



Evaluation of Low Earth Orbit (LEO) Broadband

FINAL REPORT



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Anchorage, AK
March 2025

Prepared for:
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Report #: FHWA-AK-4000(234)

REPORT DOCUMENTATION PAGE			Form approved OMB No.	
Public reporting for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-1833), Washington, DC 20503				
1. AGENCY USE ONLY (LEAVE BLANK) FHWA-AK-4000(234)		2. REPORT DATE 3/31/2026	3. REPORT TYPE AND DATES COVERED Final Report - September 2024-July 2025	
4. TITLE AND SUBTITLE Evaluation of Low Earth Orbit (LEO) Broadband			State project numbers Federal project numbers State # HFHWY00395 Federal # 4000(234)	
6. AUTHOR(S) Ryan Marlow Alaska Department of Transportation & Public Facilities, Statewide Research Office				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) State of Alaska, Alaska Dept. of Transportation and Public Facilities Research and Technology Transfer 3132 Channel Drive Juneau, AK 99801-7898			8. PERFORMING ORGANIZATION REPORT NUMBER HFHWY00395	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) State of Alaska, Alaska Dept. of Transportation and Public Facilities Research and Technology Transfer 3132 Channel Drive Juneau, AK 99801-7898			10. SPONSORING/MONITORING AGENCY REPORT NUMBER Federal project numbers FHWA-AK-4000(234)	
11. SUPPLEMENTARY NOTES Performed in cooperation with industry partners to support system evaluation and operational validation				
12a. DISTRIBUTION / AVAILABILITY STATEMENT No restrictions			12b. DISTRIBUTION CODE N/A	
13. ABSTRACT (Maximum 200 words) This report documents the evaluation of Low Earth Orbit (LEO) broadband systems for use in remote and rural transportation operations. The study assessed the performance, reliability, cost, and operational applicability of LEO connectivity across fixed facilities, mobile fleet deployments, maritime operations, and emergency response scenarios. Field testing was conducted over more than 400 days using multiple hardware configurations and integrated network architectures. Data collected included bandwidth performance, system uptime, environmental impacts, and usage patterns. The results demonstrate that LEO systems significantly improve connectivity, increasing bandwidth from approximately 2–5 Mbps to 100–600 Mbps while enabling real-time data transmission, live video streaming, and cloud-based processing. Centralized management platforms and pooled data plans improved asset tracking, operational visibility, and cost efficiency, with observed cost reductions of approximately 50 percent compared to traditional satellite services. When normalized against performance, this represents an estimated 100x–150x improvement in cost efficiency per unit of bandwidth. While direct cost comparisons are limited due to differing service models, LEO systems provide orders-of-magnitude increases in data capacity and enable capabilities not previously feasible. Environmental testing showed minimal performance impacts under snow, wind, and cold conditions, with rain identified as the primary limiting factor. The findings confirm that LEO broadband is a viable and scalable solution for improving connectivity, operational efficiency, and emergency response capabilities in remote transportation environments.				
14- KEYWORDS : LEO, Low Earth Orbit, Starlink, Connectivity, Network, Data,			15. NUMBER OF PAGES	
			16. PRICE CODE N/A	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT N/A	

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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LENGTH

in	inches	25.4	mm
ft	feet	0.3048	m
yd	yards	0.914	m
mi	Miles (statute)	1.61	km

AREA

in ²	square inches	645.2	millimeters squared	cm ²
ft ²	square feet	0.0929	meters squared	m ²
yd ²	square yards	0.836	meters squared	m ²
mi ²	square miles	2.59	kilometers squared	km ²
ac	acres	0.4046	hectares	ha

MASS (weight)

oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg

VOLUME

fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft ³	cubic feet	0.0283	meters cubed	m ³
yd ³	cubic yards	0.765	meters cubed	m ³

Note: Volumes greater than 1000 L shall be shown in m³

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (°F-32)	Celsius temperature	°C
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ILLUMINATION

fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m ²	cd/cm ²

FORCE and PRESSURE or STRESS

lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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LENGTH

mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi

AREA

mm ²	millimeters squared	0.0016	square inches	in ²
m ²	meters squared	10.764	square feet	ft ²
km ²	kilometers squared	0.39	square miles	mi ²
ha	hectares (10,000 m ²)	2.471	acres	ac

MASS (weight)

g	grams	0.0353		oz
kg	kilograms	2.205		lb
mg	megagrams (1000 kg)	1.103	short tons	T

VOLUME

mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m ³	meters cubed	35.315	cubic feet	ft ³
m ³	meters cubed	1.308	cubic yards	yd ³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 °C+32	Fahrenheit temperature	°F
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ILLUMINATION

lx	lux	0.0929	foot-candles	fc
cd/cm ²	candela/m ²	0.2919	foot-lamberts	fl

FORCE and PRESSURE or STRESS

N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

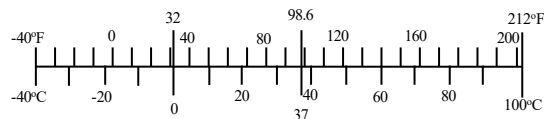


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Acknowledgements

The research reported herein was performed by the Alaska Department of Transportation & Public Facilities (DOT&PF) under the Research, Development, and Technology Transfer (RD&T2) program. The project was led by Ryan Marlow, Emerging Technologies Coordinator, DOT&PF, with support from Pat Dryer and Tim Glassett, DOT&PF, in coordination with the DOT&PF Remote Sensing Lab as the primary operational and development team. The Remote Sensing Lab, under the leadership of Caprice Larimer-Musty, Remote Sensing Lab Manager, and Brian Edinger, UAS Program Manager, provided critical support in the development, deployment, and management of mobile LEO communication kits, as well as operational support during emergency response activities. Their work included the setup, management, and field deployment of Starlink systems and associated equipment.

Technical guidance and coordination were provided by Vince Yelmen, Department Technology Officer, Office of Information Technology (OIT), State of Alaska, with additional support from Jeremy Arnold, DOT&PF Information Technology. Their contributions included network integration, system architecture guidance, and alignment with enterprise IT standards.

The Remote Sensing Lab also played a key role in ensuring compliance with federal requirements under 2 CFR 200, including asset tracking, inventory management, and accountability of deployed equipment used in support of this research.

The team also recognizes the collaboration and support of the State of Alaska Office of Information Technology (OIT), including network integration, governance alignment, and enterprise system support, which were essential to the successful evaluation of Low Earth Orbit (LEO) broadband systems.

Industry collaboration with Armada provided critical capabilities for asset tracking, data management, and system monitoring, enabling large-scale evaluation and operational validation of deployed systems.

This work was supported by the Federal Highway Administration (FHWA) through the Alaska DOT&PF RD&T2 program. The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein.

Executive Summary

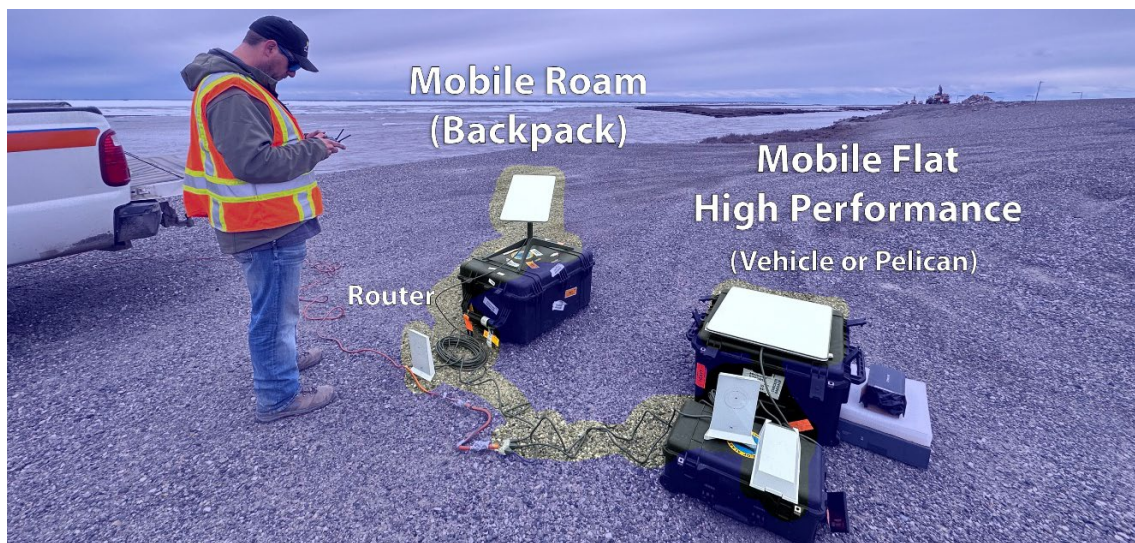
This report presents the results of an evaluation of Low Earth Orbit (LEO) broadband systems to address longstanding connectivity limitations across Alaska's remote transportation environments. The Alaska Department of Transportation & Public Facilities (DOT&PF) historically operated with limited and unreliable connectivity, with many facilities and field operations constrained to 2–5 Mbps bandwidth, restricting the use of modern tools, real-time data, and coordinated response capabilities.

This research evaluated LEO broadband performance across fixed facilities, mobile fleet deployments, maritime operations, and emergency response scenarios over a period exceeding 400 days. The study included integration with enterprise network systems, development of mobile deployment kits, and implementation of centralized management platforms for asset tracking, data usage monitoring, and cost control.

Results demonstrate that LEO systems increased available bandwidth to approximately 100–600 Mbps, enabling real-time data transmission, live video streaming, and cloud-based processing from remote locations. Deployment times were reduced from hours to minutes, and connectivity was extended statewide, including areas previously considered inaccessible. Centralized management and pooled data models reduced recurring connectivity costs by approximately 50 percent while improving operational visibility and resource allocation. When normalized against performance, this represents an estimated 100x–150x improvement in cost efficiency per unit of bandwidth.

The research also identified key operational considerations, including the need for enterprise network integration, centralized governance, and environmental mitigation strategies. Performance remained stable under most environmental conditions, with heavy precipitation identified as the primary limitation.

The findings confirm that LEO broadband provides a viable, scalable solution for improving connectivity, enabling real-time operations, and enhancing emergency response capabilities. This work establishes a repeatable deployment model and supports the adoption of LEO systems as a standard component of transportation operations in remote and rural environments.



(Figure 1- Mobile Field Testing Dalton Highway- Sag River Flooding 2024)

CHAPTER 1 - INTRODUCTION AND RESEARCH APPROACH

1.1 Problem Statement and Research Objective

Alaska's transportation system operates across vast, remote, and environmentally challenging regions where traditional broadband infrastructure is limited, unreliable, or cost-prohibitive. Prior to this study, many DOT&PF facilities and field operations relied on legacy satellite and rural internet services providing approximately 2–5 Mbps of bandwidth at high recurring costs. These limitations prevented the effective use of modern operational tools, including cloud-based applications, real-time video, geographic information systems (GIS), and connected technologies.

The lack of reliable connectivity created operational inefficiencies, delayed decision-making, and limited the Department's ability to coordinate emergency response and statewide operations. As the State of Alaska advances toward a cloud-first environment, addressing connectivity gaps became critical to ensuring that remote facilities and field teams could operate as part of a unified system.

The objective of this research was to evaluate the viability, performance, and cost-effectiveness of Low Earth Orbit (LEO) broadband systems for transportation operations in Alaska. Specifically, the study aimed to determine whether LEO systems could provide reliable, high-speed connectivity; support real-time data workflows; integrate with enterprise networks; and serve as a scalable solution for remote and emergency operations.

1.2 Scope of Study

The scope of this study included the evaluation of LEO broadband systems across a range of operational environments and use cases within DOT&PF. Testing and deployment were conducted in:

- Fixed facilities, including maintenance and operations (M&O) sites and remote sensing labs
- Mobile environments, including Statewide Equipment Fleet (SEF) vehicles
- Maritime environments, including Alaska Marine Highway System (AMHS) vessels
- Emergency response and rapid deployment scenarios



(Figure 2 - SEF DOT&PF Starlink Fleet Testing)

The study evaluated multiple hardware configurations, including standard, enterprise, and portable LEO terminals, and assessed integration with enterprise network infrastructure, including secure routing through the State of Alaska (SOA) Wide Area Network (WAN).

The evaluation also included development and testing of mobile deployment kits, edge compute systems for local data processing, and centralized management platforms for asset tracking, usage monitoring, and cost allocation.

1.3 Research Approach

The research followed a phased approach focused on real world deployment, operational testing, and system integration.

Initial efforts included coordination with internal DOT&PF teams, the State of Alaska Office of Information Technology (OIT), and industry partners to establish deployment environments and integration requirements. LEO systems were deployed across selected sites and mobile platforms to evaluate performance under operational conditions.

The study emphasized practical implementation, including:

- Integration of LEO systems with enterprise networking infrastructure
- Development of mobile deployment configurations for rapid response
- Implementation of centralized management and monitoring tools
- Evaluation of communication systems using LEO backhaul

Testing was conducted iteratively, with findings used to refine deployment models, improve system reliability, and develop standardized operational workflows.

1.4 Methodology

The evaluation was conducted over a period exceeding 400 days, allowing for long-term assessment of system performance across seasonal and environmental conditions.

Field testing included:

- Deployment of LEO systems across multiple regions and operational scenarios
- Integration with enterprise networking systems, including secure WAN routing
- Use of centralized management platforms to collect usage and performance data
- Validation of communication systems, including radio over IP (ROIP) integration

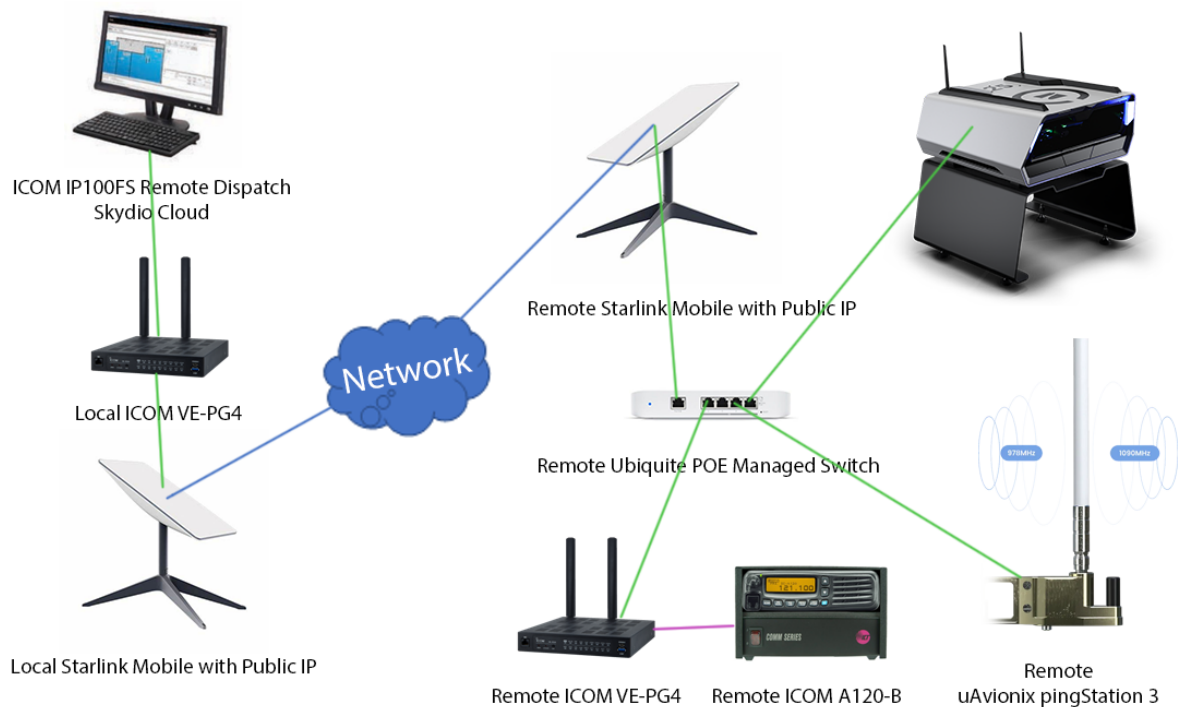
Data collection focused on:

- Bandwidth performance (download and upload speeds)
- System uptime and reliability
- Environmental impacts on performance
- Data usage and consumption patterns
- Deployment time and operational efficiency

Performance metrics were derived from a combination of:

- Network monitoring systems
- Centralized management platforms
- Field observations and operational use

The methodology emphasized real-world operational conditions rather than controlled laboratory testing, ensuring that results reflect actual deployment environments and use cases relevant to transportation operations in Alaska.



(Figure 3 – Remote Drone and ROIP Configuration via Starlink)

CHAPTER 2 - FINDINGS

Prior to the implementation of Low Earth Orbit (LEO) broadband systems, connectivity across rural Alaska relied primarily on legacy satellite and terrestrial solutions that provided limited bandwidth and high operational costs. Typical performance ranged from approximately 2–5 Mbps, which constrained the use of modern tools such as cloud services, real-time collaboration platforms, and high-resolution data transfer.

Traditional satellite systems, including geostationary and low-bandwidth LEO providers, were optimized for voice and low-data-rate communications. These systems typically operate under per-megabyte billing models and do not support high-throughput applications such as live video streaming or large-scale data transfer. As a result, they were not suitable for supporting modern transportation operations requiring real-time situational awareness and data-driven decision-making. The emergence of LEO broadband systems represents a significant advancement, providing high-speed, low-latency connectivity capable of supporting enterprise-level applications in remote environments.

2.1 Connectivity Performance Improvements

The introduction of LEO broadband systems resulted in a substantial and measurable increase in available bandwidth across all tested environments. Field deployments demonstrated an increase in connectivity from approximately 2–5 Mbps under legacy systems to sustained speeds ranging from approximately 100 to 600 Mbps under LEO systems. This represents an order-of-magnitude improvement in network performance and fundamentally changes the types of operations that can be supported in remote environments. The increase in bandwidth enabled reliable use of cloud-based platforms, large data uploads, and continuous communication between field teams and centralized operations. The performance gains were consistent across multiple deployment scenarios, including fixed facilities, mobile environments, and maritime applications, confirming that LEO broadband provides a scalable and high-performance solution for statewide connectivity.



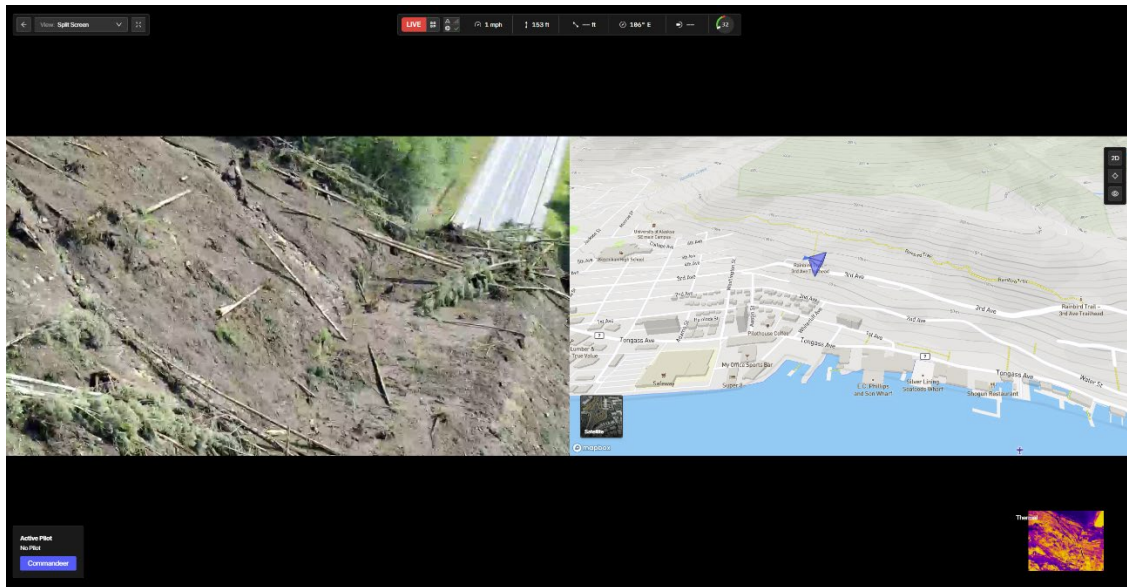
(Figure 4 - Emergency Response FirstNet Cellular Back Haul Over Starlink Enterprise)

2.2 Real-Time Data and Operational Workflows

The increase in bandwidth enabled a fundamental shift in operational workflows from delayed, batch-based processes to real-time data-driven operations. Prior to LEO deployment, field data such as imagery, LiDAR, and video were collected and stored locally, then transferred manually or uploaded over extended periods due to bandwidth limitations. This introduced delays ranging from hours to days before data could be accessed and used for decision-making. With LEO connectivity, data can now be transmitted directly from the field to centralized systems or cloud environments in real time. This enables immediate processing, analysis, and dissemination of information, significantly reducing the time between data collection and actionable insight. The ability to operate in real time improves coordination, enhances decision-making speed, and reduces reliance on physical data transport, which is particularly critical in remote and time-sensitive operational scenarios.

2.3 Live Video Streaming Capability

A significant operational capability enabled by LEO broadband is the ability to stream live video from remote and mobile environments. This capability was not feasible under previous connectivity conditions and represents a major advancement in situational awareness and coordination. Field teams can now transmit continuous video feeds to centralized operations centers, allowing leadership and supporting personnel to observe conditions in real time. This enhances communication, reduces uncertainty, and supports more informed decision-making during both routine operations and emergency response scenarios. Live streaming also enables collaboration across agencies by providing a shared, real-time view of operational environments, which is particularly valuable during large-scale or multi-agency incidents.



(Figure 5 – Live Stream and Control via Skydio X10 Drone over Starlink)

2.4 Deployment Efficiency and Mobility

Deployment methods evolved significantly over the course of the research. Early deployments required large, fixed installations with 120V power requirements, often involving generators, inverters, and vehicle modifications. These configurations were effective but introduced complexity, increased setup time, and limited scalability. The introduction of smaller, low-power systems, particularly portable LEO terminals, enabled a transition to rapid deployment models. Current configurations allow systems to be deployed in minutes using standard 12V vehicle power or

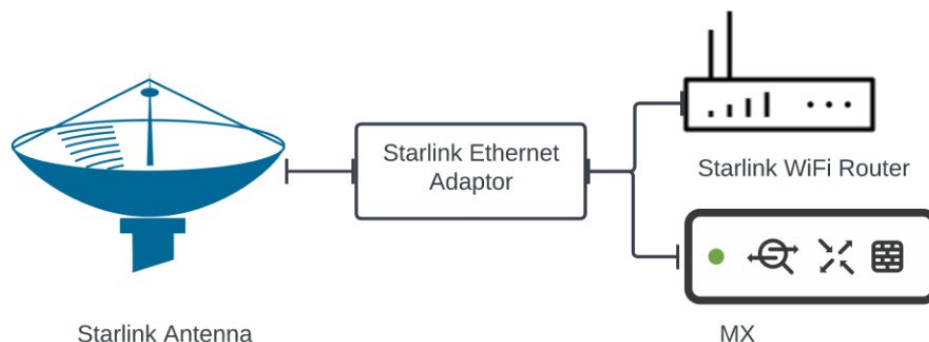
portable battery systems, often requiring no permanent installation. This shift enables true mobility, allowing any vehicle or field team to establish connectivity quickly and reliably. The reduction in deployment time from hours to minutes represents a significant operational improvement and supports rapid response scenarios where time is critical.

2.5 Environmental Performance

LEO broadband systems demonstrated strong performance across a wide range of environmental conditions typical of Alaska. Field testing confirmed minimal performance degradation during snowstorms, blizzard conditions, extreme cold temperatures, high wind events, and dust exposure. Additionally, no consistent or measurable impact on system performance was observed during periods of elevated auroral activity. These findings indicate that LEO systems are well suited for Arctic and sub-Arctic environments. The primary environmental limitation identified was heavy precipitation, particularly rain, which can attenuate satellite signals and reduce performance temporarily. In regions such as Southeast Alaska, mitigation strategies including the use of higher-power enterprise terminals and multi-terminal array configurations were implemented successfully to maintain connectivity during adverse weather conditions.

2.6 Network Architecture and Integration

A multi-tier network architecture was developed to support the diverse operational requirements of DOT&PF. This architecture integrates LEO connectivity with enterprise network systems and edge computing capabilities. At fixed facilities, LEO systems are integrated into the State of Alaska Wide Area Network (SOA WAN) through Cisco Meraki infrastructure, providing secure and redundant connectivity. Edge compute systems were deployed to enable local processing of large datasets, such as imagery and LiDAR, reducing the need to transmit all data to cloud environments and improving processing efficiency in bandwidth-constrained scenarios. In mobile and emergency deployments, LEO systems are used as direct-to-internet solutions, enabling rapid connectivity without reliance on existing infrastructure. This layered architecture allows operations to continue seamlessly across connected, disconnected, and degraded environments.



(Figure 6 - Network Configuration with Gen2 Starlink Panels with Meraki Router)

2.7 Communications Integration (ROIP)

The integration of LEO broadband with existing radio communication systems using Radio over IP (ROIP) technologies represents a significant advancement in communication capabilities. Traditional radio systems are limited by line-of-sight constraints and require extensive infrastructure such as towers and repeaters to extend coverage. By using LEO connectivity as a backhaul, radio communications can be transmitted over IP networks, effectively extending coverage statewide without the need for additional physical infrastructure.

This research demonstrated successful integration with Motorola and ICOM communication systems, enabling radio traffic to be transmitted and received through mobile and portable assets. Field-deployed systems, including vehicle-based and portable configurations, were able to connect radio networks through LEO backhaul, allowing users to communicate beyond traditional coverage areas without reliance on fixed base stations or repeater infrastructure.

This capability enables communications to originate from or be extended to any location where LEO connectivity is available, significantly improving operational flexibility and coverage in remote environments. Mobile units and rapid deployment kits can now serve as temporary or on-demand communication nodes, supporting emergency response, field operations, and interagency coordination.

The integration of LEO broadband with radio systems enhances interoperability, reduces dependence on costly infrastructure expansion, and provides a scalable solution for extending communication capabilities across Alaska's transportation network.

2.8 Asset Management and Operational Visibility

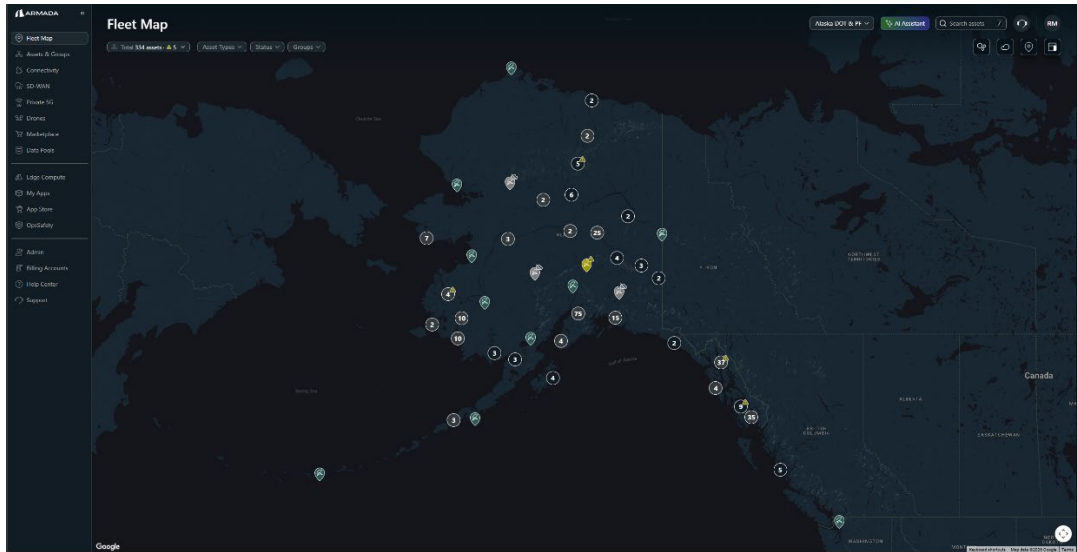
The implementation of the Armada Atlas platform enabled centralized management and real-time visibility of all deployed assets, including LEO terminals, drones, routers, and edge compute systems. The platform currently manages approximately 291 active service lines across DOT&PF operations, providing a comprehensive view of system deployment and utilization statewide. Atlas provides a geospatial representation of asset locations and operational status, allowing both operational personnel and leadership to understand resource distribution, network activity, and system performance in real time.

In addition to asset tracking, the platform provides detailed network performance statistics, including bandwidth utilization, uptime, and connection health across all service lines. These capabilities allow operators to monitor system performance continuously and identify issues proactively. Atlas also supports centralized firmware and configuration management, enabling remote updates and standardization of deployed systems without requiring field intervention. This ensures that all devices remain current, secure, and aligned with enterprise network requirements.

The system further enables configurable alerts and notifications, including thresholds for data usage, connectivity loss, and device health. These alerts provide immediate awareness of abnormal conditions and support rapid response to operational issues, particularly in remote environments where manual monitoring is not feasible.

The ability to view assets, service lines, and network performance centrally supports rapid decision-making, particularly during emergency scenarios, by enabling immediate identification of available equipment, associated custodians, and nearby resources. This capability allows for dynamic reallocation of assets without delay, reducing the need for redundant deployments and preventing unnecessary procurement of equipment already in the field.

In addition to location-based visibility, the integration of service line tracking enables detailed monitoring of network usage, supporting operational awareness and cost accountability at both the project and enterprise level. This visibility improves coordination across teams, enhances resource utilization, and ensures that deployed systems are used efficiently and in alignment with operational needs. The scale of deployment, as reflected by the number of managed service lines, demonstrates that LEO connectivity has transitioned from pilot testing to a fully operational, enterprise-level system.



(Figure 7 - Armada Atlas Fleet Map Monitoring Dashboard)

2.9 Data Pool Management and Cost Optimization

Centralized data pool management was implemented to optimize bandwidth usage and reduce operational costs. Instead of maintaining individual subscriptions for each terminal, shared data pools allow multiple devices to draw from a centralized allocation of bandwidth. This approach aligns costs with actual usage and eliminates expenses associated with idle or underutilized devices.

A key advancement in the pooled data model is the ability to place terminals in an inactive or standby status without incurring data charges, allowing assets to remain deployed and ready without generating unnecessary costs. This capability significantly improves operational flexibility by enabling rapid activation of systems when needed while avoiding continuous billing for unused devices.

Additionally, the transition from traditional monthly subscription models to an annual, pre-purchased data allocation provides greater cost predictability and simplifies budget management. This model reduces administrative overhead and allows DOT&PF to plan and allocate resources more effectively across projects and operational needs.

The transition to pooled data plans resulted in an approximate 50 percent reduction in recurring connectivity costs, while also improving scalability and efficiency. Bandwidth can be dynamically allocated across deployments based on demand, ensuring that capacity is available where it is needed most. This approach supports large-scale operations while maintaining cost control and maximizing the value of deployed infrastructure.

2.10 Cost Efficiency and Capability Comparison

While direct cost comparisons between LEO systems and traditional satellite services are limited due to fundamentally different service models, the research demonstrates a significant improvement in cost efficiency when normalized against performance. LEO systems provide bandwidth increases from approximately 2–5 Mbps to 100–600 Mbps while reducing overall connectivity costs by approximately 50 percent through the use of pooled data models and optimized resource allocation.

In addition to operational cost improvements, hardware costs associated with LEO systems are substantially lower than comparable satellite solutions. Starlink terminals are available at relatively low unit costs and are widely distributed through commercial retail channels, including outlets such as West Marine, Best Buy, Costco, and Home Depot. This broad availability enables rapid

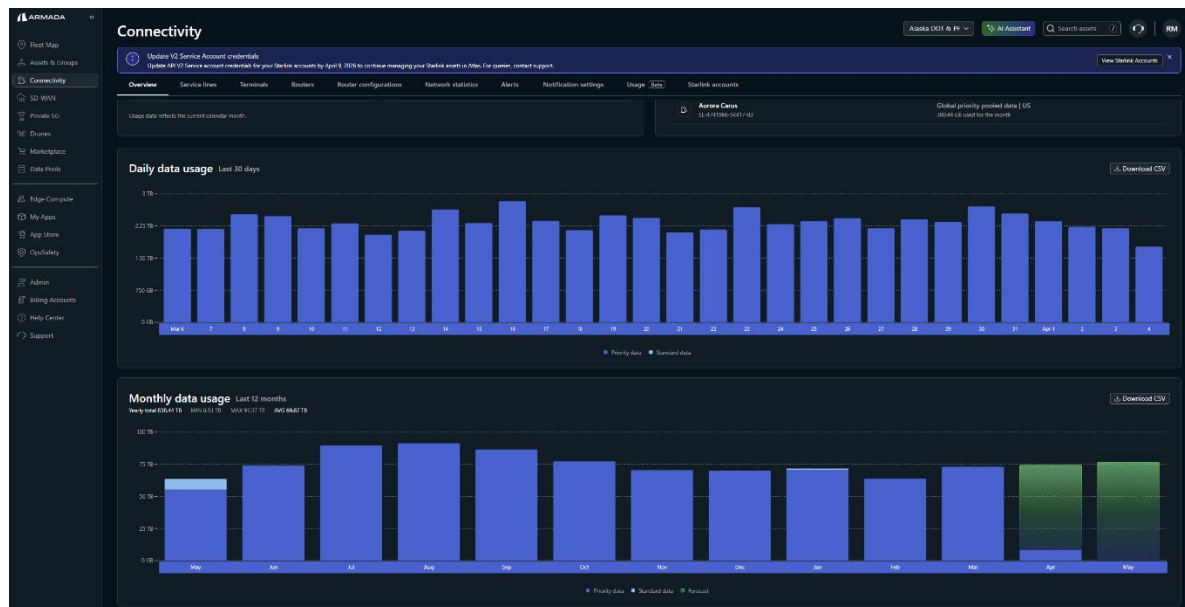
procurement and deployment without reliance on specialized vendors or extended acquisition timelines. In contrast, alternative systems such as OneWeb and Iridium require higher-cost hardware and specialized service agreements, which significantly limit scalability and rapid deployment for high-bandwidth use cases.

When evaluated on a cost-per-bandwidth basis, LEO systems provide an estimated 100x–150x improvement in cost efficiency. Traditional systems such as Iridium operate at kilobit-level speeds with per-megabyte billing, while LEO systems support gigabyte- to terabyte-scale data transfer under pooled or high-capacity plans. This fundamental difference in both hardware cost and service model effectively places traditional satellite providers at a disadvantage for high-throughput operational use, particularly where real-time data, video streaming, and cloud integration are required.

As a result, LEO systems not only reduce cost but also enable capabilities that were previously infeasible, fundamentally changing the cost-performance relationship of satellite communications and establishing a new baseline for operational connectivity.

2.11 Long-Term Monitoring and Predictive Analytics

System performance and usage were monitored continuously over a period exceeding 400 days, providing a comprehensive dataset for evaluating reliability and usage patterns. Monitoring included daily and monthly data consumption, system uptime, and network performance metrics. This long-term dataset confirmed the stability and reliability of LEO systems across seasonal and environmental conditions. Additionally, the data enabled the development of predictive models for forecasting network usage and capacity requirements. These predictive capabilities support proactive planning, allowing DOT&PF to optimize resource allocation, manage costs, and scale deployments effectively.



(Figure 8 - Armada Atlas Daily and Monthly Data Utilization Metrics)

2.12 Governance and Compliance

A centralized governance framework was implemented to manage procurement, deployment, and operation of LEO systems. All devices are treated as managed enterprise assets and are tracked, assigned, and monitored through centralized systems. This approach ensures alignment with State of Alaska IT policies and compliance with federal requirements under 2 CFR 200, including asset tracking, inventory management, and accountability. The governance model includes approval processes for both procurement and deployment, ensuring that all systems are integrated into

approved network environments and meet security and compliance standards.

2.13 Hardware Evolution and Reliability

Hardware advancements during the study improved both deployment efficiency and system reliability. Early systems relied on proprietary cabling and high-power configurations that were susceptible to degradation under sustained use and environmental conditions. These issues were mitigated through the adoption of standardized, low-voltage power systems, including USB-C-based configurations, which improved reliability and simplified maintenance. The transition to smaller, portable devices also reduced deployment complexity and increased operational flexibility, enabling broader adoption across field operations.

2.14 Industry Collaboration

The research was conducted in collaboration with industry partners, including Armada, whose platform provided critical capabilities for asset tracking, data management, and system monitoring. This collaboration enabled the development of scalable management models and supported real-world validation of LEO system performance and operational workflows. Industry partnership played a key role in accelerating deployment, refining system architecture, and ensuring that solutions were aligned with practical operational requirements.



(Figure 9 – SEF Setup Diagram for Fleet Integration)

CHAPTER 3 - INTERPRETATION, APPRAISAL, AND APPLICATIONS

3.1 Interpretation of Findings

The results of this study demonstrate that Low Earth Orbit (LEO) broadband systems fundamentally change how transportation operations can be conducted in remote and infrastructure-limited environments. The observed improvements in bandwidth, reliability, and deployment speed enable a transition from delayed, disconnected operations to real-time, fully integrated workflows. This shift is not incremental; it represents a structural change in how data is collected, transmitted, and used to support decision-making across the transportation system.

The ability to transmit large datasets, stream live video, and integrate field operations directly with centralized systems allows DOT&PF to operate as a connected, statewide network rather than a collection of isolated facilities and field teams. This capability directly addresses the core problem identified at the outset of the research: the inability to support modern operational tools and workflows due to limited connectivity. The findings confirm that LEO broadband removes this constraint and enables the adoption of technologies such as cloud-based systems, real-time monitoring, and integrated communications.

3.2 Operational and Economic Impact

The implementation of LEO broadband systems has a direct and measurable impact on operational efficiency and cost. While observed cost reductions of approximately 50 percent compared to legacy satellite services are significant, the more meaningful metric is the improvement in cost efficiency relative to performance. When normalized against bandwidth, LEO systems provide an estimated 100x–150x improvement in cost efficiency per unit of data capacity. This shift enables the use of applications and workflows that were previously not feasible under traditional cost structures.

Operationally, the ability to deploy connectivity rapidly and operate in real time reduces response times, improves coordination, and minimizes the need for redundant deployments. The centralized visibility provided by asset management platforms allows leadership to identify available resources immediately and allocate them effectively, reducing duplication of effort and unnecessary expenditures. These improvements contribute to both direct cost savings and indirect cost avoidance, particularly in emergency response scenarios where rapid deployment and coordination are critical.

3.3 Applications to Practice

The findings of this research support immediate application across multiple operational domains within DOT&PF and similar agencies. LEO broadband systems can be integrated into standard practice for fixed facilities, mobile operations, and emergency response deployments. The development of a tiered network architecture, combining enterprise WAN integration, edge compute systems, and direct LEO connectivity, provides a flexible and resilient model that can be adapted to a wide range of operational scenarios.

In practice, this means that connectivity can be treated as a foundational component of operations rather than a limiting factor. Field teams can operate with the same level of connectivity as centralized offices, enabling consistent workflows and improved communication. The integration of LEO systems with radio communications through ROIP

further extends this capability by eliminating traditional coverage limitations and enabling statewide communication without additional infrastructure.

3.4 Integration into Standards and Policies

The results of this study support the incorporation of LEO broadband systems into DOT&PF standards, specifications, and operational policies. To ensure consistent and secure deployment, LEO systems should be integrated into enterprise network architectures and managed through centralized platforms. This includes routing all traffic through secure network infrastructure, enforcing standardized configurations, and maintaining compliance with state IT policies and federal requirements.

The governance model developed during this research, including centralized procurement, dual approval processes, and asset tracking, provides a framework for managing LEO systems at scale. These practices ensure that deployments remain controlled, secure, and compliant while supporting operational flexibility. The use of pooled data plans and centralized management platforms should also be incorporated into policy to maintain cost efficiency and scalability.

3.5 General Recommendations

Based on the findings of this research, the following recommendations are provided for implementation:

LEO broadband systems should be adopted as a standard component of remote transportation operations, particularly in environments where traditional connectivity is limited or unavailable. Deployment models should prioritize a tiered architecture that combines enterprise integration, edge compute capabilities, and rapid deployment configurations to support a range of operational needs.

All LEO systems should be integrated into secure enterprise networks and managed through centralized platforms to ensure compliance, visibility, and control. Standardized hardware configurations should be defined to match specific use cases, including portable systems for rapid deployment and higher-capacity systems for persistent operations in challenging environments.

Organizations should implement pooled data models to optimize bandwidth usage and reduce costs, and should leverage centralized monitoring systems to support real-time decision-making and resource allocation. Finally, LEO systems should be integrated with existing communication systems to extend coverage and improve coordination across the transportation network.

3.6 Limitations and Considerations

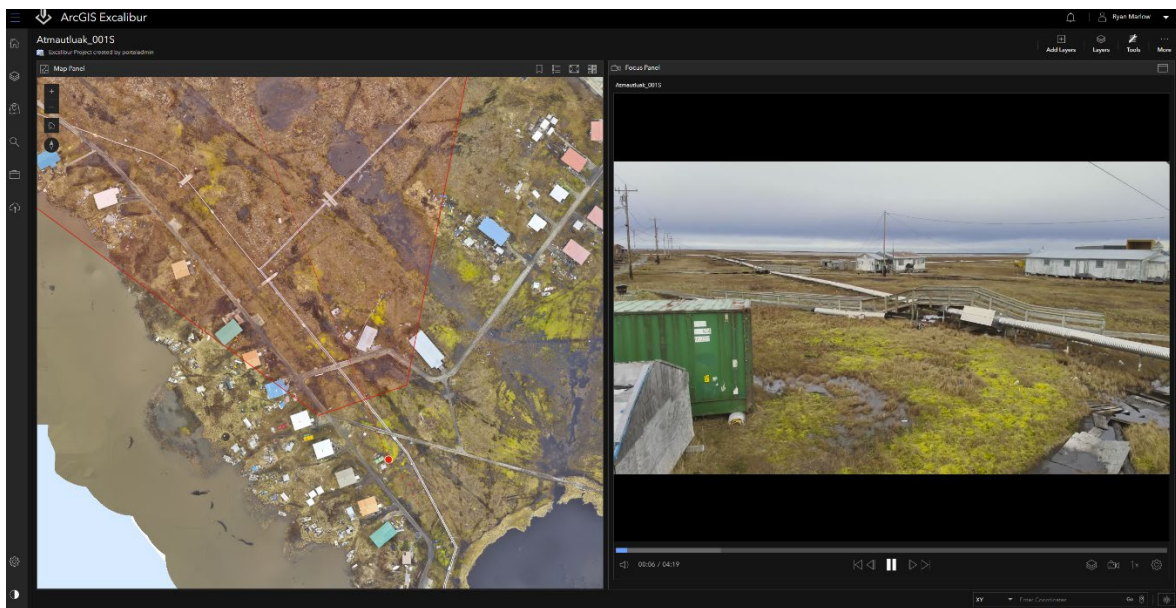
While LEO broadband systems provide significant advantages, several limitations must be considered. The primary environmental limitation identified during this study is the impact of heavy precipitation, particularly rain, which can temporarily reduce signal performance. Terrain obstruction, including areas with limited sky visibility, can also affect connectivity, particularly in mountainous regions and high-latitude environments.

Additionally, the effectiveness of LEO systems depends on proper integration with enterprise network infrastructure and centralized management systems. Without these elements, deployments may become difficult to manage and may introduce security and cost risks. Power requirements for higher-capacity systems and the need for redundancy in critical operations should also be considered in deployment planning.

3.7 Broader Implications

The findings of this research extend beyond DOT&PF and are applicable to other transportation agencies and organizations operating in remote or infrastructure-limited environments. The demonstrated ability to provide high-speed connectivity without reliance on traditional infrastructure suggests that LEO broadband can serve as a foundational technology for modernizing operations in rural and underserved regions.

The combination of high-performance connectivity, centralized management, and flexible deployment models represents a shift in how infrastructure is delivered and managed. This approach enables organizations to bypass traditional limitations and adopt a more agile, scalable, and data-driven operational model.



(Figure 10 – Video and Imagery Uploaded direct to Esri GIS Environment Via Starlink)

CHAPTER 4 - CONCLUSIONS AND SUGGESTED RESEARCH

4.1 Conclusions

This research confirms that Low Earth Orbit (LEO) broadband systems provide a viable, scalable, and transformative solution to longstanding connectivity challenges across Alaska's transportation system. The results demonstrate that LEO systems significantly improve bandwidth, reliability, and deployment flexibility, enabling a transition from delayed, disconnected operations to real-time, integrated workflows.

The increase in available bandwidth from approximately 2–5 Mbps to 100–600 Mbps allows for the use of modern technologies, including live video streaming, cloud-based data processing, and real-time communication. These capabilities were not achievable under previous connectivity conditions and represent a fundamental shift in operational capability. The ability to deploy connectivity rapidly, often within minutes, further enhances operational effectiveness, particularly in emergency response and remote field environments.

While direct cost savings of approximately 50 percent were observed compared to legacy satellite services, the more significant impact is the improvement in cost efficiency relative to performance. When normalized against bandwidth, LEO systems provide an estimated 100x–150x improvement in cost efficiency. This shift enables high-volume data transfer and real-time operations at a cost that is sustainable for statewide deployment.

The research also demonstrates that LEO systems are highly resilient under most environmental conditions typical of Alaska, including snow, wind, and extreme cold. Heavy precipitation was identified as the primary environmental limitation; however, this can be mitigated through system design, including the use of higher-capacity terminals and multi-terminal configurations.

The development of a multi-tier network architecture integrating enterprise systems, edge compute, and LEO connectivity enables operations across connected, disconnected, and degraded environments. Centralized management platforms provide critical capabilities for asset tracking, usage monitoring, and cost control, allowing the system to scale efficiently while maintaining accountability and compliance with federal requirements under 2 CFR 200.

The findings further demonstrate that LEO broadband enables new operational capabilities, including statewide communication through integration with radio systems, real-time situational awareness, and improved coordination during emergency response. These capabilities reduce reliance on traditional infrastructure and eliminate many of the limitations associated with legacy communication systems.

Based on these results, LEO broadband should be considered a standard component of transportation operations in remote and rural environments. The deployment model developed through this research provides a repeatable framework for implementation and can be applied across DOT&PF and other agencies operating in similar conditions.

4.2 Suggested Research

While this study confirms the viability and effectiveness of LEO broadband systems, several areas for further research have been identified to support continued development and optimization.

1. Future research should focus on improving performance under adverse weather conditions, particularly heavy precipitation, including the evaluation of advanced antenna configurations and multi-terminal array systems. Additional work is needed to further quantify performance impacts in high-latitude and terrain-obstructed environments to refine deployment strategies in these regions.
2. Further research should also explore integration with additional communication systems, including expanded use of radio over IP (ROIP) and interoperability across multiple agencies and jurisdictions. This includes evaluating the potential for fully integrated communication systems that combine broadband, radio, and sensor networks into a unified operational platform.
3. The development of standardized deployment configurations and design guidelines would support broader adoption and consistency across agencies. This includes defining best practices for hardware selection, network architecture, and system integration based on specific operational requirements.
4. Additional research is recommended in the area of edge computing and data management, particularly in optimizing the balance between local processing and cloud-based workflows. This includes evaluating methods for reducing bandwidth demand while maintaining data quality and accessibility.
5. Long-term studies on usage patterns and predictive analytics would further enhance the ability to manage network resources and control costs. Continued monitoring and analysis will support improved forecasting, capacity planning, and optimization of pooled data models.
6. Further research should evaluate policy and governance frameworks to support large-scale deployment, including procurement strategies, compliance requirements, and integration with statewide IT infrastructure. This will ensure that LEO systems can be deployed sustainably and remain aligned with evolving operational and regulatory needs.

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APPENDIX A

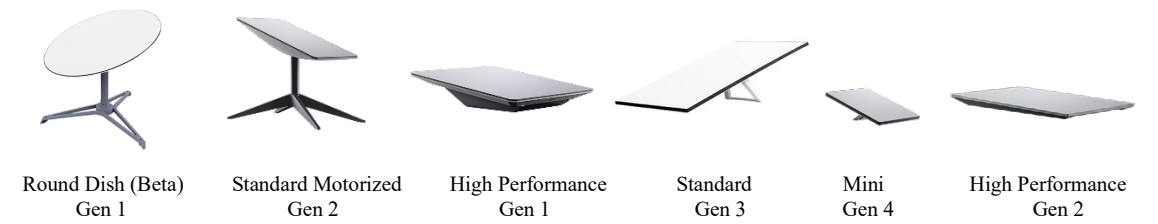
LEO Equipment Breakdown

This appendix summarizes the Low Earth Orbit (LEO) broadband hardware evaluated during this research. Testing and operational deployment focused on *Starlink Standard (Gen 2 and Gen 3), High Performance (enterprise flat panel), and Mini (Gen 4 portable systems)* across fixed facilities, mobile fleet environments, maritime operations, and emergency response scenarios.

Each hardware type was assessed for performance, power requirements, deployment time, environmental resilience, and integration with enterprise network systems. Results confirmed that Standard and Gen 3 systems provide the primary backbone for facility and WAN-integrated deployments, High Performance systems improve reliability in adverse conditions such as heavy precipitation, and Mini systems enable rapid, low-power deployment for mobile and emergency use.

Starlink Round Dish (Gen 1 / Beta) hardware was not included in testing due to its limited relevance to current deployments. Alternative LEO providers, including *OneWeb* and *Iridium*, were reviewed for comparison but not field-tested due to limitations in cost, availability, and bandwidth capability for high-throughput operational use.

These findings support a tiered hardware deployment model aligned with operational requirements, including mobility, reliability, and bandwidth demand.



Provider	Model/System	Generation	Typical Speed	Hardware Cost	Service Cost	Deployment Type	Primary Use Case	Weather / Known
Starlink	Round Dish (Beta)	Gen 1	50–150 Mbps	~\$499	Monthly	Fixed	Initial testing	Rain fade, high power
Starlink	Standard Motorized (Rectangular)	Gen 2	100–250 Mbps	~\$599	Monthly / pooled	Fixed / modified mobile	Early deployments	Rain attenuation, requires 120V power
Starlink	High Performance	Gen 1	150–220 Mbps	~\$2,500–\$3,500	Priority /	Fixed / maritime	High reliability	Best rain mitigation, high
Starlink	Standard (Gen 3)	Gen 3	100–400+ Mbps	~\$349–\$599	Monthly / pooled	Fixed / semi-mobile	Facility backbone	Moderate rain impact, requires structured
Starlink	Mini	Gen 4 (Portable)	50–100 Mbps	~\$250–\$400	Monthly / portable	Fully portable	Emergency / fleet	Lower throughput, moderate rain sensitivity,
Starlink	High Performance	Gen 2	400-600+ Mbps	~\$2,000	Priority /	Fixed / maritime	High reliability	Best rain mitigation, high
OneWeb	Enterprise LEO Terminal	Enterprise	50–200 Mbps	~\$10,000	Contract-based	Fixed	Enterprise / government	Limited mobility, availability constraints, less
Iridium	Certus 100	Legacy LEO	0.02–0.088 Mbps	~\$1,500–\$3,000	Per MB billing	Portable	Voice / low data	Extremely low bandwidth, not suitable for high data