodic inspections of ballistic glass become part of standard motor transportation maintenance procedures.

In addition to focusing inspections on the three MEFs, this sample has one other limitation. Inspections were conducted on vehicles within unit motor pools at the time of collection. If vehicles were

² For more information on Marine Corps prepositioning programs, see Headquarters, United States Marine Corps, *Prepositioning Programs Handbook*, 2nd edition, Washington, D.C., January 2009.

³ The “other” fleet of vehicles consists of non-MEF and prepositioned stock units. Units included are Marine Corps Forces Reserve, Marine Corps Forces Central Command, Marine Corps Forces Southern Command, Marine Corps Forces Europe, Marine Corps Forces Africa, Marine Corps Forces Special Operations Command, Headquarters United States Marine Corps, Marine Corps Security Force Regiment, and Depot Maintenance Float Allowance.

being used in support of missions (e.g., assigned to a deployed MEU) or training events, they were not inspected. It is possible that the vehicles in the best state, with little to no delamination, were not present at the time of inspection. This may have resulted in a higher rate of observed delamination. Also, since the focus of this study was on the windshields, data on side windows were not collected.

Delamination Criteria

Delamination can include cloudiness, bubbles, spots, whiteness, discoloration, and visual distortion. Other visual distortions, such as chipped glass, are not a cause of delamination and therefore are not included in this study. The study team categorized delamination into three states: no delamination, partial delamination, and full delamination, as defined in Table 3.2.

Marine Corps PEO LS developed criteria to evaluate windshield delamination that renders vehicle operations unsafe from a driver visibility perspective. PEO LS derived its criteria from MIL-STD-882E, *Department of Defense Standard Practice: System Safety*, in order to ensure a systematic approach to system safety risk.⁴ The outcome of

Table 3.2
Description of Delamination States

Windshield State	Description
No delamination	No cloudiness, bubbles, spots, whiteness, discoloration, or visual distortion observable anywhere on windshield
Partial delamination	Cloudiness, bubbles, spots, whiteness, discoloration, or visual distortion observed in the area of the windshield outside of the wiped area
Full delamination	Cloudiness, bubbles, spots, whiteness, discoloration, or visual distortion observed in the wiped area of the windshield

SOURCE: PEO LS, 2017.

⁴ Interview with Marine Corps PEO LS, January 18, 2017. According to program managers, delamination in the wiped area is a greater safety concern than delamination outside the wiped area. MIL-STD-882E identifies the Department of Defense approach for identifying hazards and assessing and mitigating associated risks encountered in the development, test, production, use, and disposal of defense systems. For more information, see U.S. Depart-

PEO LS's assessment was a criterion that allowed for a medium level of risk.

According to PEO LS guidelines, any windshield with delamination present in the wiped area of the windshield (the area the windshield wiper traverses) is considered delaminated and, for the purposes of this study, has full delamination. The research team included the partial delamination state because delamination tends to spread from the outer edges of a windshield toward the wiped area; knowing the number of partially delaminated vehicles is helpful for predicting future delamination in the wiped area and the costs associated with replacing or repairing the glass. Future Marine Corps data collection efforts could help determine the progression of delamination more accurately.

One additional clarification regarding PEO LS criteria is that any amount of cloudiness, bubbles, spots, whiteness, discoloration, or visual distortion counts as delamination. For example, under these criteria, a bubble smaller than a penny counts as delamination.

Inspection Method

The method for visually inspecting the vehicles was developed by the RAND study team, Operations Analysis Directorate (OAD), PEO LS, and individuals serving on the study advisory committee. For each vehicle inspected, the data collection team recorded the vehicle's serial number and whether any delamination was observed in the wiped area of the windshield. The team then placed a large plexiglass sheet divided into 91 numbered grid squares next to the windshield and recorded which squares had evidence of delamination. Thus, more-detailed data on the extent of delamination in the inspected vehicles are also available. For a subset of windshields, the data collection teams recorded information on the serial numbers and manufacture dates of the windshields. The inspection procedure is described in greater detail in Appendix B. This inspection process emphasized identifying visual evidence of delamination. It should be noted that materials can delaminate without any visual indication, but the purpose of this

report is to identify signs of delamination that impair driver and passenger visibility.

Current Scope of Delamination

There were observable differences in delamination by vehicle type and location. Table 3.3 presents the percentage of vehicles by type that meet the PEO LS delamination criteria on either or both windshields.

Vehicle Type

Inspections identified that HMMWV windshields are experiencing the highest rate of delamination in the fleet. Nearly 70 percent of HMMWVs across the three MEFs had delamination in one or both windshield panels meeting the PEO LS delamination criteria. At III MEF, the rate of delamination was over 90 percent. This confirmed what we heard anecdotally from SMEs. In those discussions, SMEs reported that HMMWV windshields are not being replaced for a variety of reasons, including the cost and availability of required parts, the lack of deadlining criteria, and reluctance by commanders to order HMMWV windows when they expect that some vehicles will be replaced by JLTVs.

MTVR windshields had the second-highest delamination rate. At I MEF and II MEF, close to 50 percent of MTVRs were affected,

Table 3.3
Percentage of Vehicles Meeting PEO LS Delamination Criteria on Either Windshield

Vehicle Type	I MEF	II MEF	III MEF	Weighted Average
HMMWV	75%	58%	94%	69%
LVSR	0%	5%	33%	3%
M-ATV	36%	50%	N/A	39%
MRAP	29%	20%	N/A	26%
MTVR	48%	59%	84%	58%

NOTE: N/A = not applicable. Delamination in the wiped area of either windshield or both windshields would deadline the vehicle under PEO LS, 2017.

while 84 percent of III MEF's vehicles had delamination in at least one windshield. While the percentage of MTVRs impacted is less than HMMWVs, replacement windshields for MTVRs are significantly more expensive.

Minimal delamination was observed on the LVSR fleet, but the proportion of the LVSR fleet inspected was comparatively low. One reason for the low levels of delamination may be due to recent Marine Corps efforts to install egress handles in the LVSRs. The installation process required replacement of ballistic glass windshields with a different-sized glass panel and frame. Most of the windshields looked new, but further maintenance analysis is required to confirm this observation. Similarly, it is difficult to make an assessment on M-ATVs and MRAPs due to the low number of vehicles observed in the fleet. SMEs indicated that many of these vehicles had recently had their windshields replaced in depot overhaul programs.

Geographic Location

Of the three MEFs, III MEF appears to be experiencing the highest rate of delamination in its windshields. However, it should be noted that III MEF's vehicle availability for sampling was lowest due to the 31st MEU's deployment. This could also have had an impact on the high rate of delamination observed, as vehicles with the highest state of readiness were mostly likely prioritized to be sent on MEUs.⁵ I and II MEF had similar rates of delamination. At I MEF, HMMWVs showed more signs of delamination, while at II MEF, MTVRs had slightly higher rates. The impact of weather on delamination is outside the scope of this study, but the presence of significant rates across three diverse sites suggests that, at a minimum, delamination occurs in all three climates.

⁵ Data collection was primarily used to set the initial conditions for the simulation model. If we exclude the III MEF data from our calculations and base the initial conditions for the III MEF and "other" fleets on the weighted average of the I MEF and II MEF data, there are approximately 450 fewer vehicles with delamination in the wiped area of either windshield and 700 fewer windshields requiring replacement (out of a total of nearly 16,000 vehicles) in the first year of the simulation.

Although no prepositioned stock was inspected, interviewees indicated that delamination occurs on equipment stored on ships, but only a small number of cases of delamination have been observed on the vehicles being stored in the caves in Norway.

Delamination Time

SMEs indicated that full delamination seemed to be occurring at approximately four years, with some windshields showing signs much earlier or much later. To confirm this, during vehicle inspections, teams recorded the glass manufacture date when it was observable. Of the 2,084 windshields inspected (this includes both left and right windshields on a total of 1,042 vehicles), 272 windshields had observable manufacturing dates (found on the HMMWV and MTRV).⁶ Table 3.4 shows the sample size and percentage of windshields with delamination in the wiped area for each manufacture year.

Of the windshields with manufacture dates, no delamination meeting the PEO LS criteria was observed in HMMWV and MTRV windshields manufactured in 2014 or later (three years of age or less). At around four years from the time of the inspection (2013), the MTRV begins to show signs of delamination. After five years (2012), both the MTRV and HMMWV windshields had a significant amount of delamination, with roughly 50 percent or more showing delamination. The numbers remain high for older windshields, but not all are delaminated.

While this analysis helped verify SME perspectives on delamination rates and the probabilities of delamination in the simulation model, there are some limitations to these results. First, the analysis does not account for different manufacturers. There is no single manufacturer of ballistic glass for the Marine Corps, and this analysis does not account for any variations in manufacturing processes. Additionally, glass manufacturing may have improved over the past ten years and

⁶ The date formatting varied significantly across windshields, so we made a best estimate or dropped the windshield from the data set used to analyze delamination time if the month/year combination was ambiguous. In addition, it was difficult to verify when windshields were installed on vehicles. The assumption was that glass was installed in the same year it was manufactured; however, maintenance data supporting this assumption was limited.

Table 3.4
HMMWV and MTVR Delamination, by Manufacture Year

Year of Manufacture	HMMWV		MTVR	
	Number of Windshields Observed	Percentage Delaminated	Number of Windshields Observed	Percentage Delaminated
2006	N/A	N/A	1	100
2007	18	78	N/A	N/A
2008	7	86	12	42
2009	19	89	9	78
2010	44	86	18	78
2011	1	0	11	55
2012	3	67	64	48
2013	4	0	4	50
2014	5	0	20	0
2015	3	0	6	0
2016	4	0	1	0

NOTE: N/A = not applicable.

could result in a longer delamination time for windshields manufactured in recent years; longer observation time is required to determine the validity of this assumption.⁷ Second, the inconsistent date format was problematic in determining the precise year of manufacture, and it was not possible to determine the date of installation. Although SMEs indicated that some windshields delaminated while in DLA storage, those windshields are most likely exposed to more heat and humidity after they are installed on vehicles. Third, the analysis does not account for differences in location, use, or storage of the vehicles.

⁷ Although environmental testing standards increased over this period, we do not have sufficient data to detect an improvement in life span for more-recent manufacture dates. As part of our sensitivity analysis, we allow average delamination time to vary from three to six years. A significantly longer delamination time (eight to ten years or more on average) would require a simulation longer than ten years and establishing assumptions about when ballistic glass with an improved life span began to be (or will be) installed. As we discuss in the next chapter, the simulation model uses a baseline probability distribution with an average of four years, but the distribution ranges from two to 12 years to allow for variability across individual windshields.

Modeling Replacement and Sustainment Costs

One of the reasons Marine Corps units do not typically order new windshields relates to a limited maintenance budget that does not account for the full cost of replacing damaged ballistic glass.¹ Units are challenged to predict when windshields will delaminate, which leads to an unsteady demand and makes it difficult for commanders to submit accurate, justifiable budget requests for windshield maintenance. From a Marine Corps-wide perspective, the aggregate cost of replacing windshields—or repairing them, should this technology mature—is unknown.

This chapter describes the model the RAND team created to forecast annual sustainment costs and vehicle availability across six scenarios: status quo, replace, repair, automotive glass, a hybrid of replace and repair, and JLTV integration. Chapter Five presents the modeling results.

Modeling Approach

Researchers developed a computer simulation model using ExtendSim v9.2 software. Such programs as ExtendSim are well suited for processing large data sets and including intricate restrictions, such as processing times, physical capacity, personnel availability, and throughput

¹ Other reasons for not ordering windshields include long wait times due to limited supply and a lower priority compared with other maintenance needs (which is driven, in part, by the lack of deadlining criteria).

rates. ExtendSim offers database tools to organize, analyze, and present input parameters and results unavailable in simpler programs, such as Microsoft Excel.

Modelers began by running each scenario according to a set of baseline parameters and used sensitivity analyses to alter one or more of these parameters to assess excursions of interest. The following baseline parameters are common to all four scenarios:

- **Time Horizon.** All scenarios and excursions had a ten-year time horizon.²
- **Vehicle Type.** The model incorporates six vehicle types: HMMWV (Armored), HMMWV (M1114), LVSr, M-ATV, MRAP, and MTVR.
 - HMMWVs are divided into two types because the M1114 variant has different windshield NIINs than the other armored HMMWVs. The model accounts for the different NIINs since each windshield type has a unique cost and supply availability rate.
- **Geographic Location.** Each scenario uses five geographic locations: I MEF, II MEF, III MEF, a generic location representative of all prepositioned stocks, and one that accounted for all remaining units.
 - For I and II MEF, vehicles and their windshields have an initial state based on the 10-percent sample described in Chapter Three, extrapolated to apply to the full population of vehicles at each location.
 - For III MEF, vehicles have an initial state based on the 10-percent sample for armored HMMWVs and MTVRs. For M1114 HMMWVs, LVSrs, MRAPs, and M-ATVs, the model uses a weighted average of all three locations because the III MEF sample did not include a sufficient number of those types of vehicles.

² The study description originally specified a five-year projection, but we extended the length of the simulation to ten years to ensure that it would reach a steady replacement rate after the initial backlog of delaminated windshields was repaired or replaced.

- For prepositioned stocks, the starting state is no delamination. This reflects the current practice of loading ships with ready equipment.
- For remaining units, a weighted average from I, II, and III MEF vehicles (based on the population of vehicles sampled at each site) is used.
- **Time to Replace.** No more than 15 repairs may be completed per day at each location. This number was arrived at based on discussions with SMEs. Although this caused delays of up to several months in the replacement scenario, the impact is minimal when considering a year-long maintenance cycle.
- **Time to Delaminate.** The baseline of each scenario assumes an average of four years to delamination in the wiped area. Since there is considerable uncertainty about the speed of delamination, we conducted excursions using sensitivity analyses to examine average times of three, five, and six years.³

The model incorporates three states for windshields: no delamination (State 1), partial delamination (State 2), and delamination in the wiped area (State 3).⁴ The following rule set applies to transitions between states:

- Each windshield is modeled separately, so the left and right windshields can delaminate at different times.⁵

³ For the purpose of this study, the average rate of delamination is estimated at four years. Environmental testing requirements for ballistic glass have been increasing over time, but we did not have sufficient data on manufacture dates to detect an increase in the life span of the glass. Therefore, if new technology increases the life span of ballistic glass beyond six years, the results of this study should be revisited.

⁴ The PEO LS delamination criteria for HMMWVs specify a subset of the wiped area, although the criteria are equivalent to the wiped area for other vehicle types. We use the term *wiped area* for simplicity.

⁵ This assumption was supported by data collection, where the inspection team observed some vehicles with driver and passenger windshields in different states of delamination. Data on the percentage of windshields observed in each combination of states are provided in Table B.6.

- Transitions are from State 1 to State 2 and from State 2 to State 3. We assume that no windshield can move directly from State 1 to State 3. Field observations and interviews indicated that sudden delamination or the appearance of a bubble in the wiped area is physically possible but rare.
- Replacing or repairing a windshield means restoring it to State 1.
- For the base model of each scenario, the transition between State 1 and State 2 takes approximately two years. The exact duration depends on a draw from a probability distribution applied to each vehicle in each year to simulate the likelihood of delamination over time. The transition from State 2 to State 3 follows the same rule set.⁶
- Transition probabilities followed a cumulative distribution of two-year average and three-year standard deviation to go from one state to the next. Table 4.1 shows the transition probabilities by year for different average delamination rates. The same probabilities are applied to the transition from State 1 to State 2 and from State 2 to State 3.
- Windshields spend a maximum of six years in State 1 and six years in State 2.

Model inputs include the number of vehicles with windshields in each state of delamination at each location. Each year, the model determines whether a windshield will transition to the next state of delamination based on the number of years in the current state and the predetermined probability distribution. If a windshield's delamination has advanced to State 3, the vehicle is taken to maintenance for windshield replacement or repair.

⁶ It is possible that once delamination begins (i.e., a transition from State 1 to State 2), it proceeds more quickly from State 2 to State 3. However, we do not have any firm evidence that this occurs, and in any case, no action is taken in the model until the vehicle reaches State 3. Additional field data collection, with multiple observations of the same vehicles over time (and ideally linked to the manufacture and installation dates of ballistic glass), could be used to refine the transition probabilities in the model.

Table 4.1
Transition Probabilities, by Year

Year	Three Years	Four Years	Five Years	Six Years
1	0.4338	0.3694	0.3085	0.2525
2	0.5662	0.5000	0.4338	0.3694
3	0.6915	0.6306	0.5662	0.5000
4	0.7977	0.7475	0.6915	0.6306
5	0.8783	0.8413	0.7977	0.7475
6	1.0000	1.0000	1.0000	1.0000

Scenarios

In this section, we describe each of the six scenarios that were run through the model. Model results, in terms of ten-year cumulative costs and numbers of windshields replaced, as well as vehicle availability at the end of the ten-year simulation, are presented in Chapter Five.

Scenario 1: Status Quo

The status quo scenario reflects current Marine Corps maintenance practices, involving a limited number of orders for replacements when a windshield reaches State 3, with the remainder left unaddressed or deferred until the vehicle's next scheduled depot-level maintenance. To reflect these practices and the low windshield stocks available within the supply system, the number of windshields replaced is constrained to no more than the average number of windshields ordered by the Marine Corps (by NIIN) over the last five years. This ensures that demand does not outpace current supply. This scenario is designed to determine cost and vehicle availability should the Marine Corps elect to continue its current practices. A status quo scenario also provides an opportunity to verify that model parameters reflect current conditions.

Scenario 2: Replace Fully Delaminated Windshields

The second scenario lifts the supply system constraint. This scenario is designed to determine cost and availability should the Marine Corps replace all current and future windshields that reach State 3.

Scenario 3: Repair Fully Delaminated Windshields

The third scenario examines costs and availability in the event that the Marine Corps elects to build a facility that repairs ballistic glass rather than to replace the glass. PEO LS is currently working with potential vendors to create a prototype facility for relaminating glass. The objective is to reduce costs and transform ballistic windshields from a consumable to a secondary repairable. The model uses PEO LS estimates as the basis for this scenario's rule set.

According to PEO LS, a current estimate of the cost and time to develop a single functioning prototype repair line using the proposed process to repair 1,000 windshields per year is approximately \$5 million and, conservatively, one year. A repair facility with a throughput of 5,000 windshields per year is estimated to cost \$7.8 million to establish. The following rule set applies to this scenario:

- The relamination cost per window is estimated to be approximately half the cost of buying a new window and frame.
- The prototype facility is capable of repairing 1,000 windshields per year. Excursions for 3,000, 5,000, and 8,000 windshields per year reflect the possibility of scaling up production.
- The base scenario and excursions all assume that it takes one year to establish the facility.
- Although we do not have estimates of the fixed costs to establish repair facilities with capacities of 3,000 or 8,000 windshields per year, we selected these levels for comparison with the status quo and replacement scenarios.

The model assumes that repaired glass has the same life span as replacement glass, but we also conduct sensitivity analyses on shorter and longer life spans. One potential vendor is conducting tests to determine whether the repair process can extend the glass's life span, but understanding whether this is possible will require years of testing.

Scenario 4: Transition to Automotive Glass

The fourth scenario is designed to examine cost and vehicle availability based on a partial transition to automotive glass. We assume that bal-

listic glass will be retained in all vehicles in prepositioned stocks and other vehicles needed for MEUs, and replaced as soon as it reaches State 3. A breakdown of the number of vehicles needed for contingency operations is depicted in Table 4.2. There are no automotive glass NIINs for the M-ATV and MRAP, so we assume that they also retain ballistic glass. The remaining vehicles transition to automotive glass (also upon reaching State 3), with risk accepted for a large-scale contingency that requires additional vehicles outfitted with ballistic glass.⁷ Like the second scenario, the model provides replacements for State 3 ballistic glass with no supply constraints.

This scenario potentially decreases costs and increases vehicle availability for training, but may also entail risks. First, using automotive glass for a portion of the fleet reduces demand for ballistic glass. This may lead to lower stocks and lengthen manufacturing timelines in the event that a rapid acquisition is undertaken during a large-scale or prolonged conflict. A low demand may reduce defense industrial base capacity to produce ballistic glass. However, since the Army has a much larger number of tactical vehicles with ballistic glass installed, its decisions on how to address ballistic glass delamination would most likely

Table 4.2
Vehicles Required to Support Contingency Operations

Vehicle Type	I MEF	II MEF	III MEF	Prepositioned
HMMWV (M1114)	93	93	31	255
HMMWV (Armored)	126	126	42	1,225
LVSr	0	0	0	256
M-ATV	0	0	0	231
MRAP	0	0	0	139
MTVR (Armored)	123	123	41	1,070

SOURCE: Data are from TLMC-OST as of March 2017. Additional information was provided by the Marine Corps Capabilities Development Directorate in June 2017.

⁷ One additional assumption is that automotive glass remains in State 1 for the duration of the ten-year period after installation. Although automotive glass does not delaminate, some windshields may need to be replaced due to cracks or other damage. If selected, implementing this approach would require further analysis to arrive at accurate cost and availability rates to replace damaged automotive glass.

have larger effects on the industrial base than Marine Corps demands. Additionally, the Marine Corps prioritizes having vehicles at a high state of readiness to be able to deploy, making this scenario counter to its culture. If automotive glass is used instead of ballistic glass, units will be training with equipment that is potentially inappropriate for wartime. SMEs in the motor transportation community raised this concern during the 2016 Marine Corps Technology Assessment Group and in interviews conducted for this study.⁸ The motor transportation community at I MEF and II MEF also voiced the opinion that automotive glass is not a viable solution. We included the scenario in this study to examine its cost implications because it is reportedly under consideration by the Army for some tactical vehicles that will remain in garrison and are not needed to deploy.

Scenarios 5 and 6: Hybrid and JLTV Integration

After the analysis of the four original scenarios was completed, the sponsor and study advisory committee asked us to adapt the model to consider two additional scenarios. Scenario 5 is a hybrid scenario that combines replacement of the less expensive HMMWV windshields (as in Scenario 2) with repair of the more expensive windshields of the other tactical vehicles (as in Scenario 3). This approach would allow the Marine Corps to test the repair technology with a facility sized to repair 5,000 windshields per year, while still achieving 100-percent vehicle availability at a lower cost than Scenario 2. In Scenario 6, we generated estimates of the changes in costs that would occur when the JLTV is fielded under Scenario 2 (Replace Immediately) and Scenario 3 (Repair). We projected the rate at which the planned 5,500 JLTVs would be fielded to the MEFs and other locations to replace M1114s and other armored HMMWVs, assuming that the costs of JLTV windshields are the same as those of the M-ATV and that the life span of ballistic glass installed in JLTVs is similar to that of vehicles in the current inventory. Based on available information, we assumed that

⁸ Another SME noted that the frames of automotive glass windshields may need to be modified to fit onto armored HMMWVs, LVSRs, and MTVRs.

JLTVs would be fielded and HMMWVs would be removed from the fleet, as shown in Table 4.3.⁹

Table 4.3
Estimated JLTV Fielding Schedule

Location	2020	2021	2022
I MEF	+828 JLTVs -414 HMMWV M1114s -414 HMMWV other	+763 JLTVs -381 HMMWV M1114s -382 HMMWVs other	+763 JLTVs -381 HMMWV M1114s -382 HMMWVs other
II MEF	+621 JLTVs -310 HMMWV M1114s -311 HMMWVs other	+381 JLTVs -190 HMMWV M1114s -191 HMMWVs other	+381 JLTVs -190 HMMWV M1114s -191 HMMWVs other
III MEF	+207 JLTVs -103 HMMWV M1114s -104 HMMWVs other	+191 JLTVs -95 HMMWV M1114s -96 HMMWVs other	+191 JLTVs -95 HMMWV M1114s -96 HMMWVs other
Prepositioned	N/A	+572 JLTVs -286 HMMWV M1114s -286 HMMWVs other	+572 JLTVs -286 HMMWV M1114s -286 HMMWVs other
Other	+30 JLTVs -15 HMMWV M1114s -15 HMMWVs other	N/A	N/A
Total	+1,686 JLTVs -842 HMMWV M1114s -844 HMMWVs other	+1,907 JLTVs -952 HMMWV M1114s -955 HMMWVs other	+1,907 JLTVs -952 HMMWV M1114s -955 HMMWVs other

SOURCE: Based on Headquarters, United States Marine Corps, 2014, and email communication with Marine Corps Combat Development and Integration Fires and Maneuver Integration Division, September 2017.

NOTE: N/A = not applicable.

⁹ For more information on the JLTV program, see Andrew Feickert, *Joint Light Tactical Vehicle (JLTV): Background and Issues for Congress*, Washington, D.C.: Congressional Research Service, May 31, 2017.

Modeling Limitations

A limitation of the model is the assumption that the composition of the fleet remains constant over the next ten years, except in Scenario 6. This is unrealistic due to the introduction of new capabilities (e.g., JLTVs) and at least some phasing out of legacy platforms. Although we partially address this limitation with the JLTV scenario, other changes in the tactical vehicle fleet are likely to occur over the next ten years. For example, as the Marine Corps continues to adapt to the future operating environment, the table of equipment at each location may change. A second consideration is that we only model windshield replacements. Ballistic glass is also installed in side windows, gunner's turrets, and some engineering equipment, so in future efforts the model should be scaled up to account for replacements of these windows when they become delaminated. Finally, the model is predicated on assumptions about time to delamination that are derived from limited observation and SME input. To increase fidelity, a longer-term observation of time to delamination would be beneficial. We recommend that the Marine Corps make this data collection a regular part of vehicle preventative maintenance checks, which will provide a more accurate understanding of the time associated with delamination of the ballistic glass.¹⁰

¹⁰ In addition, because of the large number of vehicles in the simulation model, it took approximately three hours to run each scenario in ExtendSim. Therefore, we ran the simulation only once for each scenario, using one set of draws from the delamination probability distribution. Ideally, a Monte Carlo experiment (i.e., running each scenario multiple times with different draws from the delamination probability distribution) would be used to generate mean outcomes and standard errors for each scenario.

Modeling Results

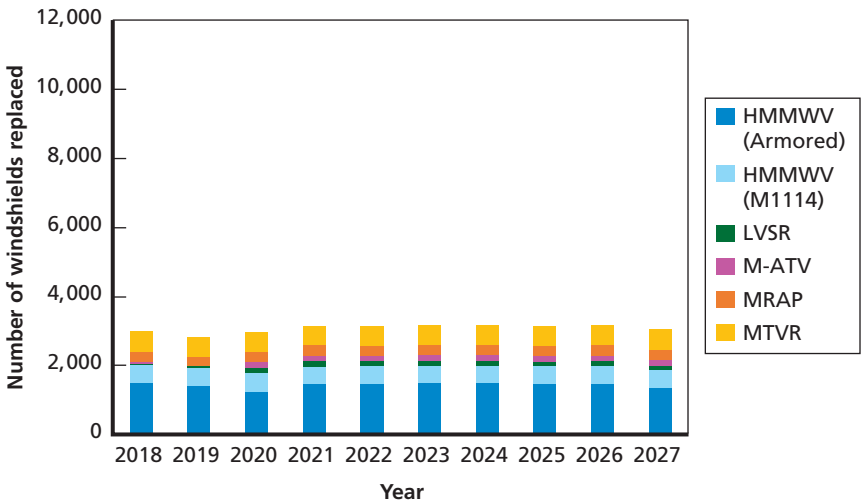
This chapter presents modeling results from the six scenarios examined (status quo, replace, repair, transition to automotive glass, hybrid, and JLTV integration). Each scenario was evaluated on cost, number of windshields replaced, and percentage of the fleet available for training or operations. Detailed model results for each scenario are provided in Appendix C.

Scenario 1: Status Quo

The status quo scenario is intended to represent the way the Marine Corps is currently responding to the delamination problem. In this scenario, the number of windshields replaced is constrained to no more than the average number ordered over the last five years. This scenario results in a total of 31,000 windshields installed over the ten-year period with a cumulative cost of \$79 million. This equates to a steady state of approximately 3,100 windshields replaced per year at a cost of \$8 million per year in FY 2017 dollars. These results are depicted in Figures 5.1 and 5.2.

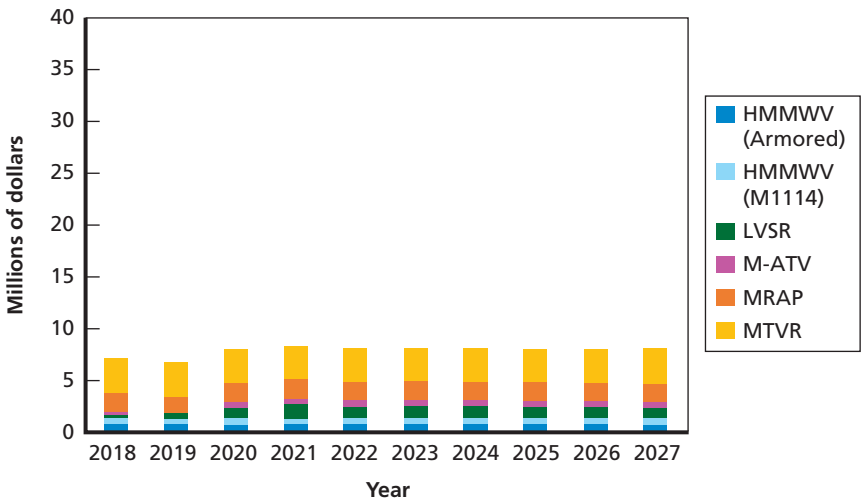
Under the status quo scenario, equipment readiness collapses. The number of available vehicles (those with no delamination in the wiped area of either windshield) falls from a peak of 11,000 to 3,500 (out of 15,820 total vehicles) at year ten because delamination is occurring faster than windshields are being replaced. This collapse is displayed in Figure 5.3. Because of differences in the constraints on windshield replacements, this equates to 30-percent availability for

Figure 5.1
Number of Windshields Replaced, Status Quo Scenario



RAND RR2285-5.1

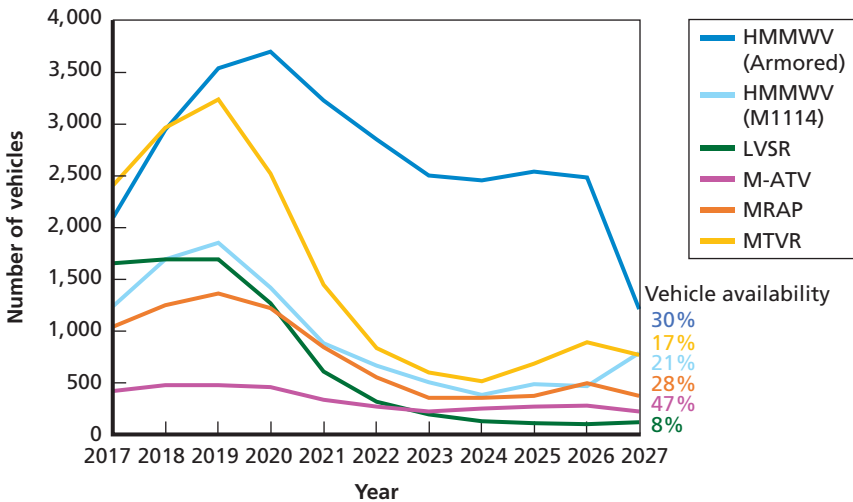
Figure 5.2
Annual Costs to Replace Windshields, Status Quo Scenario



NOTE: Costs are in FY 2017 dollars.

RAND RR2285-5.2

Figure 5.3
Vehicle Availability, Status Quo Scenario



RAND RR2285-5.3

armored HMMWVs, 21 percent for HMMWV M1114s, 17 percent for MTRVs, 47 percent for M-ATVs, 28 percent for MRAPs, and 8 percent for LVSrs.¹

The current replacement strategy results in low availability of vehicles—replacement does not keep pace with the rate of delamination. In addition, this scenario would represent a suboptimal investment strategy if the intent is to keep costs constant. The Marine Corps may have options to maintain better availability across fleets at a similar cost, although the costs of MTRV and LVSr windshields are higher

¹ Vehicle availability increases in the first few years of the simulation for two reasons. First, we assume that there is no delamination on vehicles when prepositioned, so windshield replacements do not begin until a few years into the model. Also, some vehicle types have high initial availability, such as LVSrs (98 percent available), M-ATVs (88 percent), and MRAPs (76 percent), so the constraints on windshield replacement rates are not binding in the first few years. Second, replacement of HMMWV windshields in 2015–2016 was below the five-year average, so there is some recovery of vehicle availability before it begins to decline.

than HMMWV windshields. In any case, the status quo is unsustainable if the Marine Corps intends to maintain a high state of readiness.

A sensitivity analysis extending the delamination timeline to an average of six years had minimal impact on the status quo results because the constraints on the number of windshields replaced are still binding. However, vehicle availability at the end of year ten improves somewhat to 5,700, or about 36 percent availability across all six vehicle types.

Scenario 2: Replace Fully Delaminated Windshields

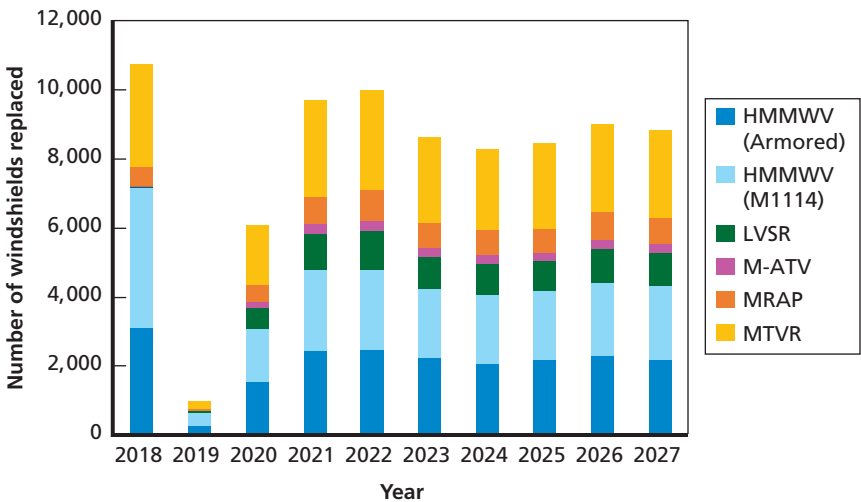
Scenario 2 is similar to Scenario 1, but it removes the constraint on the number of NIINs that can be replaced. In this case, 81,000 windshields are installed over the ten-year period at a cumulative cost of \$272 million in FY 2017 dollars.² The scenario has an initial surge of 10,760 windshield replacements in the first year, which drops to less than 1,000 in the second year, as new windshields are not yet delaminated.³ Beginning in year six, the number of replacements evens out to a steady state of 8,500 to 9,000 annually, or about one-quarter of the total number of windshields. The steady state annual cost in this scenario is approximately \$30 million per year. The results are depicted in Figures 5.4 and 5.5.

In this scenario, vehicle availability reaches 100 percent in the first year and remains there until year ten. However, this comes at a higher cost than the status quo. The ten-year total cumulative cost to

² There is a total of approximately 16,000 vehicles in the simulation, with 32,000 left and right windshield panels. Thus, on average, each panel is replaced 2.5 times during the ten-year simulation, or every four years.

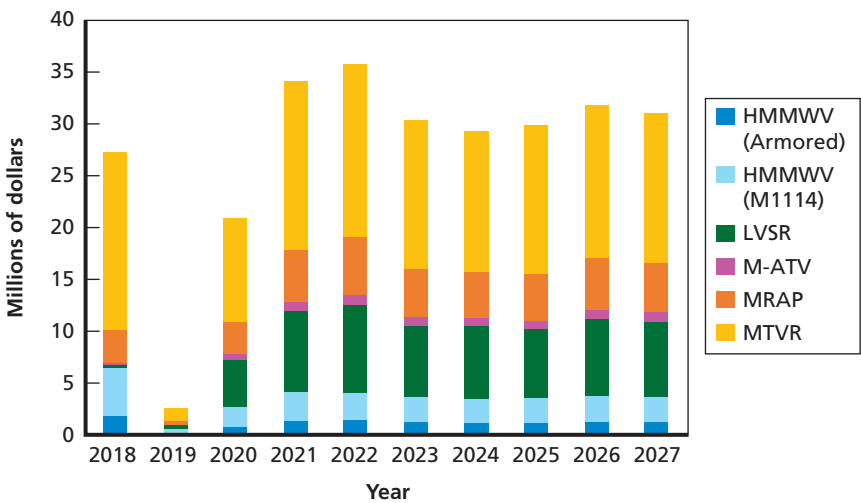
³ There are approximately 7,000 vehicles that are considered unavailable at the beginning of the simulation because there is delamination in the wiped area of one windshield or both windshield panels. Of these vehicles, about 4,000 needed to have both windshield panels replaced, leading to a total of almost 11,000 replacements in the first year.

Figure 5.4
Number of Windshields Replaced, Replace Scenario



RAND RR2285-5.4

Figure 5.5
Annual Costs to Replace Windshields, Replace Scenario



NOTE: Costs are in FY 2017 dollars.

RAND RR2285-5.5

replace all windshields as soon as they reach State 3 is \$272 million in FY 2017 dollars. Divided by vehicle type, the costs are

- MTRV: \$132 million
- LVSR: \$57 million
- MRAP: \$40 million
- HMMWV M1114: \$24 million
- Armored HMMWV: \$12 million
- M-ATV: \$7 million.

Additionally, DLA does not currently maintain sufficient inventories of ballistic glass to support the demands in this scenario. The Marine Corps would need to coordinate its plans with DLA (and the Army, as the major customer for some windshield types) to increase procurement. It might also be more feasible to ramp up replacement rates at a steadier pace rather than to replace the entire backlog of delaminated windshields in the first year.

Scenario 3: Repair Fully Delaminated Windshields

Instead of replacing glass, Scenario 3 examined the use of a repair facility. The prototype repair facility originally proposed by PEO LS had a throughput of 1,000 windshields per year. However, this production rate would be insufficient, as it falls below the status quo replacement rate. We also had no firm basis on which to decide which vehicle types would be prioritized. Therefore, our analysis considered repair facilities with higher throughputs of 3,000, 5,000, and 8,000 windshields per year.

At 3,000 windshields per year, similar to the status quo, a single facility can repair 30,000 windshields over ten years with cumulative costs of \$50.8 million. This price is for the repair only and does not account for the fixed costs associated with establishing the facility.⁴

⁴ PEO LS also provided an estimate that a repair facility with a throughput of 5,000 windshields would have a fixed cost of \$7.8 million, but we do not have estimates of the fixed costs for other repair facility sizes.

Vehicle availability falls from 11,000 to 6,600. Since the repair facility does not have enough capacity to repair all delaminated windshields, we assumed that priority would go to the highest cost windshields, where the savings would be greatest. Based on windshield costs, the order of priority would be LVSR windshields, followed by windshields for the MRAP, MTRV, M-ATV, HMMWV M1114, and Armored HMMWV.

At 5,000 windshields per year, which is equivalent to the larger facility being assessed by the contractor, 50,000 windshields would be installed over ten years with cumulative costs of \$82.8 million. Vehicle availability falls from 11,000 to 8,900, with priority still going to the costliest windshields.

At 8,000 windshields per year, similar to the steady state in Scenario 2, 72,800 windshields would be installed over ten years, with cumulative costs of \$122.1 million. Vehicle availability increases to 14,500 over that period. These results, along with those for the original four scenarios, are summarized in Table 5.1.

Table 5.1
Comparison of Costs and Vehicle Availability

Scenario	Number of Windshields Replaced over Ten Years	Ten-Year Cost (FY 2017 \$ millions)	Vehicle Availability in Year Ten
1. Status Quo	30,800	79.0	3,522 (22%)
2. Replace Immediately	81,000	272.1	15,820 (100%)
3. Repair 1,000 per year	Insufficient capacity, must decide how to allocate		
3a. Repair 3,000 per year	30,000	50.8 ^a	6,653 (42%)
3b. Repair 5,000 per year	50,000	82.8 ^a	8,973 (57%)
3c. Repair 8,000 per year	72,900	122.1 ^a	14,563 (92%)
4. Automotive Glass	45,100	100.2	5,453 (34%)
Ballistic portion	24,400	96.2	5,453 (100%)
Automotive portion	20,700	4.0	10,367 (100%) ^b

^a Excludes fixed costs of repair facility, estimated at \$5.0 million for 1,000 windshields per year and \$7.8 million for 5,000 windshields per year.

^b Available for training, but not for deployment if ballistic glass is required.

Scenario 4: Transition to Automotive Glass

Scenario 4 considered an option where a portion of the vehicular fleet's ballistic glass would be replaced with automotive glass when it reached State 3. In this scenario, a portion of the fleet retained ballistic glass (prepositioned stocks, a portion of the MEF fleet, MRAPs, and M-ATVs). The ballistic glass portion of this scenario resulted in 24,400 installations over ten years at a cost of \$96.2 million and vehicle availability of 100 percent. The remaining portion of the fleet outfitted with automotive glass required 20,700 installations over ten years at a cost of \$4.0 million. The total number of installations and cumulative costs for Scenario 4 over ten years were 45,100 at \$100.2 million. The availability of vehicles for training was 100 percent; however, overall availability for deployment was only 34 percent, if all vehicles need to be armored for deployment.

Sensitivity Analyses

As discussed in Chapter Four, we also conducted a sensitivity analysis on the length of time it takes for windshields to delaminate. These results are summarized in Table 5.2. The number of windshields replaced and ten-year costs remain fairly constant (there is a marginal decrease, but the changes are small, except in Scenario 2) and this analysis does not change the rankings of the scenarios in terms of relative costs and vehicle availability.

Table 5.3 shows the results of an additional sensitivity analysis that we performed for the repair facility scenario due to uncertainty about the cost of the repair process. After speaking with PEO LS, we determined that repair costs could range from one-third of the cost of a new windshield to as much as two-thirds of the cost. Therefore, the repair scenario was run under three different cost parameters, one where the repaired glass cost one-third, one where it cost one-half, and one where it cost two-thirds of the cost of new windshields.

Table 5.2
Sensitivity Analysis on Time to Delaminate

Scenario	Delamination Timeline (years)	Number of Windshields Replaced over Ten Years	Ten-Year Cost (FY 2017 dollars)	Vehicle Availability in Year Ten
1. Status Quo	4	30,800	79.0	3,522 (22%)
	6	30,400	78.4	5,684 (36%)
2. Replace Immediately	3	87,800	296.5	15,820 (100%)
	4	81,000	272.1	15,820 (100%)
	5	74,700	250.3	15,820 (100%)
	6	68,400	228.6	15,820 (100%)
3c. Repair 8,000 per year	3	74,500	125.4 ^a	13,213 (84%)
	4	72,900	122.1 ^a	14,563 (92%)
	5	70,900	119.8 ^a	15,706 (99%)
	6	65,700	110.3 ^a	15,820 (100%)

^a Excludes fixed costs of repair facility, estimated at \$7.8 million for 5,000 windshields per year.

Table 5.3
Sensitivity Analysis on the Cost of the Repair Process

Scenario	Number of Windshields Replaced over Ten Years	Ten-Year Cost ^a (FY 2017 \$ millions)	Vehicle Availability in Year Ten
3a. Repair 3,000 per year at 50% cost	30,000	50.8	6,653 (42%)
3b. Repair 5,000 per year at 50% cost	50,000	82.8	8,973 (57%)
3c. Repair 8,000 per year at 50% cost	72,900	122.1	14,563 (92%)
3-1a. Repair 3,000 per year at 33% cost	30,000	33.5	6,625 (42%)
3-1b. Repair 5,000 per year at 33% cost	50,000	55.5	8,862 (56%)
3-1c. Repair 8,000 per year at 33% cost	72,800	81.3	14,620 (92%)
3-2a. Repair 8,000 per year at 66% cost	72,900	163.3	14,676 (93%)

^a Excludes fixed costs of repair facility, estimated at \$7.8 million for 5,000 windshields per year.

Scenarios 5 and 6: Hybrid and JLTV Integration

The results of the hybrid and JLTV scenarios are shown in Table 5.4. In Scenario 5, all delaminated HMMWV windshields are replaced, and all other windshields are repaired at a facility with a throughput of 5,000 windshields per year. This scenario resulted in 80,800 windshields replaced over the ten-year period at a cost of \$153.7 million and with 100-percent vehicle availability in year ten. Thus, replacement rates and vehicle availability were similar to Scenario 2 at a cost of only about \$30 million more than a repair facility with a capacity of 8,000 windshields per year. To determine whether the capacity of 5,000 repairs per year was sufficient, we also ran a version of the model with a capacity of 8,000 repairs per year. This resulted in minimal impact (80,900 repairs over ten years at a cost of \$154.4 million and the same vehicle availability). Therefore, it appears that a facility capable of 5,000 repairs per year would be appropriate to achieve 100-percent vehicle availability.

Scenario 6, which incorporates JLTV fielding, results in some short-term reductions in windshield replacements and costs, because they are assumed to have no delamination when they are initially

Table 5.4
Results of the Hybrid and JLTV Scenarios

Scenario	Number of Windshields Replaced over Ten Years	Ten-Year Costs (FY 2017 \$ millions)	Vehicle Availability in Year Ten
5. Hybrid (Repair 5,000 per year)	80,800	153.7 ^a	15,820 (100%)
5a. Hybrid (Repair 8,000 per year)	80,900	154.4 ^a	15,820 (100%)
6a. JLTV (Replace Immediately)	73,900	294.4	15,820 (100%)
6b. JLTV (Repair 5,000 per year)	50,000	93.6 ^a	8,173 (52%)
6c. JLTV (Repair 8,000 per year)	69,400	139.5 ^a	13,976 (88%)

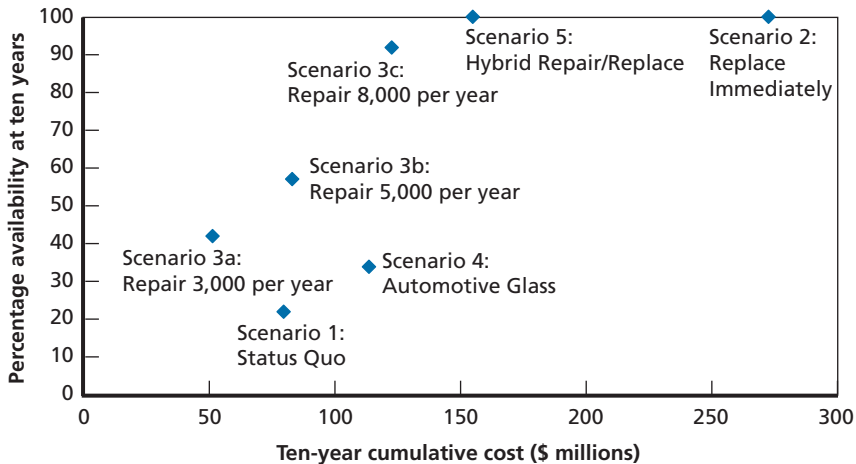
^a Excludes fixed costs of repair facility, estimated at \$7.8 million for 5,000 windshields per year.

fielded. However, as the JLTV windshields begin to delaminate, repair and replacement costs increase because JLTV windshields are more expensive than HMMWV windshields. As a result, ten-year costs are approximately 10- to 15-percent higher than the comparable scenarios without JLTVs. Total cumulative costs ranged from \$93.6 million to \$294.4 million, based on three different replace and repair assumptions.

Cost-Effectiveness Analysis

One way to compare the model results for each scenario is by using cost-effectiveness analysis, with vehicle availability in year ten as the measure of effectiveness.⁵ Figure 5.6 compares each of the four original scenarios in Table 5.1, as well as the hybrid scenario with a repair

Figure 5.6
Cost-Effectiveness of Scenarios



NOTE: Costs are in FY 2017 dollars.

RAND RR2285-5.6

⁵ Francois Melese, "The Economic Evaluation of Alternatives," in Francois Melese, Anke Richter, and Binyam Solomon, eds., *Military Cost-Benefit Analysis: Theory and Practice*, Abingdon, U.K.: Routledge Studies in Defence and Peace Economics, 2015, pp. 74–109.

capacity of 5,000 windshields per year (Scenario 5 in Table 5.4). Vehicle availability at year ten is shown on the y-axis, and ten-year cumulative cost is shown on the x-axis. Scenarios in the upper-left of the chart are preferred, because they achieve higher vehicle availability at lower cost. For example, the hybrid scenario (5) would be preferred over replacing all windshields immediately because it achieves the same availability in year ten at a lower cost. A caveat is that this framework does not capture all risks associated with each scenario. For example, a large enough repair facility might be able to achieve 100-percent availability in year ten at a lower cost than the hybrid scenario, but since the repair technology has not yet been operated at this scale, there is a risk that the desired availability would not be achieved.

To summarize, as the Marine Corps currently operates, there is an increasing risk that ballistic glass delamination will significantly affect equipment readiness. The availability of vehicles for training and deployment continues to fall at current windshield replacement rates. Replacing all windshields with delamination in the wiped area is more expensive but fixes vehicle availability issues. However, DLA does not currently have the inventory to support this high rate of replacement. If the repair technology being developed can be operated at a sufficient scale, then using a repair facility would be a less costly approach, but it would need to be sized to meet steady-state demands. A hybrid scenario that combines the replacement of lower-cost HMMWV windshields with the repair of higher-cost windshields achieves high vehicle availability, would allow the Marine Corps some time to test the repair technology, and would reduce pressure on DLA to increase its inventory of ballistic glass. Using automotive glass improves vehicle availability for training but could be problematic if a large-scale contingency requires rapid deployment of those vehicles. In the next chapter, we outline recommended approaches based on these modeling results and SME interviews.

Findings and Recommendations

Findings and recommendations are derived from interviews, observations during data collection, and modeling results.

Findings

The Marine Corps currently has approximately 16,000 tactical vehicles that require ballistic glass. Based on our field data collection, a significant percentage of these vehicles have delamination in the wiped areas of their windshields, particularly in the HMMWV and MTRV fleets. This degrades vehicle effectiveness and could pose a serious risk to equipment readiness. An analysis of a limited sample of windshield manufacture dates indicates that half or more of windshields manufactured in 2012 or earlier are delaminated, which supports an average time to delamination of four to six years. It may be possible to refine this estimate by collecting maintenance data on vehicle serial numbers in the sample.

Using a simulation model estimating sustainment costs and vehicle availability over a ten-year period, we found that at current replacement rates, delamination will continue to outpace replacements, and vehicle availability is likely to collapse over time. To restore 100-percent vehicle availability, replacing all delaminated windshields immediately would cost approximately \$272 million over ten years. If the repair technology proves to be reliable, then constructing one or more repair facilities could be a less costly approach, but the facility would need to be sized to meet steady-state demands of 6,000 to 8,000 windshields

annually, depending on the speed of delamination. Use of automotive glass in training vehicles offers a lower-cost option but involves significant concerns and therefore is not recommended for the Marine Corps at this time.

Recommendations

Assuming that the repair technology can be scaled up, a promising alternative is a hybrid solution based on building a repair facility with a capacity of 5,000 windshields per year that would focus on repairing higher-cost windshields (i.e., for LVSRs, MTVRs, and MRAPs), while replacing lower-cost HMMWV windshields. This approach would also reduce reliance on DLA to acquire inventories of ballistic glass. The benefits and risks of each of the most promising options that achieve high rates of vehicle availability are summarized in Table 6.1. Senior leaders should weigh these benefits and risks when choosing the best course of action.

Table 6.1
Benefits and Risks of Replace, Repair, and Hybrid Scenarios

Scenario	Benefits and Risks
2. Replace Immediately	Benefits: high vehicle availability, assuming sufficient ballistic glass is in stock Risks: highest-cost option; could take time for DLA to acquire increased inventories
3. Repair	Benefits: lower-cost approach to achieve high vehicle availability Risks: technology is in development; may be difficult to scale up or may delaminate faster than newly manufactured glass
5. Hybrid	Benefits: allows time to test repair technology while improving vehicle availability; less reliance on DLA to acquire inventories Risks: higher costs than Scenario 3 if repair technology is effective

Additional Mitigation Steps

The Marine Corps should continue to develop and implement improved specifications, including service life and environmental testing requirements, for newly manufactured glass to improve its life span. The Marine Corps should also coordinate with the Army, which has large, armored tactical vehicle fleets and should support continued research into better manufacturing technology. A significant improvement in the life span of ballistic glass (in the range of eight to ten years) could reduce future costs after the initial backlog of delaminated glass is replaced or repaired.¹ Some marginal improvements in the life span of ballistic glass might also be possible if operators and maintainers cover windshields when vehicles are not in use to reduce sun exposure. In addition, the Marine Corps should consider how much of the tactical vehicle fleet, particularly HMMWVs, LVSRs, and MTVRs, needs to be armored for future operations. Does the need for armored tactical vehicles for operations in Iraq and Afghanistan reflect a permanent change, or will fewer of these vehicles, or different types of vehicles, be needed in the future?

Finally, the Marine Corps should adopt maintenance procedures that specify deadlining criteria for ballistic glass delamination, and ensure the reporting and collection of relevant data to inform future resource allocation decisions. Additional data collection could better inform the average time to delamination. The Marine Corps could use GCSS-MC maintenance data to determine the year that ballistic glass was last installed for the vehicle serial numbers included in this study. It could also use the same data collection approach to inspect additional vehicles, or conduct follow-up analyses on the vehicles included in this study. Data collection and modeling could also be extended to side windows and gunner's turrets. These steps would improve forecasts of future ballistic glass sustainment costs.

¹ One reviewer suggested that future improvements in camera and monitor technology over the next ten years could allow ballistic glass to be replaced with armor embedded with multiple cameras, leveraging technologies associated with self-driving cars, tank periscopes, radar, and miniaturization. Future digital vision fields incorporating night vision, 360-degree views, and other enhancements may eventually be superior to ordinary vision through ballistic glass.

Interview Protocol for Subject-Matter Experts

1. What is your role in addressing problems related to delamination of ballistic glass in Marine Corps vehicles?
2. How were these windshields/side windows fielded?
 - a. Where would you suggest looking to help identify the number of vehicles that were fielded with this equipment?
3. How have delamination problems evolved over time?
4. Have changes in specifications and testing standards (e.g., ATPD 2352) helped reduce these problems?
 - a. Are any changes in these standards currently being considered?
5. What are the issues affecting the inability to meet maintenance demand (e.g., is this an issue with manufacturing, depot)?
6. How are maintainers characterizing these issues? Are they deadlining the vehicles?
 - a. What terms do they use to describe the issue in their maintenance reports or product quality deficiency reports?
7. What supply and maintenance systems or documentation do you recommend that we review to help us get a clearer picture of these issues?
8. What are some of the challenges in measuring the extent of delamination and forecasting future replacement costs?
9. What mitigation steps are currently being considered by the Marine Corps?
 - a. What are the advantages and disadvantages of different approaches?

10. Are you aware of how ballistic glass delamination is affecting the other services?
 - a. To the extent you are aware, what steps are they taking to mitigate this problem?
11. Are there other individuals or organizations that you would recommend we talk with?

Specific to PEO LS:

What factors are being considered for vehicle deadlining criteria?
What are the advantages and disadvantages of different criteria?

Data Collection Methodology

Marine Corps maintenance databases do not accurately track delamination occurring on tactical vehicle windshields. Many units do not replace delaminated windshields, either because of the cost or because there are no deadlining criteria that specify when they must be replaced. To overcome this data limitation, the research team conducted in-person visual inspections of a sample of more than 1,000 tactical vehicles, with support from Marine Corps personnel. Researchers visited three Marine Corps installations and provided data collection instructions to III MEF personnel. Data were collected from 43 units at these locations. The remainder of this appendix documents the data collection method so as to enable similar future efforts, at least until such time that Marine Corps maintenance systems accurately reflect delamination.¹

Data Collection Design

Site Selection

Marine Corps tactical vehicles examined in this study—the HMMWV, M-ATV, MRAP, LVSF, and MTVR—are used by both the operational forces and the supporting establishment. Table B.1 depicts the current inventory of armored vehicles across Marine Corps commands

¹ A copy of the data set can be obtained from the authors, with the permission of the research sponsor.

and organizations.² In aggregate, most vehicles are located at one of the three MEFs: I MEF in Camp Pendleton, California; II MEF in Camp Lejeune, North Carolina; and III MEF in Okinawa, Japan. Other locations include deployed units and organizations, reserve component units, prepositioned stocks, depots, training locations, and headquarters. The study team elected to collect data from the three MEFs in order to inspect a statistically meaningful number of vehicles during the time allotted for this project. The other benefit of selecting the MEFs as inspection sites is that the sample reflects different climate and storage conditions (e.g., Okinawa frequently experiences typhoons). A pilot test also included one headquarters unit in Quantico, Virginia, at which time the data collection approach was finalized.

Inspections at each of the MEFs included visits to the motor pools of the units listed in Table B.2. The sample included vehicles from air, ground, logistics, and MEF headquarters units, such as communications and reconnaissance battalions. Including a wide array of units helped to ensure that the sample accounts for differences in the ways the vehicles may be operated, maintained, or stored.

Sample Size

Due to the large size of the vehicle fleet and the number of locations, inspecting every vehicle was neither plausible nor necessary. Researchers established a goal of inspecting 10 percent of each vehicle type at each of the three MEFs (e.g., 10 percent of the HMMWVs located at I MEF). The sampling strategy is shown in Table B.3. Because of the small numbers of M-ATVs and MRAPs assigned to the MEFs, the research team aimed to collect more than a 10-percent sample to provide a better basis for extrapolation.

In Table B.4, we show the actual number of vehicles inspected at each location, along with the original sample size goals. At the MEFs, we did not find any HMMWV MAKs or MTRVs with RTAA upgrades

² In the simulation model, prepositioned stocks (Maritime Prepositioning Squadron [MPS]-2, MPS-3, MCPP-N, and MEU Augmentation Program-Kuwait [MAP-K]) were combined into a single category. Vehicles owned by the remaining organizations (other than the MEFs) were grouped into the "Other" category.

Table B.1
Current Armored Tactical Vehicle Inventory, by Command or Organization

TAMCN	I MEF	II MEF	III MEF	MARFOR RES	MPS- 2	MPS- 3	MCPP- N	MAP- K	MARFOR CENTCOM	MARFOR SOC	HQTRS USMC	MARFOR SOUTHCOM	MARFOR EUCOM	MARFOR AFRICOM	Marine Corps Security Force Regiment	DoDAAC Not Found in TFSMS	MCCDC DMFA
D0003	556	483	358	107	308	293	68	22	19	33	135	0	0	0	0	79	365
D0005	98	84	60	0	56	57	10	5	7	20	14	0	0	0	0	3	101
D0007	44	40	36	4	40	50	5	2	1	0	1	0	0	0	0	10	64
D0013	40	39	34	16	30	33	18	5	12	0	7	0	0	0	0	4	54
D0015	64	60	32	50	28	34	2	4	1	2	22	0	0	0	1	7	31
D1063	36	0	12	36	0	0	0	0	0	0	4	0	0	0	0	0	15
D0023	9	6	0	0	2	2	0	6	0	0	4	0	0	0	0	159	45
D0025	36	38	0	0	3	3	0	123	1	0	10	0	4	0	0	4	904
D0027	N/A	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D0036	44	19	2	0	0	0	0	231	13	4	3	0	0	0	0	8	225
D0052	46	33	16	4	86	100	0	3	2	0	21	0	0	0	0	144	1
D0053	10	7	6	0	14	16	0	0	0	0	1	0	0	0	0	22	5
D0054	13	10	4	2	9	5	0	1	1	0	5	0	0	0	0	8	3
D0030 (Armament)	783	720	497	689	115	45	95	0	8	8	179	0	0	0	31	22	582
D0032 (Tow)	89	71	44	50	26	6	4	0	0	0	92	0	0	0	0	7	56
D0033 (Cargo)	303	269	180	180	116	112	17	0	15	0	18	0	0	0	0	73	136
D0034 (C2)	170	161	90	86	445	408	22	0	1	115	32	0	0	2	0	11	93

Table B.1—Continued

TAMCN	I MEF	II MEF	III MEF	MARFOR RES	MPS- 2	MPS- 3	MCPP- N	MAP- K	MARFOR CENTCOM	MARFOR SOC	HQTRS USMC	MARFOR SOUTHCOM	MARFOR EUCOM	MARFOR AFRICOM	Marine Corps Security Force Regiment	DoDAAC Not Found in TFSMS	MCCDC DMFA
D1001	109	95	66	68	31	28	10	0	1	3	34	0	0	0	0	2	41

SOURCE: Data were pulled March 21, 2017 from TLCM-OST and additional information was provided by I and II MEF Motor Transport Maintenance personnel.

NOTE: MARFOR = U.S. Marine Corps Forces. RES = Reserve. CENTCOM = Central Command. SOC = Special Operations Command. HQTRS USMC = Headquarters, U.S. Marine Corps. SOUTHCOM = Southern Command. EUCOM = European Command. AFRICOM = Africa Command. DoDAAC = Department of Defense Activity Address Code. TFSMS = Total Force Structure Management System. MCCDC DMFA = Marine Corps Combat Development Command Depot Maintenance Float Allowance. C2 = command and control. N/A = not applicable. TAMCNs are defined in Table 2.1. Vehicles are grouped by type and location in Table 2.2.

Table B.2
Units Included in Vehicle Inspections

I MEF	II MEF	III MEF
11th Marine Regiment	2nd Combat Engineer Battalion	9th Engineer Support Battalion
11th MEU	2nd Law Enforcement Battalion	Combat Logistics Battalion-31 31st MEU
13th MEU	2nd Maintenance Battalion	Battalion Landing Team 3/5 31st MEU
1st Radio Battalion	2nd Marine Regiment	Combat Logistics Battalion-4
1st Transportation Support Battalion	2nd Radio Battalion	Marine Wing Support Squadron 172
3rd Assault Amphibian Battalion	2nd Reconnaissance Battalion	3rd Transportation Support Battalion
7th Engineering Support Battalion	2nd Supply Battalion	Transportation Support Battalion
9th Communications Battalion	2nd Transportation Support Battalion	Headquarters and Service Company Headquarters Battalion 3rd MARDIV
Assault Amphibian School Battalion	8th Communications Battalion	Communications Company Headquarters Battalion 3rd MARDIV
Combat Logistics Battalion-1	8th Engineer Support Battalion	Command Element 31st MEU
Combat Logistics Battalion-5	8th Marine Regiment	
Combat Services Support Company	Combat Logistics Battalion-2	
Engineering Support Battalion	Combat Logistics Battalion-6	
Headquarters Battalion	Combat Logistics Battalion-8	
Law Enforcement Battalion	Headquarters Battalion Truck Company	
Marine Headquarters Group Combat Element	II MEF Headquarters Group	
Marine Wing Support Squadron 371		

NOTE: MARDIV = Marine Division.

Table B.3
10-Percent Sample of Armored Fleet

Vehicle Type	I MEF	II MEF	III MEF
HMMWV (Armored)	145	132	88
HMMWV (MAK)	73	60	50
LVSR	37	33	20
M-ATV	4	2	0
MRAP	5	4	0
MTVR (Armored)	84	71	53
MTVR (RTAA)	77	74	50

SOURCE: TLCM-OST as of March 2017 and study sample design.

Table B.4
Number of Vehicles Inspected, by MEF

Vehicle	I MEF		II MEF		III MEF		Total Goal	Total Actual	Percentage of MEF Armored Fleet Inspected
	Goal	Actual	Goal	Actual	Goal	Actual			
HMMWV	224	242	192	193	138	82	554	517	14.2
LVSR	42	45	33	22	20	3	95	70	7.9
M-ATV	9	22	2	4	0	0	11	26	40.0
MRAP	6	16	4	5	0	0	10	21	23.6
MTVR	171	198	145	149	103	61	419	408	19.7

SOURCE: TLCM-OST as of March 2017 and study sample design and data collection.

that had ballistic glass installed. As a result, the vehicles we inspected represented more than a 10-percent sample of armored HMMWVs and MTVRs. Data collected in Okinawa fell short of the design goal due to low on-hand quantities within the motor pools. A large population of III MEF vehicles were either deployed or in use for training.

One limitation of the data collection methodology is that inspections were conducted on vehicles found in the unit motor pools at the time of collection. If vehicles were being used in support of missions (e.g., assigned to a deployed MEU) or training events, they were not inspected. Thus, it is possible that the vehicles in the best state, with little to no delamination, were not present at the time of inspection.

This may have resulted in a higher rate of delamination being observed. Also, since the focus of this study was on the windshields, data on side windows were not collected.

Delamination Criteria

Delamination can include cloudiness, bubbles, spots, whiteness, discoloration, and visual distortion. The study team categorized delamination into three states: no delamination, partial delamination, and full delamination, as defined in Table B.5.

Marine Corps PEO LS developed criteria to evaluate window delamination that renders vehicle operations unsafe based on MIL-STD-882E, *Department of Defense Standard Practice: System Safety*, in order to ensure a systematic approach to system safety risk.³ The outcome of PEO LS’s assessment was a criterion that allowed for a medium level of risk.

According to PEO LS guidelines, any delamination present in the wiped area of the windshield (the area the windshield wiper traverses) is considered delaminated and, for the purposes of this study, is defined as *full delamination*. The research team included the partial delamina-

Table B.5
Description of Delamination States

Windshield State	Description
No delamination	No cloudiness, bubbles, spots, whiteness, discoloration, or visual distortion observable anywhere on windshield
Partial delamination	Cloudiness, bubbles, spots, whiteness, discoloration, or visual distortion observed in the area of the windshield outside of the wiped area
Full delamination	Cloudiness, bubbles, spots, whiteness, discoloration, or visual distortion observed in the wiped area of the windshield

SOURCE: PEO LS, 2017.

³ Interview with Marine Corps PEO LS, January 18, 2017. According to program managers, delamination in the wiped area of the windshield is a greater safety concern than delamination outside this area. MIL-STD-882E identifies the Department of Defense approach for identifying hazards and assessing and mitigating associated risks encountered in the development, test, production, use, and disposal of defense systems. For more information, see U.S. Department of Defense, 2012.

tion state because delamination tends to spread from the outer edges of a windshield towards the wiped area; knowing the number of partially delaminated vehicles is helpful for predicting future delamination in the wiped area and the costs associated with replacing or repairing the glass.

One additional clarification regarding PEO LS criteria is that any amount of cloudiness, bubbles, spots, whiteness, discoloration, and/or visual distortion counts as delamination. For example, a bubble smaller than a penny counts as delamination.

Inspection Method

RAND researchers developed the method for visually inspecting the vehicles in close collaboration with OAD, PEO LS, and individuals serving on the study advisory committee.

Personnel

One or more RAND researchers and a representative from OAD led inspection teams at I MEF and II MEF. After coordination with the senior enlisted marine responsible for monitoring the MEF's motor transportation assets, inspection leads used a team of four to six junior enlisted marines to visually examine the required number of vehicles. This number and mix of personnel resulted in inspections being conducted within two days. The RAND researchers and OAD representative, together with the senior enlisted marine, assigned vehicles to pairs of inspectors and monitored data collection to ensure consistency and thoroughness. Junior marines familiar with the vehicles enabled inspections to proceed at a measured but swift pace. Based on their experience driving and/or maintaining the vehicles, these individuals could quickly and accurately identify whether coloring or spots were a result of delamination or another source of damage (e.g., scratches, markings left over from tape, dirt).

Representatives from RAND and OAD were unable to inspect vehicles at III MEF, but a detailed briefing was provided to the Marine Corps inspection team.

Measurement Device

To ensure systematic and consistent inspections, the data collection teams used plexiglass templates to mark where delamination was observed on each vehicle's windshield. Each template was divided into 91 numbered, one-inch squares. Inspection teams recorded which squares had delamination on data collection sheets. Figure B.1 depicts the plexiglass being placed by a marine onto a windshield. The same size and type of plexiglass was used at all three sites. Handles enabled the teams to carry the device with ease.

Measurement Instructions

Delamination can be difficult to identify. Dirty windshields or the presence of dew may make the windshield appear to be delaminated. Teams used towels and spray bottles with water to wipe the interior and exterior of the windshields. They also removed film or other protective layers that appeared on a small percentage of the vehicles. The full set of instructions provided to inspectors appears in Figure B.2.

Figure B.1
Plexiglass Template Applied to Windshield



SOURCE: Photo by Robert Hayden. Used with permission.

RAND RR2285-B.1

Figure B.2
Instructions for Inspection Teams

Instructions

1. Prior to examining vehicles, consider wearing sunglasses. Delamination can be difficult to spot in sunny conditions. Viewing the windshield with and without glasses may be helpful.
2. Stand next to the vehicle (HMMWV) or climb on top of it (all others).
3. If the outside of the windshield has a protective film, remove it.
4. Move the windshield wipers, cables, or any other objects off the windshield as needed.
5. Using water and cloth, thoroughly wipe the windshield on the outside of the vehicle. Make sure there is no dirt or other removable substance on the windshield.
6. Visually examine the windshield for signs of delamination on any part of the glass. Any delamination counts, even if there is a small spot. If the glass has zero signs of delamination, record and move on to the next vehicle.
7. If the windshield has any signs of delamination, place the plexiglass against the windshield. Align as flat against the windshield as possible. It is recognized that, in some cases, exterior objects may be in the way (e.g., Cougar's driver's side bracket that holds the antenna).
8. Record the grid squares where there is delamination.

Other Guidance

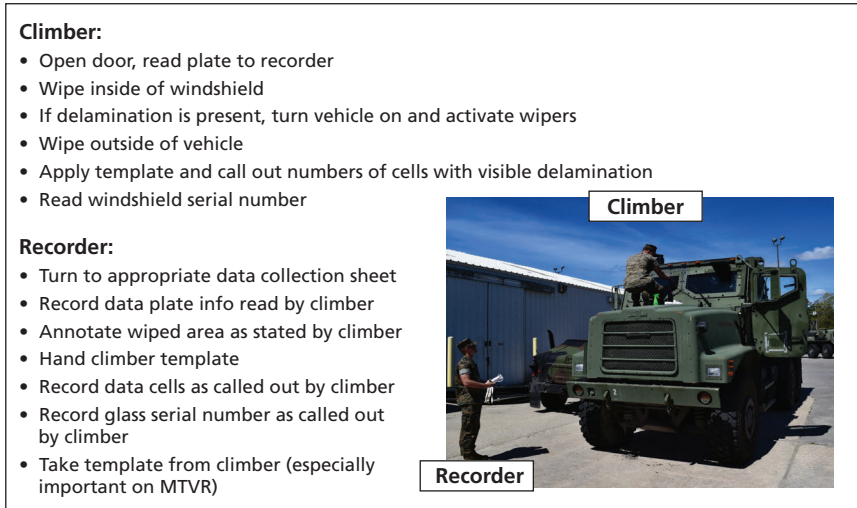
1. Work should be conducted during daylight hours only.
2. Work should be conducted in clear conditions (not during rain or dust storms).

RAND RR2285-B.2

Each pair of inspectors included a recorder and a climber. The recorder's primary responsibility was to write down the information provided by the climber, who read the vehicle's data plate, applied the plexiglass to the vehicle's windshield, and called out the numbers of the grid squares impacted by delamination. The recorder also prompted the climber to provide all the information required on the data collection sheet. This arrangement ensured that the recorder used the recording template properly and that no data elements were unintentionally not collected. Figure B.3 depicts the roles of the recorder and climber.

Each data collection team received a binder with a supply of data collection sheets for the different vehicle types. Figures B.4 through B.8 display the data collection sheets. The orange outline indicates the wiped area of the windshield. In addition to marking the grid squares with visible delamination, inspectors marked a check box if delamination was observed in the wiped area, and recorded the vehicle serial and registration numbers, the unit at which the vehicle was located, and the model number of the vehicle. For LVSRs and MTRVs, inspectors

Figure B.3
Recorder and Climber Roles



SOURCE: Photo by Robert Hayden. Used with permission.

RAND RR2285-B.3

also noted whether the vehicle had an egress handle. Where visible, inspectors also recorded the serial number of the glass, as shown in Figure B.9. Approximately 20 percent of windshields had visible serial numbers.

Lessons Learned

For future efforts, data collection teams should consider the following observations:

- wind makes data collection difficult (doors close and templates fall)
- sunglasses did not assist in identifying delamination
- some vehicles have exterior brackets (see Figure B.10), which prevent the plexiglass template from fitting directly on the windshield. In this case, data collectors should place it at a 90-degree angle to the hood of the vehicle, as close to the windshield as possible.

Figure B.4
HMMWV Data Collection Sheet

Wiped area

P	1	8	15	22	29	36	43	50	57	64	71	78	85
A	2	9	16	23	30	37	44	51	58	65	72	79	86
S	3	10	17	24	31	38	45	52	59	66	73	80	87
E	4	11	18	25	32	39	46	53	60	67	74	81	88
N	5	12	19	26	33	40	47	54	61	68	75	82	89
G	6	13	20	27	34	41	48	55	62	69	76	83	90
E	7	14	21	28	35	42	49	56	63	70	77	84	91
R													

Wiped area

1	8	15	22	29	36	43	50	57	64	71	78	85
2	9	16	23	30	37	44	51	58	65	72	79	86
3	10	17	24	31	38	45	52	59	66	73	80	87
4	11	18	25	32	39	46	53	60	67	74	81	88
5	12	19	26	33	40	47	54	61	68	75	82	89
6	13	20	27	34	41	48	55	62	69	76	83	90
7	14	21	28	35	42	49	56	63	70	77	84	91

Mfr's Serial Number:

Unit:

Registration Number:



SOURCE: Photo by Robert Hayden. Used with permission.
NOTE: Mfr = manufacturer.

RAND RR2285-B.4

- cloudy days make it more difficult to see the delamination from the outside looking into the vehicle but less difficult to see from the inside of the vehicle
- rain the day before yields a substantial amount of water and condensation in the vehicles, causing the data collectors to use more rags for wiping the windshields.

The results of the data collection and the extrapolation to the remainder of the fleet are summarized in Table B.6. State 1 indicates no delamination, State 2 indicates partial delamination, and State 3 indicates delamination in the wiped area of the windshield. In each pair of states, the first number represents the driver's side and the second number represents the codriver's (or passenger's) side. For example, State 2,1 indicates partial delamination on the driver's side and

Figure B.5
LVSR Data Collection Sheet

☐ Wiped area

P	1	8	15	22	29	36	43	50	57	64	71	78	85
A	2	9	16	23	30	37	44	51	58	65	72	79	86
S	3	10	17	24	31	38	45	52	59	66	73	80	87
E	4	11	18	25	32	39	46	53	60	67	74	81	88
N	5	12	19	26	33	40	47	54	61	68	75	82	89
G	6	13	20	27	34	41	48	55	62	69	76	83	90
E	7	14	21	28	35	42	49	56	63	70	77	84	91
R													

U.S. Marine Corps
Serial Number: _____

☐ Wiped area

1	8	15	22	29	36	43	50	57	64	71	78	85
2	9	16	23	30	37	44	51	58	65	72	79	86
3	10	17	24	31	38	45	52	59	66	73	80	87
4	11	18	25	32	39	46	53	60	67	74	81	88
5	12	19	26	33	40	47	54	61	68	75	82	89
6	13	20	27	34	41	48	55	62	69	76	83	90
7	14	21	28	35	42	49	56	63	70	77	84	91

Unit: _____

☐ Egress Handle





SOURCE: Photos by Robert Hayden. Used with permission.
RAND RR2285-B.5

no delamination on the passenger’s side. We used the percentage of windshields observed in each state to extrapolate to the remainder of the fleet at each location. Note that we assumed that all vehicles had no delamination in either windshield when they were placed into prepositioned stocks, and we used a weighted average of the vehicles observed at I MEF, II MEF, and III MEF to extrapolate to the “Other” category. When the sample size was too small at III MEF (for HMMWV M1114s, LVSRs, and M-ATVs), we used the weighted average.

Figure B.6
M-ATV Data Collection Sheet

Wiped area

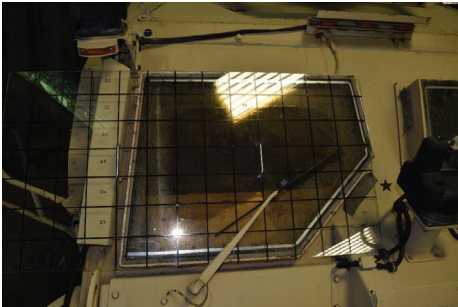
P	1	8	15	22	29	36	43	50	57	64	71	78	85
A	2	9	16	23	30	37	44	51	58	65	72	79	86
S	3	10	17	24	31	38	45	52	59	66	73	80	87
E	4	11	18	25	32	39	46	53	60	67	74	81	88
N	5	12	19	26	33	40	47	54	61	68	75	82	89
G	6	13	20	27	34	41	48	55	62	69	76	83	90
E	7	14	21	28	35	42	49	56	63	70	77	84	91
R													

Wiped area

1	8	15	22	29	36	43	50	57	64	71	78	85
2	9	16	23	30	37	44	51	58	65	72	79	86
3	10	17	24	31	38	45	52	59	66	73	80	87
4	11	18	25	32	39	46	53	60	67	74	81	88
5	12	19	26	33	40	47	54	61	68	75	82	89
6	13	20	27	34	41	48	55	62	69	76	83	90
7	14	21	28	35	42	49	56	63	70	77	84	91

Registration Number: _____

Unit: _____



SOURCE: Photo by Robert Hayden. Used with permission.
RAND RR2285-B.6

Figure B.7
MRAP Data Collection Sheet

Wiped area

P	1	8	15	22	29	36	43	50	57	64	71	78	85
A	2	9	16	23	30	37	44	51	58	65	72	79	86
S	3	10	17	24	31	38	45	52	59	66	73	80	87
E	4	11	18	25	32	39	46	53	60	67	74	81	88
N	5	12	19	26	33	40	47	54	61	68	75	82	89
G	6	13	20	27	34	41	48	55	62	69	76	83	90
E	7	14	21	28	35	42	49	56	63	70	77	84	91
R													

Wiped area

1	8	15	22	29	36	43	50	57	64	71	78	85
2	9	16	23	30	37	44	51	58	65	72	79	86
3	10	17	24	31	38	45	52	59	66	73	80	87
4	11	18	25	32	39	46	53	60	67	74	81	88
5	12	19	26	33	40	47	54	61	68	75	82	89
6	13	20	27	34	41	48	55	62	69	76	83	90
7	14	21	28	35	42	49	56	63	70	77	84	91

D
R
I
V
E
R

Customer Serial Number: _____

Unit: _____

Vehicle ID Number: _____



SOURCE: Photo by Robert Hayden. Used with permission.

RAND RR2285-B.7

Figure B.8
MTVR Data Collection Sheet

Wiped area

P	1	8	15	22	29	36	43	50	57	64	71	78	85
A	2	9	16	23	30	37	44	51	58	65	72	79	86
S	3	10	17	24	31	38	45	52	59	66	73	80	87
S	4	11	18	25	32	39	46	53	60	67	74	81	88
E	5	12	19	26	33	40	47	54	61	68	75	82	89
N	6	13	20	27	34	41	48	55	62	69	76	83	90
G	7	14	21	28	35	42	49	56	63	70	77	84	91
E													
R													

Model Number: _____

U.S. Marine Corps

Serial Number: _____



Wiped area

1	8	15	22	29	36	43	50	57	64	71	78	85
2	9	16	23	30	37	44	51	58	65	72	79	86
3	10	17	24	31	38	45	52	59	66	73	80	87
4	11	18	25	32	39	46	53	60	67	74	81	88
5	12	19	26	33	40	47	54	61	68	75	82	89
6	13	20	27	34	41	48	55	62	69	76	83	90
7	14	21	28	35	42	49	56	63	70	77	84	91

Unit: _____



D
R
I
V
E
R

SOURCE: Photos by Robert Hayden. Used with permission.
RAND RR2285-B.8

Figure B.9
Serial Number Locations on Windshields



SOURCE: Photos by Robert Hayden. Used with permission.

RAND RR2285-B.9

Figure B.10
HMMWV with Exterior Bracket



SOURCE: Photo by Robert Hayden. Used with permission.

RAND RR2285-B.10

Table B.6
Initial Conditions of Tactical Vehicle Fleet

Vehicle and State	I MEF		II MEF		III MEF		Prepositioned		Other	
	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated
HMMWV (M1114)	N = 92	N = 783	N = 129	N = 720	N = 226	N = 497	N/A	N = 255	N = 226	N = 1,519
1,1	3.26%	26	34.11%	246	20.80%	103		255	20.80%	316
1,2	0.00%	0	6.98%	50	3.98%	20		0	3.98%	60
1,3	1.09%	8	7.75%	56	4.87%	24		0	4.87%	74
2,1	2.17%	17	3.10%	22	2.65%	13		0	2.65%	40
2,2	2.17%	17	1.55%	11	2.21%	11		0	2.21%	34
2,3	8.70%	68	5.43%	39	7.08%	35		0	7.08%	107
3,1	0.00%	0	9.30%	67	5.31%	27		0	5.31%	81
3,2	19.57%	153	5.43%	39	11.50%	57		0	11.50%	175
3,3	63.04%	494	26.36%	190	41.59%	207		0	41.59%	632
HMMWV (Other)	N = 137	N = 671	N = 59	N = 596	N = 53	N = 380	N/A	N = 1,225	N = 249	N = 1,116
1,1	24.09%	162	23.73%	142	3.77%	15		1,225	19.68%	220
1,2	7.30%	49	1.69%	10	3.77%	14		0	5.22%	58
1,3	4.38%	29	3.39%	20	1.89%	7		0	3.61%	40
2,1	4.38%	29	3.39%	20	0.00%	0		0	3.21%	36
2,2	4.38%	29	6.78%	40	0.00%	0		0	4.02%	45
2,3	2.19%	15	3.39%	20	1.89%	7		0	2.41%	27

Table B.6—Continued

Vehicle and State	I MEF		II MEF		III MEF		Prepositioned		Other	
	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated
3,1	10.22%	69	6.78%	40	13.21%	50		0	10.04%	112
3,2	5.84%	39	10.17%	61	11.32%	43		0	8.03%	90
3,3	37.24%	250	40.68%	243	64.15%	244		0	43.78%	488
LVSR	N = 35	N = 366	N = 22	N = 328	N = 60	N = 195	N/A	N = 256	N = 60	N = 546
1,1	100%	366	77.27%	253	88.33%	172		256	88.33%	483
1,2	0	0	9.09%	30	3.33%	7		0	3.33%	18
1,3	0	0	4.55%	15	3.33%	7		0	3.33%	18
2,1	0	0	4.55%	15	1.67%	3		0	1.67%	9
2,2	0	0	4.55%	15	3.33%	6		0	3.33%	18
2,3	0	0	0.00%	0	0.00%	0		0	0.00%	0
3,1	0	0	0.00%	0	0.00%	0		0	0.00%	0
3,2	0	0	0.00%	0	0.00%	0		0	0.00%	0
3,3	0	0	0.00%	0	0.00%	0		0	0.00%	0
M-ATV	N = 14	N = 44	N = 4	N = 19	N = 18	N = 2	N/A	N = 231	N = 18	N = 253
1,1	64.29%	28	50%	9	61.11%	1		231	61.11%	155
1,2	0.00%	0	0	0	0.00%	0		0	0.00%	0
1,3	7.14%	3	25%	5	11.11%	0		0	11.11%	28
2,1	0.00%	0	0	0	0.00%	0		0	0.00%	0
2,2	0.00%	0	0	0	0.00%	0		0	0.00%	0

Table B.6—Continued

Vehicle and State	I MEF		II MEF		III MEF		Prepositioned		Other	
	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated
2,3	0.00%	0	0	0	0.00%	0		0	0.00%	0
3,1	28.57%	13	0	0	22.22%	1		0	22.22%	56
3,2	0.00%	0	0	0	0.00%	0		0	0.00%	0
3,3	0.00%	0	25%	5	5.56%	0		0	5.56%	14
MRAP	N = 14	N = 45	N = 5	N = 50	N = 19	N = 0	N/A	N = 139	N = 19	N = 1,131
1,1	64.29%	29	80%	40	68.42%	0		139	68.42%	774
1,2	0.00%	0	0	0	0.00%	0		0	0.00%	0
1,3	0.00%	0	20%	10	5.26%	0		0	5.26%	60
2,1	0.00%	0	0	0	0.00%	0		0	0.00%	0
2,2	7.14%	3	0	0	5.26%	0		0	5.26%	59
2,3	0.00%	0	0	0	0.00%	0		0	0.00%	0
3,1	7.14%	3	0	0	5.26%	0		0	5.26%	59
3,2	0.00%	0	0	0	0.00%	0		0	0.00%	0
3,3	21.43%	10	0	0	15.79%	0		0	15.79%	179
MTVR	N = 172	N = 838	N = 149	N = 706	N = 61	N = 532	N/A	N = 1,070	N = 382	N = 1,225
1,1	44.19%	370	35.57%	251	6.56%	35		1,070	34.82%	426
1,2	2.33%	20	2.68%	19	4.92%	26		0	2.88%	35
1,3	4.65%	39	16.11%	114	16.39%	87		0	10.99%	135
2,1	3.49%	29	3.36%	24	3.28%	17		0	3.40%	42

Table B.6—Continued

Vehicle and State	I MEF		II MEF		III MEF		Prepositioned		Other	
	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated	Percentage Observed	Extrapolated
2,2	2.33%	19	0.67%	5	0.00%	0		0	1.31%	16
2,3	12.21%	102	4.70%	33	8.20%	44		0	8.64%	106
3,1	9.30%	78	6.04%	42	4.92%	26		0	7.33%	90
3,2	2.33%	20	0.67%	5	1.64%	9		0	1.57%	19
3,3	19.19%	161	30.20%	213	54.10%	288		0	29.06%	356

NOTE: N/A = not applicable.

Simulation Model Results

In this appendix, we provide more-detailed information on the results of the simulation model for each scenario. Each set of results includes three tables, the first showing the number of windshields installed by year and vehicle type, the second showing annual costs by vehicle type, and the third showing vehicle availability by year and vehicle type.¹

¹ In the tables showing annual costs by vehicle type, the calculations were done in dollars and cents. Any discrepancies in the column or row totals are due to rounding.

Scenario 1: Status Quo

Table C.1
Number of Windshields Installed, Status Quo (Average Delamination Time:
Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	1,488	530	40	66	301	577	3,002
2019	1,422	517	61	0	250	578	2,828
2020	1,270	531	141	160	302	561	2,965
2021	1,462	499	177	159	313	540	3,150
2022	1,471	518	144	167	293	563	3,156
2023	1,487	515	148	159	314	545	3,168
2024	1,484	523	149	165	289	559	3,169
2025	1,472	517	139	167	307	551	3,153
2026	1,462	545	135	166	298	562	3,168
2027	1,358	511	135	167	295	592	3,058
Total	14,376	5,206	1,269	1,376	2,962	5,628	30,817

Table C.2
Annual Costs, Status Quo (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$844,707	\$610,561	\$286,560	\$214,395	\$1,873,124	\$3,313,999	\$7,143,346
2019	\$807,246	\$595,584	\$458,956	\$0	\$1,555,750	\$3,319,977	\$6,737,513
2020	\$721,801	\$611,712	\$1,071,585	\$520,211	\$1,879,347	\$3,222,171	\$8,026,827
2021	\$829,806	\$574,849	\$1,339,147	\$517,075	\$1,947,799	\$3,101,608	\$8,310,283
2022	\$834,953	\$596,736	\$1,095,710	\$542,928	\$1,823,339	\$3,233,631	\$8,127,297
2023	\$843,991	\$593,280	\$1,139,292	\$517,176	\$1,954,022	\$3,130,302	\$8,178,063
2024	\$842,362	\$602,496	\$1,130,652	\$536,592	\$1,798,447	\$3,210,693	\$8,121,242
2025	\$835,576	\$595,584	\$1,054,622	\$542,962	\$1,910,461	\$3,164,781	\$8,103,986
2026	\$829,966	\$627,840	\$1,015,430	\$539,794	\$1,854,454	\$3,227,964	\$8,095,448
2027	\$771,354	\$588,672	\$1,027,722	\$543,200	\$1,835,785	\$3,400,215	\$8,166,948
Total	\$8,161,762	\$5,997,314	\$9,619,676	\$4,474,333	\$18,432,528	\$32,325,341	\$79,010,953

NOTE: Costs are in FY 2017 dollars.

Table C.3
Vehicle Availability, Status Quo (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	2,936	1,689	1,691	484	1,256	2,952	11,008
2019	3,527	1,847	1,691	484	1,365	3,224	12,138
2020	3,684	1,421	1,267	466	1,219	2,511	10,568
2021	3,219	888	613	347	847	1,450	7,364
2022	2,842	672	324	277	562	839	5,516
2023	2,493	512	202	234	358	607	4,406
2024	2,450	389	142	263	366	517	4,127
2025	2,530	491	118	277	377	694	4,487
2026	2,482	475	107	290	498	895	4,747
2027	1,212	797	131	229	379	774	3,522

Table C.4
Number of Windshields Installed, Status Quo (Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	1,488	530	40	66	301	577	3,002
2019	1,367	517	36	0	235	580	2,735
2020	1,054	550	142	105	269	550	2,670
2021	1,396	497	141	159	303	577	3,073
2022	1,491	519	160	161	304	531	3,166
2023	1,455	495	176	171	305	564	3,166
2024	1,496	522	142	146	296	553	3,155
2025	1,447	517	164	170	296	565	3,159
2026	1,490	526	118	161	303	549	3,147
2027	1,421	527	147	165	307	582	3,149
Total	14,105	5,200	1,266	1,304	2,919	5,628	30,422

Table C.5
Annual Costs, Status Quo (Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$844,707	\$610,561	\$286,560	\$214,395	\$1,873,124	\$3,313,999	\$7,143,346
2019	\$776,271	\$595,584	\$276,344	\$0	\$1,462,405	\$3,331,473	\$6,442,077
2020	\$600,133	\$633,601	\$1,079,627	\$341,721	\$1,673,988	\$3,159,015	\$7,488,084
2021	\$792,718	\$572,544	\$1,071,585	\$517,040	\$1,885,569	\$3,314,059	\$8,153,515
2022	\$846,253	\$597,888	\$1,219,992	\$523,581	\$1,891,792	\$3,049,893	\$8,129,399
2023	\$825,895	\$570,240	\$1,345,152	\$556,008	\$1,898,015	\$3,239,361	\$8,434,671
2024	\$849,028	\$601,344	\$1,083,138	\$474,768	\$1,842,008	\$3,176,277	\$8,026,563
2025	\$821,471	\$595,584	\$1,238,112	\$552,806	\$1,842,008	\$3,245,181	\$8,295,162
2026	\$845,800	\$605,952	\$893,642	\$523,546	\$1,885,569	\$3,153,303	\$7,907,812
2027	\$806,663	\$607,104	\$1,109,300	\$536,762	\$1,910,461	\$3,342,753	\$8,313,043
Total	\$8,008,939	\$5,990,402	\$9,603,452	\$4,240,627	\$18,164,939	\$32,325,314	\$78,333,672

NOTE: Costs are in FY 2017 dollars.

Table C.6
Vehicle Availability, Status Quo (Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	2,938	1,694	1,691	484	1,256	2,909	10,972
2019	3,549	1,759	1,691	484	1,365	3,085	11,933
2020	3,895	1,723	1,515	484	1,365	2,782	11,764
2021	3,910	1,339	1,002	431	1,136	2,070	9,888
2022	3,400	1,157	583	354	776	1,493	7,763
2023	3,053	793	344	303	613	1,211	6,317
2024	2,736	690	228	278	556	924	5,412
2025	2,904	530	143	309	531	762	5,179
2026	3,037	650	114	353	585	788	5,527
2027	3,043	763	122	369	535	852	5,684

Scenario 2: Replace Immediately

Table C.7
Number of Windshields Installed, Replace Immediately (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	3,119	4,056	40	66	510	2,969	10,760
2019	270	396	57	0	54	213	990
2020	1,557	1,542	605	176	506	1,728	6,114
2021	2,460	2,365	1,027	280	799	2,815	9,746
2022	2,499	2,321	1,105	315	891	2,881	10,012
2023	2,231	2,047	906	264	742	2,478	8,668
2024	2,064	2,007	918	261	706	2,355	8,311
2025	2,175	2,018	870	244	719	2,479	8,505
2026	2,327	2,101	971	287	797	2,556	9,039
2027	2,182	2,181	947	261	764	2,506	8,841
Total	20,884	21,034	7,446	2,154	6,488	22,980	80,986

Table C.8
Annual Costs, Replace Immediately (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$1,773,290	\$4,672,513	\$286,560	\$214,395	\$3,173,731	\$17,050,786	\$27,171,276
2019	\$152,850	\$456,192	\$432,056	\$0	\$336,042	\$1,223,766	\$2,600,906
2020	\$884,252	\$1,776,385	\$4,584,451	\$572,088	\$3,148,839	\$9,925,057	\$20,891,072
2021	\$1,397,280	\$2,724,480	\$7,813,988	\$911,079	\$4,972,177	\$16,167,633	\$33,986,637
2022	\$1,419,667	\$2,673,792	\$8,407,900	\$1,024,951	\$5,544,693	\$16,547,046	\$35,618,049
2023	\$1,266,933	\$2,358,144	\$6,883,928	\$858,826	\$4,617,466	\$14,232,555	\$30,217,852
2024	\$1,172,642	\$2,312,064	\$6,982,188	\$848,948	\$4,393,438	\$13,525,866	\$29,235,146
2025	\$1,235,255	\$2,324,736	\$6,638,316	\$793,460	\$4,474,337	\$14,238,069	\$29,704,173
2026	\$1,321,781	\$2,420,352	\$7,370,660	\$933,662	\$4,959,731	\$14,680,629	\$31,686,815
2027	\$1,239,386	\$2,512,512	\$7,196,090	\$848,914	\$4,754,372	\$14,393,058	\$30,944,332
Total	\$11,863,336	\$24,231,170	\$56,596,138	\$7,006,323	\$40,374,826	\$131,984,465	\$272,056,257

NOTE: Costs are in FY 2017 dollars.

Table C.9
Vehicle Availability, Replace Immediately (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,988	3,774	1,691	484	1,365	4,518	15,820
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,518	15,820
2022	3,988	3,774	1,691	484	1,365	4,518	15,820
2023	3,988	3,774	1,691	484	1,365	4,518	15,820
2024	3,988	3,774	1,691	484	1,365	4,518	15,820
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,988	3,774	1,691	484	1,365	4,518	15,820

Table C.10
Number of Windshields Installed, Replace Immediately (Average Delamination Time: Three Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	3,119	4,056	40	66	510	2,969	10,760
2019	314	438	49	0	50	273	1,124
2020	1,999	1,996	839	254	666	2,305	8,059
2021	2,755	2,556	1,162	337	972	3,152	10,934
2022	2,484	2,379	1,114	303	869	2,937	10,086
2023	2,332	2,123	939	273	772	2,489	8,928
2024	2,409	2,291	1,007	300	772	2,737	9,516
2025	2,361	2,269	1,023	279	885	2,725	9,542
2026	2,444	2,230	1,063	284	784	2,743	9,548
2027	2,343	2,286	958	293	813	2,642	9,335
Total	22,560	22,624	8,194	2,389	7,093	24,972	87,832

Table C.11
Annual Costs, Replace Immediately (Average Delamination Time: Three Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$1,773,290	\$4,672,513	\$286,560	\$214,395	\$3,173,731	\$17,050,786	\$27,171,276
2019	\$177,922	\$504,576	\$368,598	\$0	\$311,150	\$1,568,511	\$2,930,757
2020	\$1,135,518	\$2,299,393	\$6,383,747	\$826,197	\$4,144,519	\$13,238,890	\$28,028,264
2021	\$1,565,055	\$2,944,512	\$8,836,442	\$1,096,551	\$6,048,756	\$18,103,278	\$38,594,594
2022	\$1,410,652	\$2,740,608	\$8,464,474	\$985,710	\$5,407,787	\$16,868,709	\$35,877,940
2023	\$1,324,566	\$2,445,696	\$7,158,094	\$887,848	\$4,804,156	\$14,295,666	\$30,916,026
2024	\$1,368,407	\$2,639,232	\$7,649,636	\$975,628	\$4,804,156	\$15,720,009	\$33,157,068
2025	\$1,340,993	\$2,613,888	\$7,783,576	\$907,706	\$5,507,355	\$15,650,934	\$33,804,452
2026	\$1,388,182	\$2,568,960	\$8,065,746	\$924,396	\$4,878,832	\$15,754,578	\$33,580,694
2027	\$1,330,789	\$2,633,472	\$7,279,284	\$952,670	\$5,059,299	\$15,174,219	\$32,429,733
Total	\$12,815,374	\$26,062,850	\$62,276,158	\$7,771,101	\$44,139,741	\$143,425,580	\$296,490,803

NOTE: Costs are in FY 2017 dollars.

Table C.12
Vehicle Availability, Replace Immediately (Average Delamination Time: Three Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,988	3,774	1,691	484	1,365	4,518	15,820
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,518	15,820
2022	3,988	3,774	1,691	484	1,365	4,518	15,820
2023	3,988	3,774	1,691	484	1,365	4,518	15,820
2024	3,988	3,774	1,691	484	1,365	4,518	15,820
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,988	3,774	1,691	484	1,365	4,518	15,820

Table C.13
Number of Windshields Installed, Replace Immediately (Average Delamination Time: Five Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	3,119	4,056	40	66	510	2,969	10,760
2019	215	306	54	0	38	186	799
2020	1,237	1,226	462	120	376	1,298	4,719
2021	2,144	2,043	878	234	700	2,446	8,445
2022	2,376	2,240	1,071	335	855	2,793	9,670
2023	2,170	1,997	957	264	746	2,412	8,546
2024	1,994	1,891	794	204	713	2,302	7,898
2025	1,832	1,774	781	218	582	2,066	7,253
2026	2,106	1,944	879	260	746	2,389	8,324
2027	2,097	1,979	907	256	718	2,295	8,252
Total	19,290	19,456	6,823	1,957	5,984	21,156	74,666

Table C.14**Annual Costs, Replace Immediately (Average Delamination Time: Five Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$1,773,290	\$4,672,513	\$286,560	\$214,395	\$3,173,731	\$17,050,786	\$27,171,276
2019	\$121,775	\$352,512	\$404,418	\$0	\$236,474	\$1,068,651	\$2,183,830
2020	\$702,242	\$1,412,353	\$3,525,757	\$390,091	\$2,339,849	\$7,455,190	\$15,825,482
2021	\$1,217,882	\$2,353,536	\$6,682,458	\$761,168	\$4,356,100	\$14,048,583	\$29,419,727
2022	\$1,349,738	\$2,580,480	\$8,134,472	\$1,090,214	\$5,320,665	\$16,041,681	\$34,517,250
2023	\$1,232,660	\$2,300,544	\$7,263,340	\$858,622	\$4,642,358	\$13,853,457	\$30,150,981
2024	\$1,132,592	\$2,178,432	\$6,034,148	\$663,510	\$4,436,999	\$13,221,357	\$27,667,038
2025	\$1,040,556	\$2,043,648	\$5,939,260	\$708,848	\$3,621,786	\$11,865,765	\$25,219,863
2026	\$1,196,348	\$2,239,488	\$6,692,256	\$846,052	\$4,642,358	\$13,721,694	\$29,338,196
2027	\$1,191,021	\$2,279,808	\$6,894,604	\$832,700	\$4,468,114	\$13,181,229	\$28,847,476
Total	\$10,958,104	\$22,413,314	\$51,857,274	\$6,365,601	\$37,238,434	\$121,508,393	\$250,341,119

NOTE: Costs are in FY 2017 dollars.

Table C.15
Vehicle Availability, Replace Immediately (Average Delamination Time: Five Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,988	3,774	1,691	484	1,365	4,518	15,820
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,518	15,820
2022	3,988	3,774	1,691	484	1,365	4,518	15,820
2023	3,988	3,774	1,691	484	1,365	4,518	15,820
2024	3,988	3,774	1,691	484	1,365	4,518	15,820
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,988	3,774	1,691	484	1,365	4,518	15,820

Table C.16
Number of Windshields Installed, Replace Immediately (Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	3,119	4,056	40	66	510	2,969	10,760
2019	177	259	44	0	34	176	690
2020	875	842	311	94	271	967	3,360
2021	1,781	1,723	743	195	646	1,990	7,078
2022	2,285	2,107	1,049	276	750	2,652	9,119
2023	2,186	2,038	915	277	757	2,553	8,726
2024	1,971	1,820	799	251	673	2,151	7,665
2025	1,440	1,401	621	167	486	1,595	5,710
2026	1,912	1,751	791	201	637	2,143	7,435
2027	2,039	1,811	825	259	674	2,257	7,865
Total	17,785	17,808	6,138	1,786	5,438	19,453	68,408

Table C.17
Annual Costs, Replace Immediately (Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$1,773,290	\$4,672,513	\$286,560	\$214,395	\$3,173,731	\$17,050,786	\$27,171,276
2019	\$100,181	\$298,368	\$329,266	\$0	\$211,582	\$1,011,162	\$1,950,559
2020	\$496,666	\$969,985	\$2,360,583	\$305,785	\$1,686,434	\$5,554,330	\$11,373,783
2021	\$1,011,453	\$1,984,896	\$5,656,492	\$634,591	\$4,020,058	\$11,429,538	\$24,737,028
2022	\$1,298,075	\$2,427,264	\$7,949,646	\$897,386	\$4,667,250	\$15,231,663	\$32,471,284
2023	\$1,241,718	\$2,347,776	\$6,966,842	\$900,962	\$4,710,811	\$14,662,845	\$30,830,954
2024	\$1,119,463	\$2,096,640	\$6,083,138	\$817,098	\$4,188,079	\$12,354,282	\$26,658,700
2025	\$817,890	\$1,613,952	\$4,725,414	\$543,132	\$3,024,378	\$9,160,941	\$19,885,707
2026	\$1,086,076	\$2,017,152	\$6,003,876	\$653,428	\$3,964,051	\$12,308,505	\$26,033,088
2027	\$1,157,877	\$2,086,272	\$6,275,548	\$842,646	\$4,194,302	\$12,962,841	\$27,519,486
Total	\$10,102,689	\$20,514,818	\$46,637,366	\$5,809,423	\$33,840,676	\$111,726,893	\$228,631,864

NOTE: Costs are in FY 2017 dollars.

Table C.18
Vehicle Availability, Replace Immediately (Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,988	3,774	1,691	484	1,365	4,518	15,820
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,518	15,820
2022	3,988	3,774	1,691	484	1,365	4,518	15,820
2023	3,988	3,774	1,691	484	1,365	4,518	15,820
2024	3,988	3,774	1,691	484	1,365	4,518	15,820
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,988	3,774	1,691	484	1,365	4,518	15,820

Scenario 3: Repair

Scenario 3a: Repair 3,000 Windshields per Year at 50-Percent Cost of Buying New

Table C.19
Number of Windshields Installed, Repair 3,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	1,894	1,118	0	0	0	0	3,012
2019	5	1,415	40	60	321	1,159	3,000
2020	189	1,048	49	6	79	1,626	2,997
2021	694	410	533	141	339	883	3,000
2022	795	392	543	149	357	766	3,002
2023	443	657	441	122	304	1,033	3,000
2024	650	821	153	40	264	1,071	2,999
2025	871	583	321	85	251	893	3,004
2026	1,062	660	267	72	181	758	3,000
2027	638	1,097	219	74	216	756	3,000
Total	7,241	8,201	2,566	749	2,312	8,945	30,014

Table C.20**Annual Costs, Repair 3,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$540,864	\$643,968	\$0	\$0	\$0	\$0	\$1,184,833
2019	\$1,430	\$815,040	\$143,280	\$97,490	\$998,633	\$3,327,635	\$5,383,508
2020	\$53,624	\$603,648	\$184,738	\$9,708	\$245,770	\$4,668,834	\$5,766,321
2021	\$196,920	\$236,160	\$2,044,858	\$229,431	\$1,054,632	\$2,535,683	\$6,297,685
2022	\$225,885	\$225,792	\$2,076,726	\$242,442	\$1,110,627	\$2,199,629	\$6,081,101
2023	\$125,768	\$378,432	\$1,682,827	\$198,450	\$945,744	\$2,966,462	\$6,297,683
2024	\$184,680	\$472,896	\$591,507	\$65,145	\$821,305	\$3,075,564	\$5,211,097
2025	\$245,941	\$335,808	\$1,263,962	\$138,652	\$780,861	\$2,565,152	\$5,330,376
2026	\$300,047	\$380,160	\$1,054,730	\$117,482	\$563,091	\$2,177,472	\$4,592,982
2027	\$180,748	\$631,872	\$868,307	\$120,854	\$671,976	\$2,171,499	\$4,645,256
Total	\$2,055,908	\$4,723,777	\$9,910,935	\$1,219,654	\$7,192,639	\$25,687,930	\$50,790,843

NOTE: Costs are in FY 2017 dollars.

Table C.21
Vehicle Availability, Repair 3,000 per Year at 50-Percent Cost of New
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVS	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	2,763	1,671	1,651	424	1,044	2,559	10,112
2019	2,501	2,001	1,642	478	1,139	3,405	11,166
2020	1,734	2,325	1,155	343	882	3,226	9,665
2021	1,284	1,905	942	282	694	2,668	7,775
2022	1,115	1,335	862	253	626	2,096	6,287
2023	641	918	496	139	366	1,317	3,877
2024	637	906	182	65	292	1,231	3,313
2025	1,137	819	277	79	380	1,231	3,923
2026	1,966	1,018	479	131	444	1,391	5,429
2027	2,140	1,745	554	168	492	1,554	6,653

Scenario 3b: Repair 5,000 Windshields per Year at 50-Percent Cost of Buying New

Table C.22
Number of Windshields Installed, Repair 5,000 per Year at 50-Percent Cost of New
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVS	M-ATV	MRAP	MTVR	Total
2018	1,894	2,533	40	60	321	166	5,014
2019	1,234	942	0	0	0	2,819	4,995
2020	1,084	1,539	606	149	552	1,065	4,995
2021	1,448	890	629	162	368	1,513	5,010
2022	1,159	1,214	506	181	444	1,493	4,997
2023	1,445	1,205	544	146	411	1,249	5,000
2024	1,154	1,222	473	128	429	1,592	4,998
2025	1,190	1,149	638	178	453	1,392	5,000
2026	1,357	1,107	548	144	434	1,412	5,002
2027	1,312	1,238	474	149	418	1,410	5,001
Total	13,277	13,039	4,458	1,297	3,830	14,111	50,012

Table C.23**Annual Costs, Repair 5,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$540,864	\$1,459,009	\$143,280	\$97,490	\$998,633	\$476,346	\$3,715,622
2019	\$346,779	\$542,592	\$0	\$0	\$0	\$8,094,158	\$8,983,529
2020	\$307,190	\$886,464	\$2,307,223	\$242,375	\$1,717,276	\$3,058,456	\$8,518,985
2021	\$410,808	\$512,640	\$2,397,509	\$263,680	\$1,144,849	\$4,344,642	\$9,074,128
2022	\$328,199	\$699,264	\$1,902,926	\$294,337	\$1,381,284	\$4,287,027	\$8,893,037
2023	\$410,100	\$694,080	\$2,111,038	\$237,605	\$1,278,621	\$3,587,131	\$8,318,575
2024	\$327,889	\$703,872	\$1,785,598	\$208,226	\$1,334,619	\$4,571,943	\$8,932,147
2025	\$337,700	\$661,824	\$2,435,015	\$289,585	\$1,409,283	\$3,997,668	\$9,131,075
2026	\$384,937	\$637,632	\$2,090,685	\$234,318	\$1,350,174	\$4,054,953	\$8,752,699
2027	\$371,547	\$713,088	\$1,793,570	\$242,085	\$1,300,398	\$4,048,050	\$8,468,738
Total	\$3,766,014	\$7,510,465	\$16,966,844	\$2,109,701	\$11,915,137	\$40,520,374	\$82,788,535

NOTE: Costs are in FY 2017 dollars.

Table C.24
Vehicle Availability, Repair 5,000 per Year at 50-Percent Cost of New
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	2,763	2,251	1,691	478	1,176	2,711	11,070
2019	3,724	2,843	1,637	478	1,134	4,404	14,220
2020	3,777	3,455	1,627	454	1,294	4,386	14,993
2021	3,199	2,844	1,255	325	1,000	3,654	12,277
2022	2,382	2,426	917	263	799	2,826	9,613
2023	2,288	2,165	874	274	726	2,194	8,521
2024	2,050	1,918	783	233	676	2,307	7,967
2025	1,900	1,833	941	269	680	2,354	7,977
2026	2,177	1,872	1,039	280	751	2,514	8,633
2027	2,321	2,063	955	260	771	2,603	8,973

Scenario 3c: Repair 8,000 Windshields per Year at 50-Percent Cost of Buying New

Table C.25
Number of Windshields Installed, Repair 8,000 per Year at 50-Percent Cost
of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	3,079	2,533	40	60	321	1,967	8,000
2019	320	1,887	56	6	242	1,258	3,769
2020	1,458	958	648	154	476	1,395	5,089
2021	1,802	1,748	1,105	331	735	2,290	8,011
2022	1,981	1,875	893	247	711	2,291	7,998
2023	2,280	2,040	659	205	616	2,203	8,003
2024	2,028	2,035	822	219	664	2,233	8,001
2025	1,943	1,841	844	255	709	2,401	7,993
2026	2,142	1,862	855	244	691	2,209	8,003
2027	2,011	1,979	810	239	686	2,275	8,000
Total	19,044	18,758	6,732	1,960	5,851	20,522	72,867

Table C.26**Annual Costs, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	\$873,849	\$1,459,009	\$143,280	\$97,490	\$998,633	\$5,649,862	\$9,222,123
2019	\$90,425	\$1,086,912	\$210,251	\$9,708	\$752,863	\$3,610,032	\$5,760,190
2020	\$413,094	\$551,808	\$2,458,105	\$250,499	\$1,480,840	\$4,005,891	\$9,160,238
2021	\$510,837	\$1,006,848	\$4,197,804	\$538,414	\$2,286,585	\$6,575,835	\$15,116,323
2022	\$561,876	\$1,080,000	\$3,407,690	\$401,669	\$2,211,921	\$6,578,524	\$14,241,680
2023	\$646,245	\$1,175,040	\$2,511,554	\$333,356	\$1,916,376	\$6,326,032	\$12,908,603
2024	\$575,228	\$1,172,160	\$3,105,517	\$356,229	\$2,065,704	\$6,411,992	\$13,686,830
2025	\$550,668	\$1,060,416	\$3,229,538	\$415,072	\$2,205,699	\$6,894,799	\$14,356,192
2026	\$607,257	\$1,072,512	\$3,229,430	\$396,492	\$2,149,701	\$6,342,921	\$13,798,313
2027	\$570,101	\$1,139,904	\$3,085,361	\$388,572	\$2,134,146	\$6,532,670	\$13,850,754
Total	\$5,399,581	\$10,804,609	\$25,578,530	\$3,187,501	\$18,202,468	\$58,928,558	\$122,101,247

NOTE: Costs are in FY 2017 dollars.

Table C.27
Vehicle Availability, Repair 8,000 per Year at 50-Percent Cost of New
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,948	2,251	1,691	478	1,176	3,508	13,052
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,374	3,569	1,685	477	1,336	4,273	14,714
2022	3,071	3,251	1,545	417	1,197	3,833	13,314
2023	3,435	3,256	1,364	401	1,146	3,777	13,379
2024	3,721	3,453	1,438	403	1,158	3,954	14,127
2025	3,750	3,469	1,503	439	1,234	4,200	14,595
2026	3,792	3,430	1,486	432	1,218	4,058	14,416
2027	3,689	3,501	1,557	438	1,242	4,136	14,563

Table C.28
Number of Windshields Installed, Repair 8,000 per Year at 50-Percent Cost
of New (Average Delamination Time: Three Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	3,079	2,533	40	60	321	1,967	8,000
2019	368	1,968	63	6	242	1,298	3,945
2020	2,022	1,157	854	229	543	1,764	6,569
2021	1,605	1,756	1,094	288	805	2,461	8,009
2022	2,234	2,157	794	231	616	1,968	8,000
2023	1,905	1,931	712	235	713	2,505	8,001
2024	2,404	1,974	752	214	609	2,049	8,002
2025	2,024	1,808	918	242	702	2,307	8,001
2026	1,889	1,797	914	271	721	2,405	7,997
2027	1,960	1,897	885	260	697	2,303	8,002
Total	19,490	18,978	7,026	2,036	5,969	21,027	74,526

Table C.29**Annual Costs, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Three Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$873,849	\$1,459,009	\$143,280	\$97,490	\$998,633	\$5,649,862	\$9,222,123
2019	\$104,048	\$1,133,568	\$237,520	\$9,708	\$752,863	\$3,724,952	\$5,962,658
2020	\$573,088	\$666,432	\$3,248,677	\$372,393	\$1,689,277	\$5,065,252	\$11,615,120
2021	\$455,235	\$1,011,456	\$4,181,669	\$468,636	\$2,504,355	\$7,067,229	\$15,688,580
2022	\$633,494	\$1,242,432	\$3,010,489	\$375,730	\$1,916,376	\$5,650,642	\$12,829,163
2023	\$540,065	\$1,112,256	\$2,713,692	\$381,947	\$2,218,143	\$7,193,565	\$14,159,668
2024	\$681,379	\$1,137,024	\$2,841,607	\$347,935	\$1,894,599	\$5,883,251	\$12,785,795
2025	\$573,844	\$1,041,408	\$3,492,411	\$393,698	\$2,183,922	\$6,624,518	\$14,309,801
2026	\$535,414	\$1,035,072	\$3,477,205	\$440,926	\$2,243,031	\$6,906,225	\$14,637,873
2027	\$555,855	\$1,092,672	\$3,368,937	\$422,924	\$2,168,367	\$6,613,322	\$14,222,077
Total	\$5,526,272	\$10,931,329	\$26,715,487	\$3,311,387	\$18,569,566	\$60,378,818	\$125,432,859

NOTE: Costs are in FY 2017 dollars.

Table C.30
Vehicle Availability, Repair 8,000 per Year at 50-Percent Cost of New
(Average Delamination Time: Three Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,948	2,251	1,691	478	1,176	3,508	13,052
2019	3,988	3,774	1,691	484	1,365	4,526	15,828
2020	3,988	3,774	1,691	484	1,365	4,526	15,828
2021	3,022	3,316	1,604	452	1,276	4,047	13,717
2022	3,049	3,150	1,392	378	1,048	3,287	12,304
2023	3,160	3,143	1,275	360	1,082	3,722	12,742
2024	3,756	3,244	1,298	369	1,088	3,782	13,537
2025	3,612	3,305	1,406	432	1,163	3,952	13,870
2026	3,358	3,064	1,518	431	1,193	3,901	13,465
2027	3,228	3,084	1,480	427	1,187	3,807	13,213

Table C.31
Number of Windshields Installed, Repair 8,000 per Year at 50-Percent Cost
of New (Average Delamination Time: Five Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	3,079	2,533	40	60	321	1,967	8,000
2019	278	1,842	54	6	239	1,206	3,625
2020	1,145	772	458	107	341	992	3,815
2021	2,153	1,639	920	269	679	2,176	7,836
2022	1,706	1,847	1,010	286	788	2,375	8,012
2023	2,056	2,051	785	237	626	2,247	8,002
2024	1,926	1,855	866	247	721	2,380	7,995
2025	2,024	1,955	833	239	635	2,281	7,967
2026	1,872	1,797	872	251	692	2,178	7,662
2027	2,013	1,921	855	246	688	2,287	8,010
Total	18,252	18,212	6,693	1,948	5,730	20,089	70,924

Table C.32**Annual Costs, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Five Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$873,849	\$1,459,009	\$143,280	\$97,490	\$998,633	\$5,649,862	\$9,222,123
2019	\$78,523	\$1,060,992	\$203,087	\$9,708	\$743,530	\$3,460,644	\$5,556,483
2020	\$324,581	\$444,672	\$1,741,527	\$174,062	\$1,060,855	\$2,848,709	\$6,594,407
2021	\$610,368	\$944,064	\$3,503,965	\$437,707	\$2,112,369	\$6,248,439	\$13,856,912
2022	\$483,736	\$1,063,872	\$3,836,881	\$465,128	\$2,451,468	\$6,819,705	\$15,120,790
2023	\$583,046	\$1,181,376	\$2,979,129	\$385,421	\$1,947,486	\$6,452,293	\$13,528,751
2024	\$546,141	\$1,068,480	\$3,300,001	\$401,805	\$2,243,031	\$6,834,295	\$14,393,753
2025	\$573,459	\$1,126,080	\$3,160,284	\$388,827	\$1,975,485	\$6,549,759	\$13,773,894
2026	\$530,782	\$1,035,072	\$3,315,786	\$408,005	\$2,152,812	\$6,254,192	\$13,696,649
2027	\$570,908	\$1,106,496	\$3,238,649	\$400,102	\$2,140,368	\$6,566,983	\$14,023,506
Total	\$5,175,394	\$10,490,113	\$25,422,589	\$3,168,255	\$17,826,037	\$57,684,881	\$119,767,269

NOTE: Costs are in FY 2017 dollars.

Table C.33
Vehicle Availability, Repair 8,000 per Year at 50-Percent Cost of New
(Average Delamination Time: Five Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,948	2,251	1,691	478	1,176	3,508	13,052
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,518	15,820
2022	3,361	3,491	1,655	469	1,315	4,248	14,539
2023	3,317	3,419	1,532	435	1,231	4,019	13,953
2024	3,552	3,495	1,624	467	1,300	4,228	14,666
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,954	3,740	1,678	480	1,352	4,502	15,706

Table C.34
Number of Windshields Installed, Repair 8,000 per Year at 50-Percent Cost
of New (Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	3,079	2,533	40	60	321	1,967	8,000
2019	219	1,783	33	6	223	1,155	3,419
2020	897	604	320	86	237	814	2,958
2021	1,719	1,324	732	205	570	1,773	6,323
2022	1,785	1,858	990	290	761	2,327	8,011
2023	2,033	1,888	866	246	685	2,283	8,001
2024	2,045	1,889	823	241	682	2,319	7,999
2025	1,542	1,787	663	175	559	1,834	6,560
2026	1,695	1,570	758	226	559	1,926	6,734
2027	1,978	1,757	824	242	706	2,164	7,671
Total	16,992	16,993	6,049	1,777	5,303	18,562	65,676

Table C.35**Annual Costs, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Six Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$873,849	\$1,459,009	\$143,280	\$97,490	\$998,633	\$5,649,862	\$9,222,123
2019	\$61,804	\$1,027,008	\$124,792	\$9,708	\$693,754	\$3,314,160	\$5,231,225
2020	\$254,203	\$347,904	\$1,216,042	\$139,897	\$737,310	\$2,337,542	\$5,032,899
2021	\$487,239	\$762,624	\$2,780,064	\$333,458	\$1,773,271	\$5,091,302	\$11,227,958
2022	\$506,030	\$1,070,208	\$3,762,168	\$471,719	\$2,367,471	\$6,681,898	\$14,859,494
2023	\$576,498	\$1,087,488	\$3,293,416	\$400,085	\$2,131,035	\$6,555,537	\$14,044,059
2024	\$579,855	\$1,088,064	\$3,132,805	\$392,148	\$2,121,702	\$6,659,126	\$13,973,700
2025	\$436,992	\$1,029,312	\$2,519,297	\$284,544	\$1,739,049	\$5,266,381	\$11,275,575
2026	\$480,600	\$904,320	\$2,887,683	\$367,657	\$1,739,049	\$5,530,434	\$11,909,743
2027	\$560,568	\$1,012,032	\$3,131,119	\$393,511	\$2,196,366	\$6,213,896	\$13,507,492
Total	\$4,817,639	\$9,787,969	\$22,990,666	\$2,890,217	\$16,497,640	\$53,300,138	\$110,284,269

NOTE: Costs are in FY 2017 dollars.

Table C.36
Vehicle Availability, Repair 8,000 per Year at 50-Percent Cost of New
(Average Delamination Time: Six Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,948	2,251	1,691	478	1,176	3,508	13,052
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,518	15,820
2022	3,491	3,661	1,686	476	1,345	4,439	15,098
2023	3,431	3,514	1,633	460	1,297	4,193	14,528
2024	3,682	3,588	1,665	472	1,325	4,299	15,031
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,988	3,774	1,691	484	1,365	4,518	15,820

Scenario 3-1a: Repair 3,000 Windshields per Year at 33-Percent Cost of Buying New

Table C.37
Number of Windshields Installed, Repair 3,000 per Year at 33-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	1,894	1,118	0	0	0	0	3,012
2019	5	614	40	60	321	1,959	2,999
2020	184	1,636	47	0	36	1,095	2,998
2021	677	403	582	142	339	857	3,000
2022	606	358	658	132	314	935	3,003
2023	589	691	304	133	319	966	3,002
2024	596	797	140	57	301	1,109	3,000
2025	1,083	538	200	95	257	826	2,999
2026	1,134	943	257	74	162	430	3,000
2027	681	1,052	201	69	250	748	3,001
Total	7,449	8,150	2,429	762	2,299	8,925	30,014

Table C.38**Annual Costs, Repair 3,000 per Year at 33-Percent Cost of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$361,098	\$429,312	\$0	\$0	\$0	\$0	\$790,410
2019	\$955	\$235,776	\$95,520	\$64,971	\$665,756	\$3,751,465	\$4,814,443
2020	\$34,772	\$628,224	\$118,955	\$0	\$74,664	\$2,094,924	\$2,951,539
2021	\$128,088	\$154,752	\$1,487,638	\$154,111	\$703,089	\$1,640,845	\$4,268,523
2022	\$114,562	\$137,472	\$1,691,024	\$143,136	\$651,236	\$1,790,317	\$4,527,747
2023	\$111,195	\$265,344	\$789,024	\$143,987	\$661,606	\$1,849,515	\$3,820,671
2024	\$112,668	\$306,048	\$359,140	\$61,842	\$624,274	\$2,123,737	\$3,587,709
2025	\$203,981	\$206,592	\$520,816	\$103,370	\$533,018	\$1,582,097	\$3,149,874
2026	\$214,066	\$362,112	\$678,540	\$80,420	\$335,988	\$823,355	\$2,494,481
2027	\$128,595	\$403,968	\$526,416	\$75,078	\$518,500	\$1,432,352	\$3,084,909
Total	\$1,409,980	\$3,129,601	\$6,267,073	\$826,915	\$4,768,131	\$17,088,608	\$33,490,306

NOTE: Costs are in FY 2017 dollars.

Table C.39

**Vehicle Availability, Repair 3,000 per Year at 33-Percent Cost of New
(Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	2,763	1,671	1,651	424	1,044	2,559	10,112
2019	2,491	2,012	1,644	478	1,140	3,396	11,161
2020	1,751	2,149	1,104	336	828	3,497	9,665
2021	1,279	1,664	927	260	667	2,915	7,712
2022	1,112	1,177	894	253	568	2,170	6,174
2023	669	867	498	148	334	1,317	3,833
2024	605	926	178	71	326	1,191	3,297
2025	1,253	804	182	100	431	1,171	3,941
2026	2,146	1,331	371	153	471	1,015	5,487
2027	2,317	1,956	449	161	518	1,224	6,625

**Scenario 3-1b: Repair 5,000 Windshields per Year at 33-Percent Cost
of Buying New**

Table C.40

**Number of Windshields Installed, Repair 5,000 per Year at 33-Percent Cost
of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	1,894	2,533	40	60	321	166	5,014
2019	1,235	957	0	0	0	2,803	4,995
2020	1,075	1,494	624	160	564	1,080	4,997
2021	1,418	854	637	139	415	1,544	5,007
2022	1,141	1,227	495	151	439	1,547	5,000
2023	1,477	1,203	643	153	384	1,138	4,998
2024	1,127	1,194	447	154	432	1,647	5,001
2025	1,263	1,103	555	189	459	1,429	4,998
2026	1,311	1,157	573	143	397	1,423	5,004
2027	1,241	1,230	510	140	430	1,448	4,999
Total	13,182	12,952	4,524	1,289	3,841	14,225	50,013

Table C.41**Annual Costs, Repair 5,000 per Year at 33-Percent Cost of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$361,098	\$972,672	\$95,520	\$64,971	\$665,756	\$317,613	\$2,477,629
2019	\$230,969	\$367,488	\$0	\$0	\$0	\$5,365,983	\$5,964,440
2020	\$203,006	\$573,696	\$1,593,192	\$173,502	\$1,169,739	\$2,067,918	\$5,781,054
2021	\$268,170	\$327,936	\$1,618,100	\$150,720	\$860,710	\$2,955,958	\$6,181,594
2022	\$215,455	\$471,168	\$1,238,708	\$163,630	\$910,486	\$2,961,643	\$5,961,090
2023	\$279,695	\$461,952	\$1,654,328	\$165,978	\$796,416	\$2,179,073	\$5,537,442
2024	\$213,593	\$458,496	\$1,124,960	\$166,900	\$895,968	\$3,153,282	\$6,013,199
2025	\$238,841	\$423,552	\$1,413,524	\$204,990	\$951,966	\$2,736,140	\$5,969,013
2026	\$247,957	\$444,288	\$1,451,544	\$155,138	\$823,378	\$2,724,611	\$5,846,916
2027	\$234,295	\$472,320	\$1,293,216	\$151,628	\$891,820	\$2,771,896	\$5,815,175
Total	\$2,493,079	\$4,973,569	\$11,483,093	\$1,397,457	\$7,966,239	\$27,234,117	\$55,547,552

NOTE: Costs are in FY 2017 dollars.

Table C.42
Vehicle Availability, Repair 5,000 per Year at 33-Percent Cost of New
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	2,763	2,251	1,691	478	1,176	2,711	11,070
2019	3,739	2,827	1,647	478	1,149	4,391	14,231
2020	3,794	3,516	1,614	466	1,284	4,369	15,043
2021	3,234	2,846	1,249	353	1,007	3,648	12,337
2022	2,308	2,458	907	249	796	2,917	9,635
2023	2,260	2,171	995	244	713	2,185	8,568
2024	1,980	1,932	879	216	650	2,280	7,937
2025	1,974	1,712	913	273	737	2,361	7,970
2026	2,178	1,848	990	299	739	2,446	8,500
2027	2,237	2,054	939	278	767	2,587	8,862

Scenario 3-1c: Repair 8,000 Windshields per Year at 33-Percent Cost of Buying New

Table C.43
Number of Windshields Installed, Repair 8,000 per Year at 33-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	3,086	2,533	40	60	321	1,959	7,999
2019	304	1,895	61	6	229	1,248	3,743
2020	1,484	924	650	155	438	1,354	5,005
2021	1,825	1,736	1,050	297	814	2,291	8,013
2022	1,921	1,947	871	269	700	2,291	7,999
2023	2,161	2,012	708	218	641	2,261	8,001
2024	2,128	1,991	874	218	621	2,168	8,000
2025	2,026	1,780	833	252	739	2,365	7,995
2026	2,098	1,959	798	252	688	2,207	8,002
2027	1,952	1,961	858	243	676	2,310	8,000
Total	18,985	18,738	6,743	1,970	5,867	20,454	72,757

Table C.44**Annual Costs, Repair 8,000 per Year at 33-Percent Cost of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	\$584,002	\$972,672	\$95,520	\$64,971	\$665,756	\$3,751,465	\$6,134,386
2019	\$57,208	\$727,680	\$151,803	\$6,468	\$474,946	\$2,387,892	\$3,805,997
2020	\$280,529	\$354,816	\$1,648,270	\$168,161	\$908,415	\$2,592,281	\$5,952,472
2021	\$345,071	\$666,624	\$2,662,452	\$321,966	\$1,688,236	\$4,386,259	\$10,070,608
2022	\$363,135	\$747,648	\$2,208,136	\$291,507	\$1,451,800	\$4,386,103	\$9,448,329
2023	\$408,143	\$772,608	\$1,793,196	\$236,384	\$1,329,434	\$4,328,671	\$8,868,436
2024	\$402,536	\$764,544	\$2,206,832	\$236,168	\$1,287,954	\$4,150,504	\$9,048,538
2025	\$382,922	\$683,520	\$2,120,312	\$273,408	\$1,532,686	\$4,528,178	\$9,521,026
2026	\$396,430	\$752,256	\$2,013,956	\$272,964	\$1,426,912	\$4,225,012	\$9,087,530
2027	\$368,812	\$753,024	\$2,177,968	\$263,310	\$1,402,024	\$4,422,318	\$9,387,456
Total	\$3,588,788	\$7,195,393	\$17,078,445	\$2,135,307	\$12,168,163	\$39,158,684	\$81,324,778

NOTE: Costs are in FY 2017 dollars.

Table C.45
Vehicle Availability, Repair 8,000 per Year at 33-Percent Cost of New
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,955	2,251	1,691	478	1,176	3,508	13,059
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,372	3,574	1,687	480	1,342	4,264	14,719
2022	3,100	3,242	1,534	412	1,161	3,836	13,285
2023	3,420	3,260	1,368	393	1,140	3,771	13,352
2024	3,696	3,477	1,448	416	1,186	3,909	14,132
2025	3,727	3,506	1,533	440	1,252	4,185	14,643
2026	3,823	3,498	1,471	427	1,201	4,129	14,549
2027	3,751	3,496	1,542	438	1,247	4,146	14,620

Scenario 3-2a: Repair 8,000 Windshields per Year at 66-Percent Cost of Buying New

Table C.46
Number of Windshields Installed, Repair 8,000 per Year at 66-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	3,079	2,533	40	60	321	1,967	8,000
2019	317	1,883	59	6	225	1,234	3,724
2020	1,480	973	643	192	453	1,453	5,194
2021	1,833	1,763	1,040	321	786	2,268	8,011
2022	1,918	1,899	946	231	719	2,285	7,998
2023	2,250	2,063	670	176	623	2,221	8,003
2024	2,025	1,970	878	269	664	2,196	8,002
2025	2,014	1,806	849	253	708	2,361	7,991
2026	2,138	1,943	824	240	641	2,218	8,004
2027	1,977	1,879	853	224	684	2,346	7,963
Total	19,031	18,712	6,802	1,972	5,824	20,549	72,890

Table C.47**Annual Costs, Repair 8,000 per Year at 66-Percent Cost of New (Average Delamination Time: Four Years)**

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$1,166,731	\$1,945,345	\$191,040	\$129,975	\$1,331,511	\$7,533,587	\$12,298,190
2019	\$119,554	\$1,446,144	\$295,826	\$12,942	\$933,301	\$4,722,184	\$7,529,951
2020	\$559,936	\$747,264	\$3,275,720	\$416,356	\$1,879,049	\$5,563,817	\$12,442,142
2021	\$693,661	\$1,353,984	\$5,254,275	\$696,169	\$3,260,328	\$8,684,130	\$19,942,547
2022	\$726,292	\$1,458,432	\$4,814,691	\$501,073	\$2,982,412	\$8,749,592	\$19,232,492
2023	\$851,527	\$1,584,384	\$3,387,705	\$381,610	\$2,584,204	\$8,504,092	\$17,293,522
2024	\$766,641	\$1,512,960	\$4,433,178	\$582,809	\$2,754,272	\$8,408,202	\$18,458,062
2025	\$762,299	\$1,387,008	\$4,334,454	\$549,401	\$2,936,784	\$9,040,830	\$19,010,776
2026	\$809,065	\$1,492,224	\$4,160,064	\$520,256	\$2,658,868	\$8,492,110	\$18,132,587
2027	\$748,270	\$1,443,072	\$4,324,893	\$485,927	\$2,837,231	\$8,982,726	\$18,822,120
Total	\$7,203,976	\$14,370,817	\$34,471,846	\$4,276,518	\$24,157,960	\$78,681,270	\$163,162,388

NOTE: Costs are in FY 2017 dollars.

Table C.48
Vehicle Availability, Repair 8,000 per Year at 66-Percent Cost of New
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,948	2,251	1,691	478	1,176	3,508	13,052
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,457	3,576	1,689	475	1,338	4,341	14,876
2022	3,059	3,224	1,534	441	1,205	3,857	13,320
2023	3,466	3,273	1,351	377	1,110	3,758	13,335
2024	3,692	3,488	1,446	416	1,190	3,906	14,138
2025	3,757	3,491	1,502	433	1,249	4,213	14,645
2026	3,816	3,539	1,504	417	1,223	4,104	14,603
2027	3,693	3,509	1,565	448	1,258	4,203	14,676

Scenario 4: Replace Some Windshields with Automotive Glass

Table C.49
Number of Ballistic Glass Windshields Installed, Automotive Glass Scenario
(Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	0	8	0	66	510	0	584
2019	0	0	0	0	53	0	53
2020	533	164	89	169	500	512	1,967
2021	963	321	157	293	847	779	3,360
2022	1,009	298	165	319	854	931	3,576
2023	789	252	143	252	724	722	2,882
2024	826	264	132	273	754	738	2,987
2025	814	240	128	265	728	724	2,899
2026	873	277	132	272	773	761	3,088
2027	832	257	152	284	764	754	3,043
Total	6,639	2,081	1,098	2,193	6,507	5,921	24,439

Table C.50
Number of Automotive Glass Windshields Installed (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	3,119	4,056	40	0	0	2,970	10,185
2019	272	326	62	0	0	304	964
2020	396	627	561	0	0	726	2,309
2021	506	663	868	0	0	937	2,974
2022	409	570	776	0	0	839	2,594
2023	174	268	420	0	0	390	1,251
2024	63	96	143	0	0	156	457
2025	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0
Total	4,938	6,604	2,870	0	0	6,322	20,734

Table C.51
Annual Ballistic Glass Windshield Costs, Automotive Glass Scenario (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$0	\$9,216	\$0	\$214,395	\$3,173,731	\$0	\$3,397,342
2019	\$0	\$0	\$0	\$0	\$329,819	\$0	\$329,819
2020	\$302,922	\$188,929	\$675,351	\$550,220	\$3,111,501	\$2,940,673	\$7,769,595
2021	\$546,949	\$369,792	\$1,198,500	\$953,078	\$5,270,881	\$4,474,209	\$12,813,409
2022	\$573,167	\$343,296	\$1,251,422	\$1,037,758	\$5,314,442	\$5,347,041	\$13,867,126
2023	\$448,017	\$290,304	\$1,088,546	\$819,620	\$4,505,452	\$4,146,843	\$11,298,782
2024	\$469,328	\$304,128	\$1,003,596	\$888,018	\$4,692,142	\$4,238,775	\$11,595,987
2025	\$462,292	\$276,480	\$973,184	\$861,960	\$4,530,344	\$4,158,321	\$11,262,581
2026	\$495,759	\$319,104	\$998,328	\$884,816	\$4,810,379	\$4,370,601	\$11,878,987
2027	\$472,636	\$296,064	\$1,160,924	\$923,954	\$4,754,372	\$4,330,662	\$11,938,612
Total	\$3,771,070	\$2,397,313	\$8,349,851	\$7,133,819	\$40,493,063	\$34,007,125	\$96,152,240

NOTE: Costs are in FY 2017 dollars.

Table C.52
Annual Automotive Glass Windshield Costs (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$820,779	\$1,071,652	\$4,081	\$0	\$0	\$620,694	\$2,517,206
2019	\$63,229	\$59,395	\$6,340	\$0	\$0	\$44,020	\$172,985
2020	\$84,528	\$121,809	\$55,883	\$0	\$0	\$118,774	\$380,993
2021	\$90,028	\$129,492	\$77,455	\$0	\$0	\$148,659	\$445,635
2022	\$60,658	\$87,320	\$58,467	\$0	\$0	\$120,188	\$326,633
2023	\$20,884	\$36,488	\$26,478	\$0	\$0	\$49,159	\$133,009
2024	\$8,086	\$11,718	\$8,145	\$0	\$0	\$18,097	\$46,046
2025	\$0	\$0	\$0	\$0	\$0	\$0	\$0
2026	\$0	\$0	\$0	\$0	\$0	\$0	\$0
2027	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total	\$1,148,193	\$1,517,874	\$236,850	\$0	\$0	\$1,119,590	\$4,022,507

NOTE: Costs are in FY 2017 dollars.

Table C.53
Vehicle Availability, Ballistic Glass Portion of Fleet, Automotive Glass
Scenario (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	1,519	472	256	424	1,044	1,357	5,072
2018	1,519	472	256	484	1,365	1,357	5,453
2019	1,519	472	256	484	1,365	1,357	5,453
2020	1,519	472	256	484	1,365	1,357	5,453
2021	1,519	472	256	484	1,365	1,357	5,453
2022	1,519	472	256	484	1,365	1,357	5,453
2023	1,519	472	256	484	1,365	1,357	5,453
2024	1,519	472	256	484	1,365	1,357	5,453
2025	1,519	472	256	484	1,365	1,357	5,453
2026	1,519	472	256	484	1,365	1,357	5,453
2027	1,519	472	256	484	1,365	1,357	5,453

Table C.54
Vehicle Availability, Automotive Glass Portion of Fleet (Average
Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	575	769	1,395	0	0	1,047	3,786
2018	2,469	3,302	1,435	0	0	3,161	10,367
2019	2,469	3,302	1,435	0	0	3,161	10,367
2020	2,469	3,302	1,435	0	0	3,161	10,367
2021	2,469	3,302	1,435	0	0	3,161	10,367
2022	2,469	3,302	1,435	0	0	3,161	10,367
2023	2,469	3,302	1,435	0	0	3,161	10,367
2024	2,469	3,302	1,435	0	0	3,161	10,367
2025	2,469	3,302	1,435	0	0	3,161	10,367
2026	2,469	3,302	1,435	0	0	3,161	10,367
2027	2,469	3,302	1,435	0	0	3,161	10,367

NOTE: Vehicles with automotive glass installed are available for training, but not for deployments that require ballistic glass.

Scenario 5: Replace HMMWV Windshields, Repair More-Expensive Windshields (Hybrid)

Table C.55

Number of Windshields Installed, Hybrid Scenario, Repair 5,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVS	M-ATV	MRAP	MTVR	Total
2018	3,119	4,056	40	66	510	2,985	10,776
2019	267	388	55	0	39	220	969
2020	1,499	1,469	600	160	533	1,700	5,961
2021	2,522	2,418	1,099	284	847	2,770	9,940
2022	2,536	2,301	1,064	339	806	2,804	9,850
2023	2,121	2,055	924	260	810	2,483	8,653
2024	2,085	1,988	874	247	690	2,415	8,299
2025	2,160	2,037	934	271	722	2,410	8,534
2026	2,291	2,155	963	254	795	2,598	9,056
2027	2,254	2,067	911	281	780	2,429	8,722
Total	20,854	20,934	7,464	2,162	6,532	22,814	80,760

Table C.56
Annual Costs, Hybrid Scenario, Repair 5,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2018	\$1,773,290	\$4,672,513	\$143,280	\$107,198	\$1,586,613	\$8,570,504	\$16,853,398
2019	\$151,351	\$446,976	\$207,986	\$0	\$121,329	\$631,935	\$1,559,577
2020	\$851,438	\$1,692,289	\$2,283,535	\$260,292	\$1,658,166	\$4,881,791	\$11,627,511
2021	\$1,432,156	\$2,785,536	\$4,174,556	\$461,841	\$2,635,018	\$7,953,975	\$19,443,082
2022	\$1,440,888	\$2,650,752	\$4,040,845	\$551,239	\$2,507,466	\$8,051,686	\$19,242,876
2023	\$1,204,623	\$2,367,360	\$3,520,488	\$423,094	\$2,519,910	\$7,129,862	\$17,165,337
2024	\$1,184,235	\$2,290,176	\$3,315,487	\$401,856	\$2,146,590	\$6,934,870	\$16,273,214
2025	\$1,226,890	\$2,346,624	\$3,556,747	\$440,620	\$2,246,142	\$6,920,190	\$16,737,213
2026	\$1,300,963	\$2,482,560	\$3,651,845	\$413,114	\$2,473,245	\$7,460,132	\$17,781,859
2027	\$1,280,552	\$2,381,184	\$3,480,068	\$457,276	\$2,426,580	\$6,975,021	\$17,000,681
Total	\$11,846,386	\$24,115,970	\$28,374,837	\$3,516,530	\$20,321,059	\$65,509,966	\$153,684,748

NOTE: Costs are in FY 2017 dollars.

Table C.57

Vehicle Availability, Hybrid Scenario, Repair 5,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,988	3,774	1,691	484	1,365	4,518	15,820
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,507	15,809
2022	3,988	3,774	1,691	483	1,361	4,437	15,734
2023	3,988	3,774	1,691	484	1,365	4,518	15,820
2024	3,988	3,774	1,691	484	1,365	4,518	15,820
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,988	3,774	1,691	484	1,365	4,518	15,820

Table C.58

Number of Windshields Installed, Hybrid Scenario, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	3,119	4,056	40	66	510	2,985	10,776
2019	263	382	62	0	46	216	969
2020	1,591	1,495	640	168	504	1,755	6,153
2021	2,437	2,280	1,088	292	867	2,827	9,791
2022	2,490	2,386	1,065	329	888	2,830	9,988
2023	2,172	2,063	895	252	742	2,419	8,543
2024	2,085	2,052	909	255	713	2,440	8,454
2025	2,133	2,004	951	252	734	2,490	8,564
2026	2,317	2,049	923	283	777	2,531	8,880
2027	2,199	2,123	976	251	727	2,523	8,799
Total	20,806	20,890	7,549	2,148	6,508	23,016	80,917

Table C.59
Annual Costs, Hybrid Scenario, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	Total
2018	\$1,773,290	\$4,672,513	\$143,280	\$107,198	\$1,586,613	\$8,570,504	\$16,853,398
2019	\$148,979	\$440,064	\$233,938	\$0	\$143,106	\$620,429	\$1,586,516
2020	\$903,354	\$1,722,241	\$2,431,644	\$273,134	\$1,567,948	\$5,039,746	\$11,938,067
2021	\$1,384,491	\$2,626,560	\$4,129,008	\$474,989	\$2,697,237	\$8,117,483	\$19,429,768
2022	\$1,414,380	\$2,748,672	\$4,052,768	\$534,923	\$2,762,568	\$8,126,445	\$19,639,756
2023	\$1,233,606	\$2,376,576	\$3,410,025	\$409,929	\$2,308,362	\$6,946,266	\$16,684,764
2024	\$1,184,415	\$2,363,904	\$3,453,588	\$414,885	\$2,218,143	\$7,006,260	\$16,641,195
2025	\$1,211,369	\$2,308,608	\$3,622,470	\$409,844	\$2,283,474	\$7,150,265	\$16,986,030
2026	\$1,316,251	\$2,360,448	\$3,514,272	\$460,070	\$2,417,247	\$7,267,719	\$17,336,007
2027	\$1,249,057	\$2,445,696	\$3,705,874	\$408,413	\$2,261,697	\$7,244,422	\$17,315,159
Total	\$11,819,192	\$24,065,282	\$28,696,867	\$3,493,385	\$20,246,395	\$66,089,539	\$154,410,660

NOTE: Costs are in FY 2017 dollars.

Table C.60

Vehicle Availability, Hybrid Scenario, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	Total
2017	2,094	1,241	1,651	424	1,044	2,404	8,858
2018	3,988	3,774	1,691	484	1,365	4,518	15,820
2019	3,988	3,774	1,691	484	1,365	4,518	15,820
2020	3,988	3,774	1,691	484	1,365	4,518	15,820
2021	3,988	3,774	1,691	484	1,365	4,518	15,820
2022	3,988	3,774	1,691	483	1,365	4,518	15,819
2023	3,988	3,774	1,691	484	1,365	4,518	15,820
2024	3,988	3,774	1,691	484	1,365	4,518	15,820
2025	3,988	3,774	1,691	484	1,365	4,518	15,820
2026	3,988	3,774	1,691	484	1,365	4,518	15,820
2027	3,988	3,774	1,691	484	1,365	4,518	15,820

Scenario 6: JLTv Integration

Table C.61

Number of Windshields Installed, JLTv Scenario, Replace Immediately (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	JLTv	Total
2018	3,119	4,056	40	66	510	2,985	0	10,776
2019	256	360	64	0	37	221	0	938
2020	1,480	1,539	632	173	535	1,658	0	6,017
2021	1,869	1,713	1,024	282	872	2,825	0	8,585
2022	1,257	1,192	1,074	311	847	2,936	0	7,617
2023	635	596	942	276	734	2,383	634	6,200
2024	671	529	862	234	699	2,388	1,735	7,118
2025	696	579	923	270	766	2,507	3,073	8,814
2026	682	544	960	281	825	2,487	3,322	9,101
2027	650	561	928	263	730	2,521	3,095	8,748
Total	11,315	11,669	7,449	2,156	6,555	22,911	11,859	73,914

Table C.62
Annual Costs, JLTV Scenario, Replace Immediately (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	JLTV	Total
2018	\$1,773,290	\$4,672,513	\$286,560	\$214,395	\$3,173,731	\$17,142,682	\$0	\$27,263,172
2019	\$144,988	\$414,720	\$483,960	\$0	\$230,251	\$1,269,687	\$0	\$2,543,606
2020	\$840,711	\$1,772,929	\$4,802,463	\$562,958	\$3,329,306	\$9,522,940	\$0	\$20,831,307
2021	\$1,061,567	\$1,973,376	\$7,772,302	\$917,177	\$5,426,456	\$16,225,347	\$0	\$33,376,225
2022	\$714,021	\$1,373,184	\$8,184,060	\$1,011,769	\$5,270,881	\$16,862,943	\$0	\$33,416,858
2023	\$360,675	\$686,592	\$7,152,368	\$897,692	\$4,567,682	\$13,686,855	\$2,062,202	\$29,414,066
2024	\$381,183	\$609,408	\$6,554,664	\$761,236	\$4,349,877	\$13,715,208	\$5,643,463	\$32,015,039
2025	\$395,528	\$667,008	\$7,030,300	\$878,208	\$4,766,818	\$14,399,103	\$9,997,778	\$38,134,743
2026	\$387,446	\$626,688	\$7,307,660	\$914,076	\$5,133,975	\$14,284,062	\$10,806,874	\$39,460,781
2027	\$369,040	\$646,272	\$7,035,390	\$855,794	\$4,542,790	\$14,479,215	\$10,067,440	\$37,995,941
Total	\$6,428,449	\$13,442,690	\$56,609,728	\$7,013,305	\$40,791,767	\$131,588,042	\$38,577,757	\$294,451,737

NOTE: Costs are in FY 2017 dollars.

Table C.63

Vehicle Availability, JLTV Scenario, Replace Immediately (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	JLTV	Total
2017	2,094	1,241	1,651	424	1,044	2,404	N/A	8,858
2018	3,988	3,774	1,691	484	1,365	4,518	N/A	15,820
2019	3,988	3,774	1,691	484	1,365	4,518	N/A	15,820
2020	3,144	2,932	1,691	484	1,365	4,518	1,686	15,820
2021	2,189	1,980	1,691	484	1,365	4,518	3,593	15,820
2022	1,234	1,028	1,691	484	1,365	4,518	5,500	15,820
2023	1,234	1,028	1,691	484	1,365	4,518	5,500	15,820
2024	1,234	1,028	1,691	484	1,365	4,518	5,500	15,820
2025	1,234	1,028	1,691	484	1,365	4,518	5,500	15,820
2026	1,234	1,028	1,691	484	1,365	4,518	5,500	15,820
2027	1,234	1,028	1,691	484	1,365	4,518	5,500	15,820

NOTE: N/A = not applicable.

Table C.64

Number of Windshields Installed, JLTV Scenario, Repair 5,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	JLTV	Total
2018	1,894	2,533	40	60	321	166	0	5,014
2019	1,234	942	0	0	0	2,819	0	4,995
2020	1,034	1,577	620	147	577	1,042	0	4,997
2021	1,233	841	731	183	429	1,589	0	5,006
2022	865	1,154	496	155	448	1,882	0	5,000
2023	1,045	862	655	170	462	1,245	561	5,000
2024	547	402	515	175	438	1,602	1,319	4,998
2025	374	345	414	148	414	1,328	1,981	5,004
2026	412	364	606	136	434	1,399	1,649	5,000
2027	429	318	581	175	464	1,534	1,499	5,000
Total	9,067	9,338	4,658	1,349	3,987	14,606	7,009	50,014

Table C.65
Annual Costs, JLTV Scenario, Repair 5,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSr	M-ATV	MRAP	MTVR	JLTV	Total
2018	\$540,864	\$1,459,009	\$143,280	\$97,490	\$998,633	\$476,346	\$0	\$3,715,622
2019	\$346,779	\$542,592	\$0	\$0	\$0	\$8,094,158	\$0	\$8,983,529
2020	\$293,060	\$908,352	\$2,374,492	\$239,224	\$1,795,051	\$2,992,509	\$0	\$8,602,688
2021	\$350,343	\$484,416	\$2,791,847	\$297,846	\$1,334,619	\$4,562,946	\$0	\$9,822,017
2022	\$244,515	\$664,704	\$1,839,888	\$251,572	\$1,393,729	\$5,403,828	\$0	\$9,798,236
2023	\$296,610	\$496,512	\$2,544,638	\$277,066	\$1,437,282	\$3,575,950	\$912,834	\$9,540,892
2024	\$155,437	\$231,552	\$1,961,065	\$284,629	\$1,362,618	\$4,600,588	\$2,147,164	\$10,743,053
2025	\$106,039	\$198,720	\$1,581,284	\$240,858	\$1,287,954	\$3,814,027	\$3,225,386	\$10,454,268
2026	\$116,392	\$209,664	\$2,299,319	\$221,238	\$1,350,174	\$4,017,321	\$2,687,649	\$10,901,757
2027	\$121,204	\$183,168	\$2,200,550	\$284,680	\$1,443,504	\$4,404,271	\$2,441,022	\$11,078,399
Total	\$2,571,244	\$5,378,689	\$17,736,363	\$2,194,602	\$12,403,564	\$41,941,944	\$11,414,055	\$93,640,462

NOTE: Costs are in FY 2017 dollars.

Table C.66

Vehicle Availability, JLTV Scenario, Repair 5,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	JLTV	Total
2017	2,094	1,241	1,651	424	1,044	2,404	N/A	8,858
2018	2,763	2,251	1,691	478	1,176	2,711	N/A	11,070
2019	3,728	2,805	1,640	478	1,140	4,404	N/A	14,195
2020	3,144	2,932	1,620	458	1,288	4,393	1,686	15,521
2021	2,189	1,980	1,318	357	1,029	3,735	3,593	14,201
2022	1,234	1,028	958	277	858	3,136	4,939	12,430
2023	407	324	1,021	272	827	2,502	4,122	9,475
2024	537	392	1,040	272	779	2,517	3,203	8,740
2025	596	450	866	278	692	2,335	2,829	8,046
2026	721	616	947	259	711	2,388	2,380	8,022
2027	811	672	983	262	755	2,594	2,096	8,173

NOTE: N/A = not applicable.

Table C.67

Number of Windshields Installed, JLTV Scenario, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	JLTV	Total
2018	3,079	2,533	40	60	321	1,967	0	8,000
2019	321	1,887	58	6	233	1,251	0	3,756
2020	1,462	943	628	185	420	1,369	0	5,007
2021	1,914	1,479	1,042	322	806	2,437	0	8,000
2022	1,134	1,042	1,099	309	869	2,936	2	7,391
2023	534	464	916	228	751	2,555	622	6,070
2024	658	563	864	270	714	2,393	1,725	7,187
2025	373	470	885	264	737	2,336	2,941	8,006
2026	467	346	855	213	646	2,086	3,387	8,000
2027	593	481	819	226	685	2,095	3,101	8,000
Total	10,535	10,208	7,206	2,083	6,182	21,425	11,778	69,417

Table C.68
Annual Costs, JLTV Scenario, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	JLTV	Total
2018	\$873,849	\$1,459,009	\$143,280	\$97,490	\$998,633	\$5,649,862	\$0	\$9,222,123
2019	\$90,656	\$1,086,912	\$219,610	\$9,708	\$724,864	\$3,589,944	\$0	\$5,721,693
2020	\$414,578	\$543,168	\$2,388,660	\$301,082	\$1,306,623	\$3,931,127	\$0	\$8,885,239
2021	\$542,764	\$851,904	\$3,962,919	\$523,852	\$2,507,467	\$6,997,898	\$0	\$15,386,804
2022	\$321,459	\$600,192	\$4,167,532	\$502,478	\$2,703,459	\$8,430,674	\$3,236	\$16,729,031
2023	\$151,389	\$267,264	\$3,485,247	\$370,876	\$2,336,361	\$7,336,655	\$1,011,957	\$14,959,749
2024	\$186,583	\$324,288	\$3,284,496	\$439,087	\$2,221,254	\$6,871,577	\$2,805,415	\$16,132,700
2025	\$105,878	\$270,720	\$3,366,303	\$429,600	\$2,292,807	\$6,707,984	\$4,783,086	\$17,956,378
2026	\$132,267	\$199,296	\$3,239,527	\$346,300	\$2,009,706	\$5,989,849	\$5,508,896	\$17,425,841
2027	\$168,158	\$277,056	\$3,111,453	\$367,453	\$2,131,035	\$6,015,695	\$5,044,193	\$17,115,043
Total	\$2,987,582	\$5,879,809	\$27,369,027	\$3,387,926	\$19,232,209	\$61,521,265	\$19,156,783	\$139,534,602

NOTE: Costs are in FY 2017 dollars.

Table C.69

Vehicle Availability, JLTV Scenario, Repair 8,000 per Year at 50-Percent Cost of New (Average Delamination Time: Four Years)

Year	HMMWV (Other)	HMMWV (M1114)	LVSR	M-ATV	MRAP	MTVR	JLTV	Total
2017	2,094	1,241	1,651	424	1,044	2,404	N/A	8,858
2018	3,948	2,251	1,691	478	1,176	3,508	N/A	13,052
2019	3,988	3,774	1,691	484	1,365	4,518	N/A	15,820
2020	3,144	2,932	1,691	484	1,365	4,518	1,686	15,820
2021	2,189	1,980	1,691	484	1,365	4,518	3,593	15,820
2022	1,234	1,028	1,691	484	1,365	4,518	4,938	15,258
2023	1,234	1,028	1,691	484	1,365	4,518	4,191	14,511
2024	1,234	1,028	1,691	484	1,365	4,518	3,738	14,058
2025	904	925	1,682	477	1,358	4,428	4,223	13,997
2026	799	745	1,562	432	1,212	4,025	5,002	13,777
2027	943	749	1,502	414	1,170	3,782	5,416	13,976

NOTE: N/A = not applicable.

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Over the course of operations in Afghanistan and Iraq, the U.S. Marine Corps identified a need for ballistic glass to be installed on the windshields and side-door windows of forward-deployed tactical vehicles to protect against bullets and other projectiles fired by insurgents. This requirement was satisfied with an Urgent Universal Need Statement and subsequent fielding to most up-armored vehicles. Although the glass proved reliable from a ballistics perspective, delamination—a process whereby protective material splits apart into layers due to the intrusion of moisture and dirt—created spots, bubbles, and discoloration and impaired driver visibility. In recent years, this type of degradation to ballistic glass has been occurring at a rapid pace, affecting equipment readiness and resulting in an unplanned cost burden on operational forces and depots. In this report, RAND researchers use a simulation model to estimate the effects of delaminated ballistic glass on the future sustainment costs and availability of Marine Corps tactical vehicles under various repair and replacement scenarios. Based on the model's results, the authors identify steps that the Marine Corps could take to mitigate risks associated with ballistic glass delamination.



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