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Field Evaluation of Lightweight Noise Barriers and Development of Noise Barrier Inspection and Asset Management Program

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Final Report VTRC 26-R47

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Abstract:

Noise barriers along high-volume roads reduce traffic noise using either normal-weight materials, such as concrete or brick, or lightweight materials, such as metal, composites, fiberglass, or acrylic. Although the Virginia Department of Transportation's (VDOT) current concrete noise barriers have proven durable, some lightweight metal noise barriers have failed prematurely because of corrosion, prompting the need to better understand the field performance of lightweight alternatives. This project aimed to improve the life-cycle management of VDOT's noise barrier inventory through field evaluations of lightweight barriers, development of an inspection and asset management framework, and unmanned aerial system (UAS) trial inspections.

The literature review revealed that a few state departments of transportation have noise barrier inspection or asset management programs, typically including condition ratings, deterioration models, budgets, and performance targets. A review of noise barrier databases revealed inconsistencies in field names and wall identification numbers, highlighting the need for a single authoritative dataset. Condition data indicated that most concrete and brick noise barriers were in acceptable condition, whereas more lightweight noise barriers required attention.

Field evaluations of 25 lightweight noise barriers of different material and design types found that perforated metal panels oriented horizontally performed the worst, with estimated service lives of only 10 to 15 years. Other lightweight types generally performed well, with estimated service lives of 50 years or more. Anchor bolts were vulnerable to corrosion, especially when exposed to salt spray.

Based on these findings, a proposed inspection program includes overall condition and element-level ratings of five element types and their associated defect types. Proposed inspection intervals range from 24 to 72 months based on mounting type, ability to fall onto traffic or pedestrians, and overall condition rating. The proposed asset management plan incorporates deterioration models, treatment types, and estimated costs. A Markov chain analysis over a 20-year period showed that an $11 million asset management program could maintain VDOT's noise barrier inventory below a 10% poor-condition performance target, yielding a 23% return on investment and saving $2.5 million annually.

UAS trial inspections of three noise barriers demonstrated that high-resolution photogrammetry and LiDAR can effectively assess the condition and detect misalignments of noise barriers from both sides. LiDAR was effective even for noise barriers with highly vegetated areas. UASs also showed potential for inspecting other VDOT assets.

Recommendations from the project include VDOT prohibiting the use of perforated metal panels oriented horizontally, establishing a single authoritative noise barrier database, implementing a noise barrier inspection and asset management program, pursuing future research on asset inspections using UASs, and working across divisions on geospatial workflows and data governance.

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FINAL REPORT

FIELD EVALUATION OF LIGHTWEIGHT NOISE BARRIERS AND DEVELOPMENT OF NOISE BARRIER INSPECTION AND ASSET MANAGEMENT PROGRAM

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Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
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DISCLAIMER

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INTRODUCTION

Noise barriers, also called noise walls or sound walls, help reduce traffic noise on adjacent properties by reflecting or absorbing sound waves (Federal Highway Administration [FHWA], 2001). Typically located along high-volume interstates in high-density locations, these barriers commonly consist of panels supported by posts that are often embedded in concrete shafts or bolted to structures. Although ground-mounted barriers are typically made of heavy materials like concrete or brick, structure-mounted barriers require lightweight alternatives such as metal, composites, fiberglass, acrylic, or polyvinyl chloride (PVC) to minimize dead loads on the supporting structure. Figure 1 shows examples of some of these lightweight noise barriers across Virginia.

Figure 1. Examples of Lightweight Noise Barriers Made from Different Materials: (a) Acrylic; (b) Polyvinyl Chloride; (c) Fiberglass; (d) Metal

Although the Virginia Department of Transportation's (VDOT) concrete ground-mounted barriers have demonstrated excellent durability, certain structure-mounted metal barriers have underperformed. Corrosion of some metal panel barriers has caused premature failures such as buckling, crushing, or panel slippage, leading to compromised noise reduction effectiveness and increased replacement costs. Figure 2 shows an example of this corrosion damage. In response, VDOT began using alternative lightweight materials, such as composites, acrylics, and PVC. Although these alternative materials have anecdotally performed well in terms of structural durability, a comprehensive field evaluation is required to determine the long-term durability of all lightweight material noise barriers in the VDOT inventory.

Figure 2. Example of Corrosion Damage on Metal Noise Barrier in Virginia

Furthermore, VDOT does not have a formal statewide inspection and asset management program for noise barriers. Such a program would allow VDOT to quickly evaluate long-term performance and strategically allocate funding to replace noise barriers at the end of their service lives. Currently, inspecting structure-mounted barriers is costly and logistically difficult because of access challenges, frequently requiring specialized access equipment and extensive maintenance of traffic. Other state departments of transportation (DOTs) have begun using unmanned aerial systems (UASs) for inspecting retaining walls. Therefore, UASs may offer a more cost-effective and safer alternative for inspecting noise barriers.

PURPOSE AND SCOPE

The purpose of this research was to improve the life-cycle management of VDOT's noise barrier inventory. The project consisted of three specific objectives:

1. **Durability Evaluation:** Perform an evaluation of the durability and condition of VDOT's lightweight noise barriers.
2. **Inspection and Asset Management Framework:** Develop frameworks for VDOT noise barrier inspection and asset management programs.
3. **UAS Trial Study:** Conduct UAS trial inspections of multiple noise barriers to gauge their effectiveness at inspecting the condition of noise barriers from both sides.

The scope of this project included a field survey of lightweight noise barriers across Virginia, a review of the noise barrier databases for VDOT's inventory, and a collaborative trial inspection performed with a UAS consultant.

METHODS

Overview

This project included five tasks to achieve the primary objective. The subsequent sections describe in detail the methods for the following research tasks:

1. Literature review.
2. Review of noise barrier databases for VDOT's inventory.
3. Field evaluations of VDOT's lightweight noise barriers.
4. Development of frameworks for VDOT noise barrier inspection and asset management programs.
5. UAS trial inspections of noise barriers.

Literature Review

The literature review focused on the following three topics related to noise barriers: (1) durability; (2) inspection; and (3) asset management. For the noise barrier durability portion, the literature review included research reports and publications. For the inspection and asset management portion, state DOT specifications and transportation asset management plans were reviewed.

Review of Noise Barrier Databases for VDOT's Inventory

VDOT currently maintains two databases to store data on noise barriers, both of which use geographic information systems (GIS). The VDOT Maintenance Division and the VDOT Environmental Division maintain these databases. The database maintained by the VDOT Maintenance Division primarily includes fields related to the condition of noise barriers, such as presence of structural issues, surface area disturbances, trees or heavy vegetation, drainage issues, and graffiti. In addition, it also includes a numerical condition score and grade for each noise barrier. The Maintenance Division database also includes fields related to the noise barrier type, including primary construction material and foundation type (ground or structure mounted), location, and geometry.

The database maintained by the VDOT Environmental Division contains many fields about the noise barriers, including location, FHWA identification, construction year, geometric data, primary construction material, foundation type, road and back side aesthetics, noise reduction, noise category, and construction cost.

FHWA also maintains a national noise barrier database that includes data for each state's inventory, which the VDOT Environmental Division is required to update triennially.

Information from these three databases was reviewed to evaluate VDOT's noise barrier data storage and to glean information about noise barrier durability.

Field Evaluation of VDOT's Lightweight Noise Barriers

Based on information from the noise barrier databases, 25 lightweight noise barriers across Virginia were selected for field visits. These noise barriers were visually assessed for their durability during their service lives. Multiple components of the noise barriers were inspected during these field visits, including the panels, posts, connections between the panels and posts, anchor connections between the posts and foundations, and the noise barriers' foundations.

Framework for VDOT Noise Barrier Inspection and Asset Management Program

A noise barrier inspection program would allow VDOT to better understand the current condition of its noise barriers. A noise barrier asset management program would then allow VDOT to systematically manage its noise barriers using condition data from the proposed noise barrier inspection program. If both were established, data from the inspection program could be used to inform the deterioration models within the asset management program.

The framework for the proposed inspection and asset management programs was developed based on results from the literature review and field observations.

Unmanned Aerial System Trial Inspections

The focus of the UAS trial inspections was to determine whether UASs could capture visual data to be used to evaluate a noise barrier's condition. First, ground control was established prior to UAS flights. A UAS was then flown above and around existing noise barriers, capturing Light Detection and Ranging or Laser Imaging, Detection, and Ranging (LiDAR) data at a density of 400 pts/m^2, orthoimagery at 1.27 cm ground sampling distance, and high-resolution oblique imagery to be used for constructing colorized mesh three-dimensional models. UAS flights were conducted at multiple heights above the ground to determine their effectiveness. A reputable UAS consultant conducted UAS flights, data collection, and data analysis that were then shared with the Virginia Transportation Research Council (VTRC) and the VDOT Geospatial team. All UAS flights were conducted according to VDOT policy.

Two sites were selected that included three noise barriers for trial inspection using UASs. The first site consisted of two ground-mounted noise barriers next to one another along the west side of US 460 in Christiansburg, Virginia. One of the noise barriers was made of PVC panels, and the other was made of concrete panels. Noise barriers made from two different materials were selected to evaluate a wider range of applicability of UAS inspections. The second site consisted of a structure-mounted metal noise barrier along the south side of State Route 3 in Fredericksburg, Virginia. The bridge on which the noise barrier was mounted spanned railroad tracks, making it a high-potential use case due to the difficulty of access.

RESULTS AND DISCUSSION

The following sections describe the results and present a discussion of the literature review, database review, field evaluation, development of inspection and asset management frameworks, and UAS trial inspection of noise barriers.

Literature Review

Durability

Research on noise barrier durability highlights significant performance variations based on material type. Two studies from Southern Illinois University provided data on the service life and life-cycle costs of different types and materials of noise barriers (Kay et al., 2001; Morgan et al., 2001). Although the current project is focused on lightweight noise barriers, this review also includes information on non-lightweight noise barriers.

Kay et al. (2001) defined service life as "the period of trouble-free performance with no discernible change in barrier insertion loss or appearance." Based on field evaluations of 36 noise barriers, service lives were estimated ranging from minimal to 60 years (Table 1). Notably, concrete noise barriers demonstrated the greatest durability, with estimated service lives of 50 to 60 years. The service life of concrete noise barriers was concluded to be directly related to the service life of the concrete material used. Alternatively, steel noise barriers with absorptive filling were found to deteriorate rapidly because of salt entrapment within the panels. This finding aligns with VDOT's observations of premature metal panel failures.

Table 1. Estimated Service Life for Noise Barriers in Illinois (Kay et al., 2001)

Noise Barrier Material and Type	Estimated Service Life (years)
Earth berm	50
Freestanding precast concrete	50
Glued laminated wood	25
Precast concrete cantilever	50
Precast and prestressed concrete cantilever	50
Steel with absorptive filling	Minimal[a]
Aluminum with absorptive filling	25
Tropical hardwood	8–30, depending on type
Concrete core covered in cemented wood shavings	25
Precast concrete post and panel	60
Fiberglass reinforced polymer composite	50

[a] The noise barrier inspected was noted to begin to deteriorate soon after its installation, but no estimated service life was provided.

A broader review of literature confirms these trends (Morgan et al., 2001), although estimates for concrete varied widely from 20 to 100 years (Table 2).

A life-cycle cost analysis was also conducted on noise barrier materials and types found in Illinois. Table 3 shows the results from this analysis, with materials ranked by life-cycle cost. Maintenance assumptions for this analysis included that 1% of all noise barrier materials except for earth berms would need to be replaced every 10 years, 1% of all noise barrier materials excluding earth berms would need graffiti removal every 5 years, steel posts would need to be repainted every 10 years and would have a service life of 50 years, and earth berms would require annual mowing. However, the construction of earth berms for noise abatement is not suitable in most cases because of their sizable footprint. To maintain a 2:1 slope, every foot of height requires approximately 4 feet of base, which is not practical in areas with limited right-of-way.

Table 2. Service Life Estimates for Noise Barrier Materials From Literature

Noise Barrier Material	Estimated Service Life (years)		
	Flodine (1991)	Bowlby (1992)	Lin et al. (1997)
Concrete	40	45–50	20–100
Masonry	40		
Aluminum	40		20
Steel	30		20
Plastic	25		
Wood	15	20–50	30–50
Concrete core covered in cemented wood shavings	40		

Table 3. Noise Barriers in Illinois Ranked by Estimated Life-Cycle Cost (Morgan et al., 2001) [a]

Noise Barrier Material	Estimated Initial Construction Cost (/ft^2)	Estimated Life-Cycle Cost (/ft^2)
Earth berm	$10.33	$13.93
Precast and prestressed concrete stacked panels with steel posts	$19.67	$23.70
Precast and prestressed concrete stacked panels with concrete posts	$24.33	$26.95
Timber post-and-panel (hardwood or softwood)	$16.70	$28.05
Precast and prestressed cantilever	$27.00	$29.80
Fiberglass reinforced polymer composite	$25.33	$29.98
Precast concrete full-height panels with monolithic posts	$28.33	$30.95
Glue-laminated wood	$18.33	$31.81
Concrete core covered in cemented wood shavings	$19.67	$33.81
Steel with absorptive filling	$27.67	$39.86
Aluminum with absorptive filling	$35.00	$50.15

[a] Costs are in 2001 dollars.

As Table 3 shows, earth berms had the smallest estimated life-cycle cost, whereas most other noise barrier materials and types had a life-cycle cost of approximately $30/ft^2. The concrete, timber, and composite noise barriers performed similarly, and the steel and aluminum barriers had the highest estimated life-cycle costs.

Inspection

The Wisconsin and Colorado DOTs both have published inspection manuals on noise barriers. The Wisconsin DOT manual includes specifications for element-level inspection of noise barriers (Wisconsin DOT, 2017). Three element defects are included, one addressing wall material defects and two for wall or panel movement. All three element defects are rated from Condition State 1 to Condition State 4 and are summarized as follows:

- **Wall Deterioration:** This defect reflects localized material breakdown of the wall components. Although it is only one material defect to code within an inspection report, it is recommended that the inspector indicate the specific material defect observed and measured.
- **Wall Movement:** This defect is used for all noise barriers except for those constructed with posts and panels. Movement includes lateral movement, differential settlement, or global settlement.
- **Masonry or Panel Displacement:** This defect is used for noise barriers constructed with posts and panels. It describes the panels and their movement in relation to the overall wall.

The Wisconsin DOT noise barrier inspection manual presents two elements for an inspector to choose: ground-mounted noise barrier and structure-mounted noise barrier (Wisconsin DOT, 2017). The inspection manual also describes common wall panel deterioration modes for each of the following barrier material types: concrete, timber, metal, transparent, plastic, recycled rubber, and fiber-reinforced polymer composites. In addition, the manual provides inspection details on wall panel or post movement and the recommended inspection procedures.

The Colorado DOT also has an inspection manual for its wall inventory, including both noise barriers and retaining walls (Walters et al., 2016). Colorado requires that routine inspections for retaining walls and noise barriers be conducted every 6 years, whereas inspections for bridge walls must be conducted every 4 years (Colorado DOT, 2022). Like its Wisconsin DOT counterpart, the Colorado DOT manual uses an element-level inspection concept, but it is much more detailed. It was modeled after the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* for bridges and includes the following element types (American Association of State Highway and Transportation Officials, 1998):

- **Primary Elements:** These elements are the main structural features of a wall, including the wall face, vertical supports, foundations, and anchors. They are subject to distress and deterioration and are the most important features rated during the condition assessment.
- **Secondary Elements:** These elements include the attachments, appurtenances, and surrounding features that affect the performance of the wall, such as coping, drainage elements, architectural facings, protective coatings, slopes and backfills, railings, and so on. They exhibit less distress and deterioration than primary elements.
- **Incidental Elements:** These elements accompany the primary and secondary elements and include items like sign attachments, channel condition, guardrail, leveling pad, adjacent slope, and so on.

Wall panel and post elements in the Colorado DOT manual are defined by their material type, such as reinforced concrete, prestressed concrete, masonry, steel, timber, and other materials (Walters et al., 2016). All these elements have corresponding element defects, similar to those used for bridge condition assessment. All the element defects are assessed from Condition State 1 to Condition State 4. In addition, inspectors must rate each noise barrier's overall condition on a scale from 0 to 9, with 0 representing failure and 9 representing excellent condition (Colorado DOT, 2022). Figure 3 illustrates this rating scale, which is based on a similar one from Colorado DOT's manual.

Figure 3. Example of Overall Condition Rating Scale

The inspection manual also includes detailed text and photographs for each element, including a description of the element, units of measurement, how to calculate quantities, intended use, and observable defects.

Asset Management

Both the Colorado and Minnesota DOTs have robust asset management plans for their noise barriers. According to Colorado DOT's (2022) transportation asset management plan, nearly 2,300 walls exist in its inventory, including retaining walls, bridge walls, and noise barriers (Table 4). Its noise barriers are managed through its walls program using a GIS application for analysis and planning. Consultants perform inspections, and the data are entered into the application afterward. Table 5 shows condition trends and the number of essential repair findings for Colorado DOT's walls since 2016.

Table 4. Colorado Department of Transportation Wall Asset Inventory

Wall Type	Count	Area (ft^2, in millions)
Retaining wall	2,303	9.0
Bridge wall	268	0.8
Noise barrier	357	4.2
Totals	**2,928**	**14.0**

Table 5. Colorado Department of Transportation Wall Condition Trends

Year	Total Wall Area (ft^2, in millions)	% in Fair or Good Condition	Essential Repair Findings
2021	14.0	96.5%	15
2020	13.6	96.2%	3
2019	12.9	95.8%	21
2018	12.8	95.8%	3
2017	10.1	96.7%	7
2016	10.1	95.8%	19

Colorado DOT's replacement value of its wall assets was provided as $4.9 billion. In terms of its wall area, the replacement value is $350/ft^2. The current condition rating of its walls was used to determine its current wall asset value of $3.5 billion. This figure is about 71% of the wall asset replacement value, with a unit value of $\$250/ft^2$.

The Colorado DOT wall program uses a condition-based approach to the life-cycle management of a wall, meaning condition data are used to prioritize work within available budgets (Colorado DOT, 2022). Its wall maintenance program prioritizes walls that pose substantial risks, such as those that have essential repair findings. Colorado DOT performs four different types of treatments to walls (Table 6). Currently, treatment and wall project selection is based on essential repair findings, but a prioritization scoring system is in development.

Table 6. Colorado Department of Transportation Wall Life-Cycle Treatment Activities

Treatment Work Type	Goal of Work	Example Activities	Typical $Cost/ft^2$ (2022 dollars)
Preservation	Prolong the life of the structure without changing the condition rating (i.e., preventative maintenance)	Vegetation removal and drainage clear out	$15
Maintenance	Provide expected extension of service life without changing condition	Patching	$180
Rehabilitation	Provide a change in wall condition and expected extension of service life	Replacing deteriorated blocks, resetting bulging or rotated concrete panels, or patching extensive cracks	$250
Reconstruction (replacement)	Resetting wall condition and service life	Replacement of structure	$300

Colorado DOT's current wall program consists of approximately $5.7 million in funding per year, including $1.0 million annually for inspections (Colorado DOT, 2022). This level of funding does not allow Colorado DOT to meet its performance target of less than 2.5% of wall area in poor condition. It is estimated that approximately $30.7 million per year is needed to meet this performance target, which is an additional $25 million per year.

In addition to developing a prioritization scoring system, Colorado DOT also plans to shift from a reactive wall management plan to a proactive plan, with aims to conduct more rehabilitation and replacement before emergency repairs are needed (Colorado DOT, 2022). This initiative is expected to reduce life-cycle cost and minimize disruption. Colorado DOT also plans to conduct more routine maintenance activities to preserve wall assets and slow deterioration rates. In addition, Colorado DOT plans to consolidate wall data, incorporating as-built plans, streamline inspection input and review, and integrate with a new asset management system.

Minnesota DOT's 2022 transportation asset management plan also addresses its noise barrier inventory of 464, all of which are made with either wood or concrete (Minnesota DOT, 2022). VDOT's concrete noise barriers typically have a sound-absorptive finish; however, it is unknown whether concrete noise barriers in Minnesota DOT's inventory have this finish. Table 7 shows Minnesota DOT's noise barrier inventory count, wall area, and replacement cost.

Noise barriers in Minnesota are inspected every 10 years, with off-cycle inspections conducted when serious defects are found. The replacement unit cost values in Table 7 are about 10 times less than those used by Colorado DOT. This discrepancy is likely due to Minnesota DOT's inventory consisting mostly of noise barriers, whereas Colorado DOT's inventory consists mostly of retaining walls. Retaining walls are expected to have greater replacement costs because of their increased complexity compared with noise barriers.

Table 7. Minnesota Department of Transportation Inventory and Replacement Cost [a]

Noise Barrier Material	Count	Area (ft^2, in millions)	Replacement Unit Cost/ft^2	Total Replacement Value
Wood	397	10.5	$30	$314 million
Concrete	67	1.3	$40	$52 million
Totals	**464**	**11.8**	**N/A**	**$366 million**

N/A = not applicable. [a] Costs are in 2022 dollars.

Minnesota DOT has a performance target of less than 8% of wall area in poor condition based on an element-level inspection score (Minnesota DOT, 2022). Currently, Minnesota DOT scores its walls based on element-level data scored from Condition State 1 to Condition State 4. However, it plans to add an overall condition score from 1 to 9 in addition to the element-level scoring.

Minnesota DOT plans to invest $40 million in its noise barriers during the next 10 years, including $33 million toward its wood barriers and $7 million toward its concrete barriers (Minnesota DOT, 2022). Currently, 6% of Minnesota DOT's walls are in poor condition, so this level of funding is sufficient to meet its performance target. Depending on need, up to 10% of the funding can be used for reactive maintenance, such as re-planking wood walls and minor repairs and splash zone sealing on concrete walls. These actions aid in meeting its performance target. Table 8 provides Minnesota DOT's published treatment costs for both wood and concrete barriers (Minnesota DOT, 2022). Note that these values are provided per asset and not per wall area.

Table 8. Minnesota Department of Transportation Treatment Costs for Wood and Concrete Noise Barriers[a]

Treatment	Unit Cost for Wood Barriers (per Asset)	Unit Cost for Concrete Barriers (per Asset)
Structural inspection	$500	$500
Reactive maintenance	$15,000	$300,000
Out-of-cycle inspection	$500	$500
Re-planking of walls	$375,000	N/A
Minor concrete repair	N/A	$400,000
Splash zone sealing	$8,500	$15,000
Replacement	$800,000	$800,000

N/A = not applicable. [a] Costs are in 2022 dollars.

Minnesota's transportation asset management plan also includes condition transition probability matrices developed using Markov transition probability (Minnesota DOT, 2022). This analysis assumes that assets deteriorate from one condition state to another in sequential order (i.e., from good to fair, fair to poor, and poor to very poor). Table 9 shows these deterioration models for both wood and concrete noise barriers.

The number of years in each row represents the time it takes for 50% of the noise barriers to transition from the states in the "transition state" column (Minnesota DOT, 2022). For example, this model suggests that wood noise barriers remain in good condition for an average of 35 years before transitioning to fair condition. The percentage values represent the annual probability that a barrier will either stay in its current condition or drop to a lower condition within a single year. For example, a 98% chance exists that a wood barrier in good condition will remain in good condition, and a 2% chance exists that it will drop to a fair condition.

Table 9. Minnesota Department of Transportation Deterioration Models for Wood and Concrete Noise Barriers

Noise Barrier Material	Transition States	Years	Good	Fair	Poor	Very Poor
Wood	Good to fair	35	98%	2%	N/A	N/A
	Fair to poor	20	N/A	96.6%	3.4%	N/A
	Poor to very poor	10	N/A	N/A	93.3%	6.7%
Concrete	Good to fair	50	98.6%	1.4%	N/A	N/A
	Fair to poor	20	N/A	96.6%	3.4%	N/A
	Poor to very poor	10	N/A	N/A	93.3%	6.7%

N/A = not applicable.

This deterioration model can also be used to infer service life estimates by summing the years in each transition state for each noise barrier material. For example, wood walls in Minnesota may have a service life of 65 years, whereas concrete walls may have a service life of 80 years.

Table 10 also provides a treatment impact matrix for noise barriers in Minnesota. As Table 10 demonstrates, inspections, reactive maintenance, and splash zone sealing do not improve the condition of a noise barrier. However, re-planking wood walls and making minor repairs on concrete walls can improve condition, especially for barriers in poor or very poor condition. Minnesota DOT indicated a desire to perform more frequent inspections and to seal splash zones on both wood and concrete walls more frequently to reduce deterioration rates.

Table 10. Minnesota Department of Transportation Treatment Impact Matrix for Noise Barriers

Current Condition	Structural Inspection	Reactive Maintenance	Out-of-Cycle Inspection	Re-planking on Wood/Minor Repair on Concrete	Splash Zone Sealing	Replacement
Good	Good	Good	Good	N/A	Good	N/A
Fair	Fair	Fair	Fair	90% Good/10% Fair	Fair	N/A
Poor	Poor	Poor	Poor	20% Good/80% Fair	Poor	Good
Very poor	Very poor	Very poor	Very poor	10% Good/ 50% Fair/40% Poor	Very poor	Good

N/A = not applicable.

In the future, Minnesota DOT plans to study how roadway proximity may predict deterioration rates and to evaluate alternative designs, such as steel posts and concrete panels, to reduce maintenance and installation costs.

Review of Noise Barrier Databases

The three databases reviewed for this task will be referred to as the VDOT Maintenance Database, VDOT Environmental Database, and FHWA Database. Figure 4 shows a screenshot of the VDOT Maintenance Database interface.

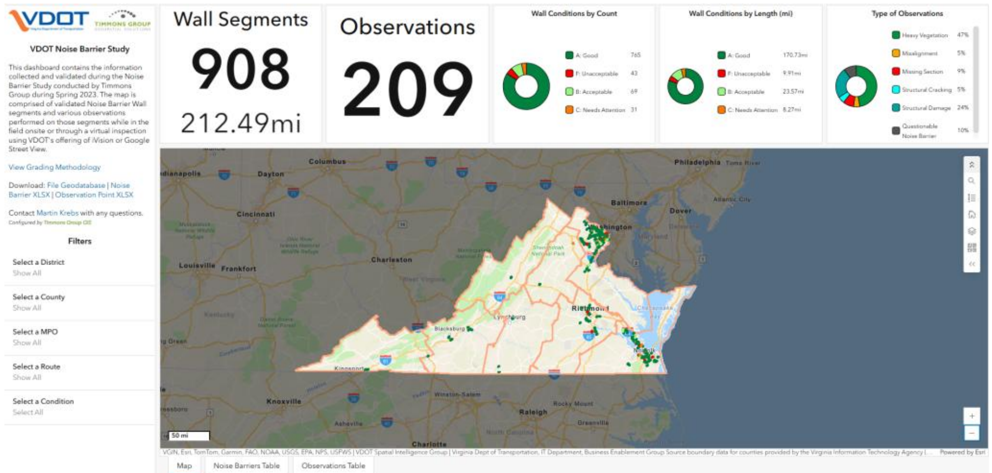

Figure 4. Screenshot of VDOT Maintenance Database for Noise Barriers

Overall, it was clear that the databases did not contain the same fields of information. For example, some of the databases contained cost information, and others contained condition information. Even if multiple databases contained the same fields, not all the data were complete or consistent between databases. In addition, there was no clear way to identify a single noise barrier within multiple databases to combine data. All three databases contained wall identification numbers, but these numbers were inconsistent between noise barriers across databases. Therefore, the following sections present data from multiple databases to provide an overview of VDOT's noise barrier inventory. VDOT could benefit from having a single authoritative source that compiles information from all databases for its noise barrier inventory.

Table 11 shows a summary of VDOT's noise barrier inventory based on material types. As Table 11 shows, the VDOT Maintenance Database contained fewer material types than the other two databases. Based on a review of recent photos of VDOT's noise barriers, it is likely that the quantities in the VDOT Environmental Database are most accurate, noting that 133 of the noise barriers did not have a material type identified. Many of the material entries in the VDOT Maintenance Database appeared to be coded incorrectly, such as coding "brick" when the material was concrete with a stamped brick finish. In addition, many of the "metal" noise barriers in the VDOT Maintenance Database appeared to be composite. Based on the information in the VDOT Environmental Database, slightly less than 20% of VDOT's noise barrier inventory is considered lightweight.

Table 12 provides the average length, height, and area of noise barriers of different materials. The most complete set of this information was provided in the VDOT Maintenance Database. Within this database, the length of the noise barrier was always provided. In some cases, the area or average height, or both, were provided. When the area was provided, it was used. However, if only the height was provided, the area was calculated. As Table 12 shows, the metal and other material types are typically shorter than the normal-weight materials but have taller heights. Wood noise barriers have the shortest average heights of any material.

Table 11. VDOT Noise Barrier Inventory Based on Material

Material	Number of Noise Barriers		
	VDOT Maintenance Database	VDOT Environmental Database	FHWA Database
Concrete and Precast Concrete	684	635	380
Brick	52	6	1
Metal	127	59	51
Wood	32	18	31
Other	13		
Acrylic		4	2
Berm		1	26
Carsonite		3	7
Combination			22
Composite		33	1
Not Provided		133	63
Totals	908	892	584

FHWA = Federal Highway Administration.

Table 12. VDOT Noise Barrier Average Length, Height, and Areas from VDOT Maintenance Database

Material	Number of Noise Barriers		
	Average Length (ft)	Average Height (ft^2)	Average Area (ft^2)
Concrete	1,541	16.2	31,028
Brick	2,110	15.0	31,808
Wood	1,379	11.8	10,869
Metal	992	17.3	14,598
Other	613	19.9	18,884
All	1,406	16.2	29,404

Table 13 shows the number of ground-mounted, structure-mounted, or ground- and structure-mounted noise barriers for each material type. These data were taken from the VDOT Maintenance Database. Most of the normal-weight materials (concrete and brick) are ground mounted. In terms of lightweight materials, wood noise barriers are also mostly ground mounted. Metal and other materials have an approximate 60-40 split between structure mounted and ground mounted.

Table 13. VDOT Noise Barrier Mounting Type from VDOT Maintenance Database

Material	Number of Noise Barriers		
	Ground Mounted	Structure Mounted	Ground and Structure Mounted
Concrete	656	14	14
Brick	51	1	0
Wood	27	5	0
Metal	52	66	9
Other	6	6	1
All	**792**	**92**	**24**

Table 14 provides information on the current condition of VDOT noise barriers of each different material type. These data were compiled from information in the VDOT Maintenance Database and were based on work that a consultant performed for VDOT on its noise barrier inventory. Each condition includes a letter grade (A, B, C, or F) and a description (good, acceptable, needs attention, and unacceptable). These grades and descriptions were based on performance standards such as evidence of cracking, evidence of corrosion, vegetation or drainage concerns, and ease of maintenance. Although the conditions in Table 14 are not based on an element-level inspection of each noise barrier, they do provide information regarding the current condition of VDOT's noise barrier inventory.

Table 14. VDOT Noise Barrier Current Condition from the VDOT Maintenance Database

Material	Number of Noise Barriers			
	A: Good	**B: Acceptable**	**C: Needs Attention**	**F: Unacceptable**
Concrete	600	61	12	11
Brick	49	3	0	0
Wood	19	4	5	4
Metal	90	1	12	24
Other	7	0	2	4
All	**765**	**69**	**31**	**43**

Table 14 shows that a large percentage of the concrete and brick noise barriers are in good condition. In terms of lightweight materials, roughly 60% of the wood noise barriers are in good condition, and the other 40% range from acceptable to unacceptable condition. Roughly 70% of the metal noise barriers are in good condition, and 30% either need attention or are in unacceptable condition. Similar trends are present for the other lightweight materials as well. This outcome aligns with the premise of the overall project that lightweight noise barriers have historically not performed as well in terms of structural durability as conventional concrete or brick noise barriers.

Table 15 shows the average construction unit cost of noise barriers made from different materials compiled from the FHWA Database. Cost is provided in units of $/ft^2 and is based on the cost at the time the noise barrier was constructed. Table 15 also includes the number of cost entries provided.

Table 15. VDOT Noise Barrier Average Construction Unit Cost from the Federal Highway Administration Database[a]

Material	Cost at Time of Construction (/ft^2)	Number of Entries
Concrete	$36.90	379
Brick	$31.67	1
Wood	$35.69	24
Metal	$31.51	36
Other	$113.45	10
All	$38.91	546

[a] Costs are in dollars at the time of construction.

The average costs are relatively similar for all but the "other" materials. Of the 10 cost data entries for the other materials, five had costs ranging from $147 to $166/ft^2, and the other five ranged from $49 to $61/ft^2. Although the cost range from $49 to $61/ft^2 is greater than for other normal-weight and lightweight materials, it does appear reasonable. However, it was unclear why the other five data points were so much greater.

Most of the cost values in Table 15 were from noise barriers constructed before 2020. In 2020, the VDOT Environmental Division estimated that noise barrier construction costs were \$42/ft^2, including materials and installation. However, the VDOT Environmental Division estimates that noise barrier material and installation costs have been \$70/ft^2 since 2020 because of increased costs for both materials and labor. This figure is slightly greater than Minnesota DOT's cost estimates of \$30/ft^2 for wood and \$40/ft^2 for concrete noise barriers.

Field Evaluation of VDOT's Lightweight Noise Barriers

A summary of the field evaluations of lightweight noise barriers is provided in the following section. This summary is divided into sections on each type of lightweight material.

Metal Panels Oriented Vertically

Noise barriers constructed with metal panels oriented vertically were used in ground-mounted and bridge-mounted applications. In general, these barriers appeared to be performing well from a corrosion standpoint. Most of these wall areas had intact coatings after many years of service. This observation is notable because two of these barriers were constructed in 1983 and 1991. Some localized coating failures had progressed to corrosion damage. Although the bases of the ground-mounted barriers appeared to exhibit good corrosion resistance, they could be susceptible to corrosion damage if poor drainage were to cause ponding at the base of the walls. The flashing at the base of the structure-mounted barriers showed more corrosion damage than the rest of the panels because of water and salt accumulation. Figure 5 shows representative photos of the condition of noise barriers with metal panels oriented vertically.

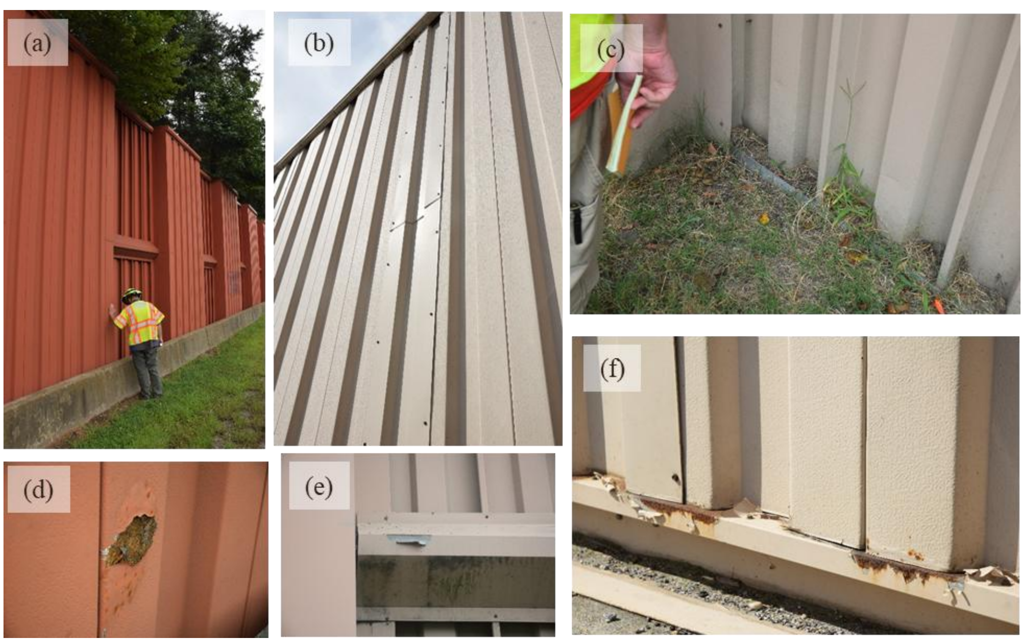

Figure 5. Photos of the Condition of Noise Barriers Constructed with Metal Panels Oriented Vertically: (a) Overall Condition of Ground-Mounted Barriers; (b) Overall Condition of Bridge-Mounted Barriers; (c) Susceptibility to Corrosion if Ponding Were to Occur; (d) Minor Section Loss at Intermittent Locations; (e) Minor Coating Failure at Intermittent Locations; (f) Corrosion Damage at Base and Flashing of Bridge-Mounted Barriers

These types of panels also appeared susceptible to impact damage. Three of the inspected barriers had impact damage, likely from vehicle or mower strikes. These impacts had bent the metal panels, exposing the metal posts behind the panels. If not repaired, the exposed posts could experience accelerated corrosion because they were not coated with the same level of corrosion protection as the metal panels. In addition, these metal panels were susceptible to vegetation growth, which could cause accelerated deterioration in the future if not maintained. Figure 6 shows representative photos of this impact damage and vegetation growth.

Figure 6. Additional Photos of the Condition of Noise Barriers Constructed with Metal Panels Oriented Vertically: (a) Impact Damage Leaving Metal Post Exposed on Ground-Mounted Barrier; (b) Impact Damage Leaving Metal Post Exposed on Bridge-Mounted Barrier; (c) Vegetation Growth; (d) Mower Impact Strikes on Ground-Mounted Barrier

Based on the field evaluations, lightweight metal panels oriented vertically can be expected to achieve a service life of 65 years.

Metal Panels Oriented Horizontally with Perforations

This type of noise barrier was constructed using metal panels oriented horizontally. The metal panels also have small circular perforations throughout their front faces and are filled with a rock wool sound-absorptive material. The back side of these panels are flat and do not contain perforations. Two of six noise barriers of this type had significant corrosion damage throughout their wall areas. The other four barriers had recently been replaced because of their previous corrosion damage. Based on field observations, the rock wool in these barriers became saturated with salt spray, causing corrosion damage from the inside out. The weight of the saturated rock wool also contributed to some of these panels collapsing between their posts and falling to the ground below, clearly causing safety concerns. Figure 7 shows representative photos of these panels with corrosion damage.

Figure 7. Photos of the Condition of Noise Barriers Constructed with Metal Panels Oriented Horizontally with Perforations: (a) Overall View from Roadway Side of Corrosion Present Throughout; (b) Closeup from Roadway Side of Corrosion Damage on Front Face of Panels; (c) Panels Collapsing Viewed from the Back Side; (d) Back Side View Showing Missing Panels that Have Fallen to the Ground

Field visits also highlighted the difficulty of inspecting noise barriers, especially those mounted to bridges, as Figure 7 shows. It is also especially difficult to inspect the bolted connections mounting the posts to the back of concrete barriers (Figure 7). A manlift, under-bridge inspection truck, or similar device is required to perform a hands-on inspection of these connections.

Based on the field evaluations, lightweight perforated metal panels oriented horizontally can be expected to achieve a service life of 10 to 15 years.

Composite Panels

Composite noise barrier panels are constructed with high-density polyethylene material coated with an ultraviolet (UV)-resistant coating and filled with rock wool sound absorption material. Overall, these types of noise barriers appeared to be performing well in terms of structural durability. One of the noise barriers displayed some cracking at intermittent locations close to the connections between the panel and posts. Thermal movement of the panels relative to the posts likely caused stress on the panels and resulted in this damage. Previous photos of the noise barrier suggested that these cracked locations had been present for about 12 years with no notable progressive damage. Therefore, this damage does not appear to warrant significant concern. Figure 8 shows photos that illustrate the damage present on the barriers constructed with composite panels.

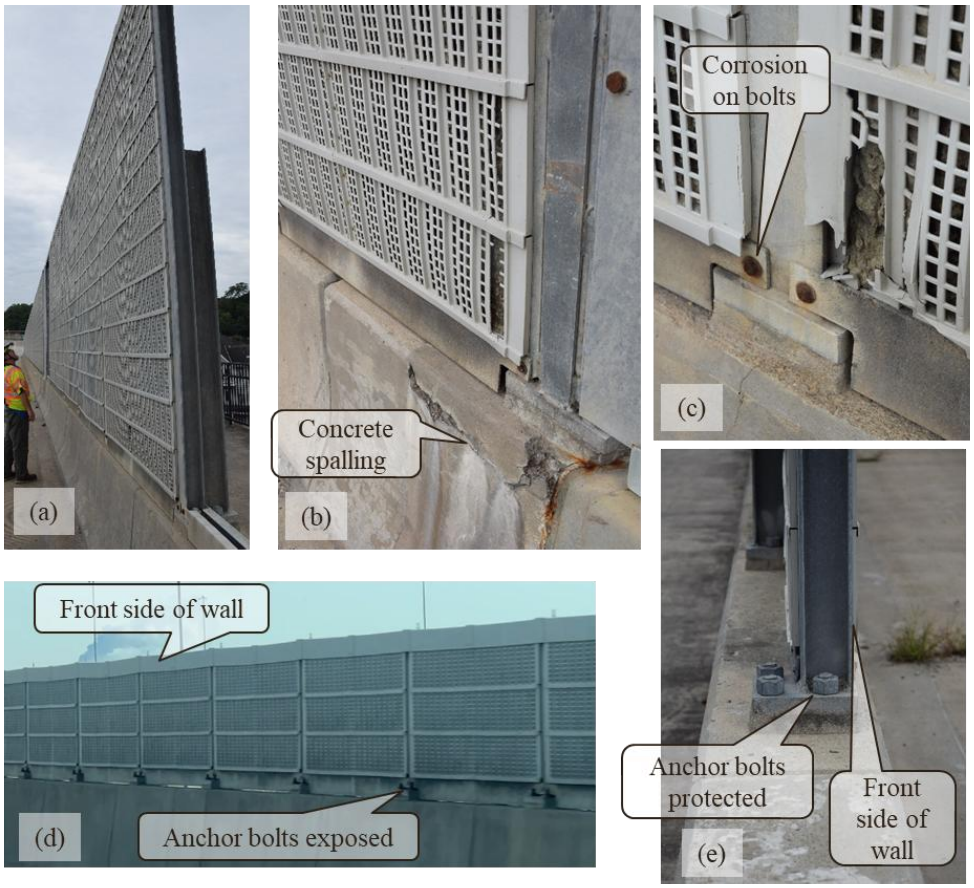

Figure 8. Photos of the Condition of Noise Barriers Constructed with Composite Panels: (a) Overall View with Barrier; (b) Closeup Showing Cracking at Intermittent Locations Near Panel-to-Post Connections and Concrete Spalling in the Barrier; (c) Closeup Showing Damage on Panels and Corrosion on Bolts Connecting Panels to Posts; (d) Exposed Anchor Bolts with Corrosion; (e) Anchor Bolts Protected from Salt Spray Showing no Corrosion

Some of the connections on the noise barriers displayed corrosion. On one of the noise barriers, the bolts connecting the panels to posts were exposed to salt spray from the roadway. On another noise barrier, the anchor bolts connecting the posts to the barrier were exposed to salt spray. In both cases, the bolts exposed to salt appeared to have corrosion, although no section loss was observed. In addition, one of the noise barriers displayed some concrete spalling in the concrete barrier where a post was mounted. This spalling was directly adjacent to a bridge joint, so it is likely that thermal movement of the bridge caused this damage.

One composite panel noise barrier manufacturer claims that its product can achieve a service life of 50 years. Based on the field evaluations, this claim appears reasonable. Composite panels may be subject to UV degradation at some point in their service life, but VDOT's current inventory of composite panel noise barriers does not appear to have experienced deterioration yet.

Polyvinyl Chloride Panel

The PVC panel noise barriers observed were performing well with no deficiencies found on the panels. Figure 9 shows representative photos of these noise barriers. Some corrosion was observed on the metal flashing connected between the panels and concrete barrier. This corroded flashing could easily be replaced if necessary. The two PVC panel noise barriers visited had two different designs for anchor connections. In the noise barrier with vertical anchor bolts connecting the posts to the concrete barrier, spalling was present in many locations. No corrosion was observed at the horizontal bolted connections between the posts and concrete barrier because these connections were protected from salt spray. However, as noted previously, these connections are extremely difficult to inspect.

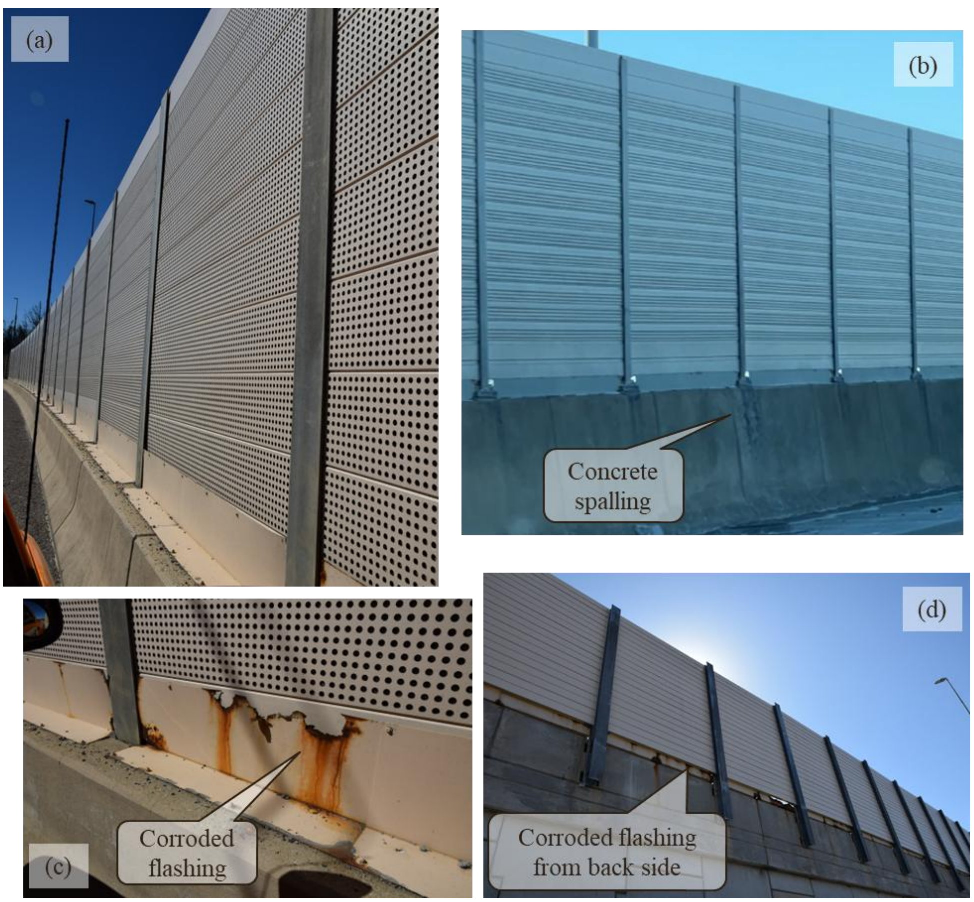

Figure 9. Photos of the Condition of Noise Barriers Constructed with Polyvinyl Chloride Panels: (a) Overall View of Barrier; (b) Concrete Spalling in Concrete Barrier at Post Connections; (c) Corroded Flashing at Panel Base; (d) Back Side of Noise Barrier Showing Post Connections and Corroded Flashing

PVC panel noise barrier manufacturers claim that their products can achieve a service life of 50 years. Based on the field evaluations, this claim appears reasonable. PVC panels are susceptible to UV degradation, but VDOT's panels do not appear to have experienced it yet.

Fiberglass Panels

Noise barriers constructed with fiberglass panels also performed well, with only minor deficiencies found on the panels. These deficiencies included very small amounts of deterioration and one instance of impact damage. In some instances, vegetation growth occurred on the noise barriers, but it did not appear to have caused any damage yet. The vertical anchor bolts connecting the posts to the concrete barrier were performing well with no visible corrosion. This condition was likely because they were on a road with less traffic relative to some of the other noise barriers inspected, so they were subject to less salt spray. Figure 10 shows representative photos of the condition of fiberglass panel noise barriers.

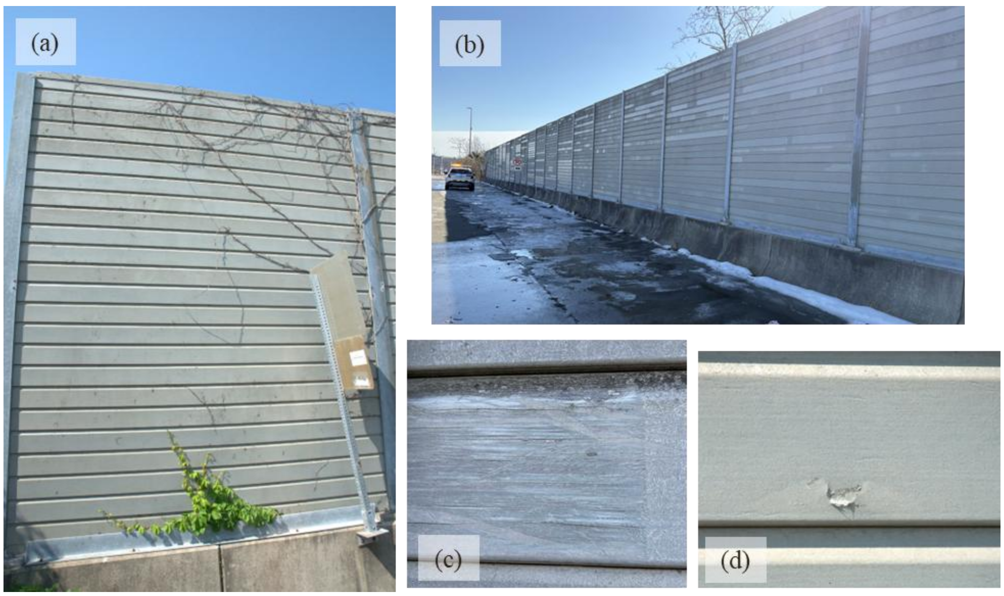

Figure 10. Photos of the Condition of Noise Barriers Constructed with Fiberglass Panels: (a) Single Panel with Vegetation Growth; (b) Overall View; (c) Closeup of Deterioration; (d) Closeup of Impact Damage

One fiberglass panel noise barrier manufacturer claims that its product can achieve a service life of 50 years. Based on the field evaluations, this claim appears reasonable. Fiberglass panels may be subject to UV degradation at some point in their service life, but VDOT's current inventory of fiberglass panel noise barriers does not appear to have experienced deterioration.

Acrylic Panels

On the noise barriers with acrylic panels, the panels appeared to be performing well overall. Figure 11 shows representative photos of the condition of acrylic panel noise barriers. The acrylic portions of the panels did not appear to have any durability issues. Multiple gaskets, designed to be between the acrylic panels and metal posts or metal bracing, were either loose or missing in all three of the noise barriers inspected. Although these missing gaskets do not pose an immediate concern, they could increase the amount of vibration in the acrylic panels, potentially leading to deterioration in the future.

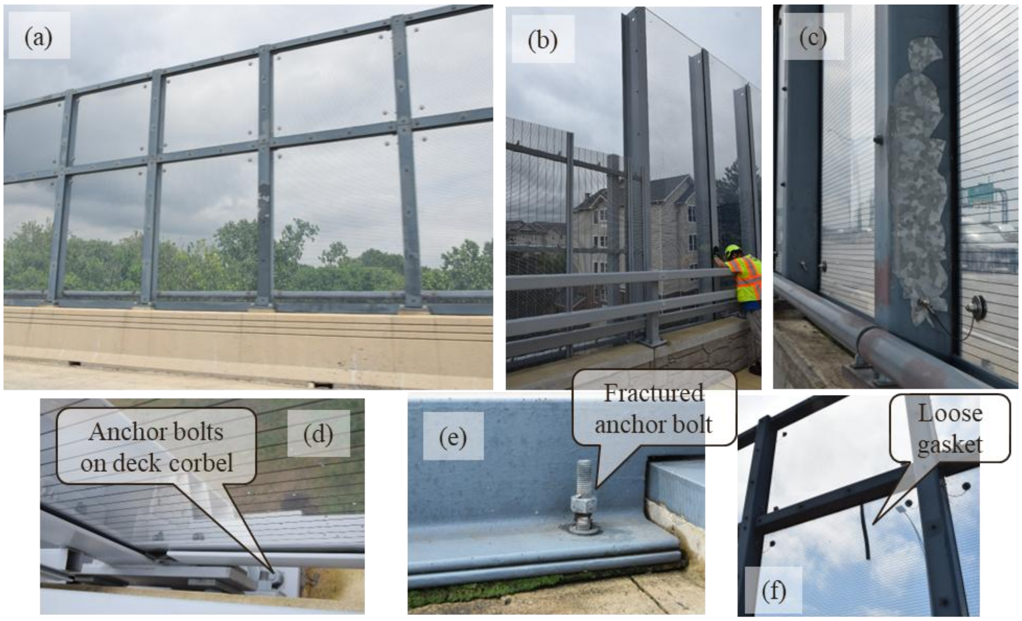

Figure 11. Photos of the Condition of Noise Barriers Constructed with Acrylic Panels: (a) Overall View Showing Coating Failures on Metal Posts; (b) Overall View of Another Noise Barrier; (c) Closeup of Coating Failure on Metal Posts; (d) Anchor Bolts on Deck Corbel Showing Good Performance; (e) Fractured Anchor Bolt and Evidence of Trapped Moisture Between Panel and Concrete Barrier; (f) Closeup of Loose Gasket Between Panel and Metal Bracing

The metal posts and bracing on these noise barriers appeared to be a duplex coating system, consisting of first galvanizing the steel and then applying a coating on top. On these steel posts and bracing members, many instances of coating failures were present and areas that had been recoated. This condition was especially true for the older noise barrier that was inspected. Two types of post connections were observed during these field visits. In the connections using vertical anchor bolts, some fractured anchor bolts and evidence of trapped moisture between the concrete barrier and metal bracing were observed. The other type of post connection consisted of horizontal bolts connecting the post to the back of the concrete barrier and vertical anchor bolts connecting the post to a concrete corbel. This connection was performing well in terms of durability because it was protected from salt spray. This type of connection also provides greater durability and redundancy than the other post connection types.

Multiple acrylic panel noise barrier manufacturers claim an expected service life of 50 years for their products. Based on the field evaluations, this claim appears reasonable. Acrylic panel noise barriers are potentially subject to UV degradation. However, it does not appear that VDOT's acrylic panels have experienced deterioration yet.

Wood Panels

Noise barriers made of wood panels did not appear to have standardized construction, seemingly having a different design for each noise barrier. Although most of the wood panel noise barriers inspected were constructed with wood posts, one had metal posts buried at its base. Field observations indicated that the structural durability of these noise barriers was highly dependent on the materials used for construction. Panels fabricated with preservative-treated structural grade wood demonstrated superior performance compared with those constructed with non-structural grade wood without preservatives. In addition, UV degradation was less notable in wood panels using waterproof structural adhesives than in those without. Furthermore, the wood panels appeared to be more susceptible to damage from vegetation growth than some of the other lightweight materials. Figure 12 shows representative photos of the condition of wood panel noise barriers inspected during the field evaluations.

Figure 12. Photos of the Condition of Noise Barriers Constructed with Wood Panels: (a) Good Condition Noise Barrier with Metal Posts; (b) Good Condition Noise Barrier; (c) Old Noise Barrier in Good Condition; (d) Subpar Quality Wood Panel Noise Barrier in Poor Condition with Vegetation Growth and Flaking Wood

Based on the field evaluations, lightweight wood panels constructed with structural grade, pressure-treated wood with structural adhesives and a UV-resistant treatment can be expected to achieve a service life of 50 years. In these cases, the good quality wood, adhesives, and treatments aid in protecting the panel from degradation caused by moisture and UV.

Framework for VDOT Noise Barrier Inspection and Asset Management Program

Inspection Program

The proposed inspection program framework includes guidance on two methods of condition assessment for noise barriers: an overall condition rating and an element-level rating. It also includes guidance on an inspection frequency for noise barriers.

It is proposed that noise barriers be inspected and rated using an overall condition rating, similar to the one in Figure 3 used by Colorado DOT and that Minnesota DOT plans to use. Using the overall condition rating, an inspector can score a noise barrier from 0 to 9, with 0 indicating a failed noise barrier and 9 indicating a noise barrier in excellent condition. This overall condition rating can then be used as a simple metric to provide a broad understanding of the overall condition of each noise barrier. This value can be incorporated into the planning, budgeting, and project prioritization of a noise barrier asset management plan.

In addition to an overall condition rating, it is proposed that each element of noise barriers be scored based on its condition state. For this element-level data, an inspector can score each condition state from 1 to 4, in which 1 represents an element in good condition, and 4 represents an element in severe condition. Proposed general categories of noise barrier elements include panels, posts, panel-to-post connections, post-to-foundation connections, and the foundation (Figure 13).

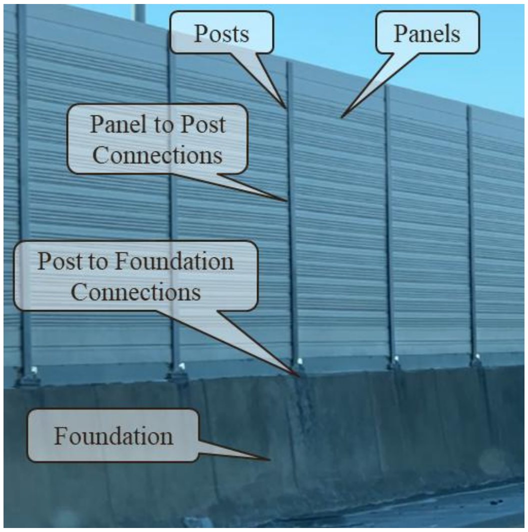

Figure 13. Proposed Categories of Noise Barrier Elements

Specific elements and associated defect types for these element categories were developed to align with the VDOT and FHWA element-level bridge inspection specifications (VDOT, 2016). Whenever possible, existing VDOT and FHWA element-level guidance was used in lieu of creating specifications from scratch. However, some new guidance was required because of the differences between noise barriers and bridges. The numbering system also aligns with the one used for VDOT bridge element-level inspection and begins where that system ends.

Table 16 shows the proposed noise barrier elements for panels and posts and includes the following material types: steel, prestressed concrete, reinforced concrete, timber and wood, masonry, and other. These elements use the same material types as those used in FHWA element-level guidance, enabling FHWA defects to be applied to each material type.

Table 16. Proposed Noise Barrier Elements for Panels and Posts

Element	Units	Element Number Based on Material					
		Steel	Prestressed Concrete	Reinforced Concrete	Timber/Wood	Masonry	Other
Panels	EA	900	901	902	903	904	905
Posts	EA	910	911	912	913	914	915

EA = each.

Although all the FHWA defects can be used for each material type of the panel and post elements, one additional defect is proposed for both prestressed concrete and reinforced concrete panel elements. This proposed defect is the absorptive finish deterioration shown in Table 17. This defect is proposed because the vast majority of VDOT's concrete noise barriers contain an absorptive finish, and it would be useful to capture the condition of that finish during routine inspections.Table 17. Proposed Additional Defect for Prestressed Concrete and Reinforced Concrete Panel Elements

Table 17. Proposed Additional Defect for Prestressed Concrete and Reinforced Concrete Panel Elements

Defect	Condition State			
	1	2	3	4
	Good	Fair	Poor	Severe
Absorptive Finish Deterioration	None.	Absorptive finish has minor deterioration.	Absorptive finish has moderate deterioration.	Absorptive finish has significant deterioration that is causing or will soon cause it to lose effectiveness.

Table 18 shows the proposed noise barrier element for panel-to-post connections. Due to the large number of connection types between noise barrier panels and posts, a single element type was proposed for connections of any type.

Table 18. Proposed Noise Barrier Elements for Panel-to-Post Connections

Element	Units	Element Number
		All Types
Panel-to-Post Connections	Each	920

Two proposed defects were identified for the panel-to-post connection element: deterioration and effectiveness (Table 19). These defects were selected for simplicity and to be applicable across a wide range of panel-to-post connection types. The first defect is "connection deterioration." This defect covers all types of deterioration or damage, including corrosion, cracking, abrasion, impacts, and so on. The second defect is "connection effectiveness" and includes only two condition states. It is scored as either 1, in which the connections are functioning as intended, or 4, in which the connections are missing or are not functioning as intended. This scoring follows the approach used for the VDOT-defined "joint effectiveness" element, which also has only two condition states (VDOT, 2016).

Table 19. Proposed Defects for Panel-to-Post Connections Element—All Types

Defect	Condition State 1 Good	Condition State 2 Fair	Condition State 3 Poor	Condition State 4 Severe
Connection Deterioration	None.	Connections have minor deterioration.	Connections have moderate deterioration.	Connections have significant deterioration that is causing or will soon cause them to lose effectiveness.
Connection Effectiveness	Connections are functioning as intended and panels are firmly connected to posts.			Connections are missing or are not functioning as intended and panels are separating from the posts.

Table 20 shows the proposed elements for the post-to-foundation connections. These elements consist of embedded, bolted, or other post-to-foundation connections. Most of the ground-mounted noise barriers have posts that are embedded in concrete, whereas most of the structure-mounted noise barriers have posts that are bolted onto a foundation. The "other" category is proposed to account for any other types of post-to-foundation connections.

Table 20. Proposed Noise Barrier Elements for Post-to-Foundation Connections

Element	Units	Element Number Based on Connection Type: Embedded	Bolted	Other
Post-to-Foundation Connections	Each	930	931	932

Because the proposed post-to-foundation elements were developed specifically for noise barriers, the FHWA and VDOT defects were not applicable. Therefore, new proposed defects were developed for these elements. Table 241 shows the proposed defects for the "embedded" post-to-foundation connections element. These defects include post deterioration, foundation deterioration, and connection effectiveness. Both post and foundation deterioration were considered because either could cause the connection to lose effectiveness in a post is embedded in concrete. A "connection effectiveness" defect was also included, similar to the one used for the post-to-foundation connection element.

Table 21. Proposed Defects for Post-to-Foundation Connections Element—Embedded

Defect	Condition State 1 Good	Condition State 2 Fair	Condition State 3 Poor	Condition State 4 Severe
Post Deterioration	None.	Post has minor deterioration adjacent to foundation.	Post has moderate deterioration adjacent to foundation.	Post has significant deterioration adjacent to foundation that is causing or will soon cause the connection to lose effectiveness.
Foundation Deterioration	None.	Foundation has minor deterioration adjacent to post.	Foundation has moderate deterioration adjacent to post.	Foundation has significant deterioration adjacent to post that is causing or will soon

Defect	Condition State			
	1	2	3	4
	Good	Fair	Poor	Severe
				cause the connection to lose effectiveness.
Connection Effectiveness	Connections are functioning as intended, and posts are firmly connected to the foundation.			Connections are not functioning as intended, and posts are separating from the foundation.

Table 22 shows the proposed defects for "bolted" post-to-foundation connections element. The defects in Table 22 were developed based on the defects used for element "CON19—FD Anchor Bolts" (anchor bolt element) in VDOT's *Traffic Ancillary Structures Inventory and Inspection Manual* specification (VDOT, 2021). These defects are justified because the anchor bolt connections between ancillary structures and noise barrier posts are similar.

Table 22. Proposed Defects for Post-to-Foundation Connections Element—Bolted

Defect	Condition State			
	1	2	3	4
	Good	Fair	Poor	Severe
Corrosion of anchor nuts or bolts	None.	Section loss of top nut/bolt < 15%.	Section loss of top nut/bolt < 30%.	Section loss of top nut/bolt ≥ 30%.
Top/level nut loose or missing	Top/level nut is present.	1 nut in 6+ bolt configuration.	1 nut in 4+ bolt configuration, or 2 nuts in 6+ bolt configuration.	2 nuts in 4+ bolt configuration, or 3 nuts in 6+ bolt configuration.
Anchor bolts broken or sheared	Anchor bolts not broken or sheared.			Anchor bolts broken or sheared.
Top nut threads not fully engaged	Threads on top nut are fully engaged.	Threads on top nut are not fully engaged for 1 nut in 6+ bolt configuration.	Threads on top nut are not fully engaged for 1 nut in 4+ bolt configuration, or 2 nuts in 6+ bolt configuration.	Threads on top nut are not fully engaged for 2 nuts in 4+ bolt configuration, or 3 nuts in 6+ bolt configuration.
Top/leveling flat washers missing	Top/leveling flat washers are present.	Top/leveling flat washer missing for 1 nut in 6+ bolt configuration.	Top/leveling flat washer missing for 1 nut in 4+ bolt configuration, or 2 nuts in 6+ bolt configuration.	Top/leveling flat washer missing for 2 nuts in 4+ bolt configuration, or 3 nuts in 6+ bolt configuration.
Multiple top/leveling washers	Multiple top/leveling washers not present.			Multiple top/leveling washers present.
Lock washers present	Lock washers not present.			Lock washers present.

Defect	Condition State			
	1	2	3	4
	Good	Fair	Poor	Severe
Anchor bolts other than steel	Anchor bolts other than steel not present.			Anchor bolts other than steel present.
Anchor bolts inaccessible	Anchor bolts accessible.			Anchor bolts inaccessible.
Ultrasonic testing of anchor bolts performed	Ultrasonic testing of anchor bolts performed.			Ultrasonic testing of anchor bolts not performed.

Finally, Table 23 shows the proposed defects for "other" post-to-foundation connections element. These defects are similar to those proposed for the post-to-panel connections element. These defects are intended to be general and to encompass all other post-to-foundation connections other than embedded or bolted connections.

Table 23. Proposed Defects for Post-to-Foundation Connections Element—Other

Defect	Condition State			
	1	2	3	4
	Good	Fair	Poor	Severe
Connection Deterioration	None.	Connections have minor deterioration.	Connections have moderate deterioration.	Connections have significant deterioration that is causing or will soon cause them to lose effectiveness.
Connection Effectiveness	Connections are functioning as intended, and posts are firmly connected to the foundation.			Connections are not functioning as intended, and posts are separating from the foundation.

Table 24 shows the proposed elements for the last element category, foundation. These foundation elements include concrete, steel, and other. Most of VDOT's noise barriers have a concrete foundation, but some structure-mounted noise barriers have a steel foundation. Although rarely used, the "other" element was included to account for other materials used for noise barrier foundations, such as if a noise barrier is mounted to an aluminum base. These elements use the same material types as those used in FHWA element-level guidance, enabling FHWA defects to be applied to each material type.

Table 24. Proposed Noise Barrier Elements for Foundation

Element	Units	Element Number Based on Foundation Type		
		Concrete	Steel	Other
Post-to-Foundation Connection	Each	940	941	942

In addition to the overall condition rating and element-level inspection data, proposed noise barrier inspection intervals were also developed. These intervals were developed based on the literature review, field observations, and engineering judgment. Table 25 shows the proposed inspection intervals.

Table 25. Proposed Noise Barrier Inspection Intervals

Noise Barrier Mounting Type	Potential to Fall onto Traffic or Pedestrians?	Overall Condition Rating	Inspection Interval (months)
Ground	No	5 or greater	72
		4 or less	60
	Yes	5 or greater	48
		4 or less	24
Structure	N/A	5 or greater	48
		4 or less	24

N/A = not applicable.

The proposed inspection intervals are based on three criteria: noise barrier mounting type; the potential of the noise barrier to fall onto traffic or pedestrians if it were to fail; and a noise barrier's overall condition rating. Structure-mounted noise barriers were always assumed to have potential to fall onto traffic or pedestrians because these noise barriers are almost always directly adjacent to the roadway shoulder.

In general, noise barriers that could fall onto traffic or pedestrians were given shorter inspection intervals to help identify potential damage that could cause injury or loss of life. Shorter inspection intervals were also given to noise barriers with lesser overall condition ratings. This means that as noise barriers deteriorate over time, they should be inspected more frequently to track deterioration.

Structure-mounted noise barriers were given inspection intervals of 2-year increments, depending on their overall condition rating, allowing noise barrier inspections to be aligned with the inspection of the structure on which they are mounted. One inspection team could then inspect both the structure and the noise barrier at the same site visit to save on mobilization costs.

Asset Management Program

This proposed asset management program includes deterioration models, treatment types and activities, performance targets, and an annual budget to ensure that limited funding minimizes the total life-cycle cost of VDOT's noise barrier inventory.

The first step in creating a proposed asset management plan was to develop an assumed noise barrier inventory. An assumed inventory was necessary because the noise barrier databases reviewed in this project differed. Concrete and brick noise barriers were grouped together in this assumed inventory because neither is lightweight, and they were assumed to deteriorate at a similar rate. Table 26 shows this assumed inventory, which was developed based on the information shown previously in Table 11 and Table 12. As Table 26 shows, quantity and area values were rounded for simplicity.

Next, an assumed current condition was developed for this inventory. Four different condition states were used in this assumed current condition: good, fair, poor, and very poor. These conditions were developed to map onto the noise barrier grades (A, B, C, and D) as shown in Table 14. The fraction of each noise barrier material in each condition was determined from the information shown previously in Table 14 but was rounded for simplicity. Table 27 shows these results. For example, 90% of all concrete and brick walls were assumed to be in good condition, 8% were assumed to be in fair condition, 1% were assumed to be in poor condition, and 1% were assumed to be in very poor condition.

Table 26. Assumed VDOT Noise Barrier Inventory

Material	Number of Noise Barriers	Average Area per Noise Barrier (ft^2)	Total Area (ft^2)
Concrete and Brick	740	31,500	23.3 million
Metal	70	11,000	0.77 million
Wood	30	15,000	0.45 million
Other	60	19,000	1.14 million
Totals	**900**	**–**	**25.7 million**

– = not applicable.

Table 27. Assumed VDOT Noise Barrier Inventory Current Condition

Material	Fraction of Noise Barriers			
	Good	Fair	Poor	Very Poor
Concrete and Brick	0.90	0.08	0.01	0.01
Wood	0.60	0.10	0.15	0.05
Metal	0.80	0.05	0.05	0.10
Other	0.60	0.00	0.10	0.30

Deterioration models were developed for each type of noise barrier material. These deterioration models were developed based on those used by Minnesota DOT and shown previously in Table 9. The deterioration model used for concrete and brick noise barriers is identical to the model used for Minnesota DOT’s concrete noise barriers because it was assumed that concrete and brick noise barriers deteriorate at similar rates. The model for wood noise barriers was assumed to deteriorate slightly faster than the one used by Minnesota DOT because Virginia has a warmer and wetter climate than Minnesota, which can cause wood to deteriorate more quickly. Deterioration models for metal and other noise barrier materials were also developed based on information learned during the analysis of the noise barrier databases and field visits. The deterioration model for the other materials assumes that their primary degradation method is from UV. Table 28 shows the proposed deterioration models for each of the materials used in VDOT’s noise barrier inventory.

Proposed treatments for noise barriers were developed based on the noise barrier asset management plans for the Colorado and Minnesota DOTs, as well as the findings from the field visits. These treatments include preservation, maintenance, rehabilitation, and replacement and can either extend the service life of a noise barrier or improve its condition. Table 29 shows these proposed treatment types, example activities for each, their assumed effectiveness, applicable noise barrier area, and their estimated cost. The applicable area considers that not all treatments will be applied to an entire wall area. For example, maintenance, such as re-coating a metal noise barrier, would likely not be necessary over the entire area. Instead, an applicable area of 50% was assumed. A similar consideration was made for rehabilitation treatments.

Table 28. Assumed Deterioration Models for VDOT's Noise Barrier Inventory

Material	From State	Years	To State			
			Good	Fair	Poor	Very Poor
Concrete and Brick	Good	50	0.980	0.020	0.000	0.000
Concrete and Brick	Fair	20	0.000	0.950	0.050	0.000
Concrete and Brick	Poor	10	0.000	0.000	0.900	0.100
Concrete and Brick	Very Poor	0	0.000	0.000	0.000	1.000
Wood	Good	25	0.960	0.004	0.000	0.000
Wood	Fair	15	0.000	0.933	0.067	0.000
Wood	Poor	10	0.000	0.000	0.900	0.100
Wood	Very Poor	0	0.000	0.000	0.000	1.000
Metal	Good	40	0.975	0.025	0.000	0.000
Metal	Fair	15	0.000	0.933	0.067	0.000
Metal	Poor	10	0.000	0.000	0.900	0.100
Metal	Very Poor	0	0.000	0.000	0.000	1.000
Other	Good	35	0.971	0.029	0.000	0.000
Other	Fair	10	0.000	0.900	0.100	0.000
Other	Poor	5	0.000	0.000	0.800	0.200
Other	Very Poor	0	0.000	0.000	0.000	1.000

Table 29. Potential Treatments, Example Activities, Assumed Effectiveness, and Estimated Costs for Noise Barriers

Treatment Type	Example Activities	Assumed Effectiveness	Applicable Noise Barrier Area	Estimated Cost (/ft^2)
Preservation	Vegetation removal	Reduces deterioration rate by 10% for good or fair assets but does not improve their condition	100%	$15
Maintenance	Re-coating and re-sealing of steel, timber, and concrete panels and posts; patching of minor cracked or spalled concrete; installation of flashing at posts; earthwork to fix drainage issues at ground-mounted noise barriers	Reduces deterioration rate by 30% for good or fair assets but does not improve their condition	50%	$30
Rehabilitation	Replacement of single or multiple panels, posts, or connections between panels and posts	Improves condition of assets of all conditions according to Table 30	25%	$105
Replacement	Complete replacement of noise barrier	Asset condition and service life are completely reset	100%	$70

The example activities for each treatment shown in Table 29 were developed based on the literature review and field evaluation observations. Preservation activities include vegetation removal, whereas maintenance activities include re-coating and re-sealing, minor concrete patching, and earthwork to fix drainage issues. Rehabilitation generally involves replacing single or multiple components, and replacement consists of completely replacing the noise barrier.

The assumed effectiveness of preservation and maintenance was assumed based on engineering judgment. The assumed effectiveness of rehabilitation was adopted from the Minnesota DOT noise barrier asset management plan as shown previously in Table 10. Table 30 shows this effectiveness matrix, and the effectiveness depends on the initial state of the asset.

Table 30. Assumed Effectiveness of Rehabilitation Treatment of Noise Barriers

From State	To State			
	Good	Fair	Poor	Very Poor
Good	1.0	0.0	0.0	0.0
Fair	0.9	0.1	0.0	0.0
Poor	0.2	0.8	0.0	0.0
Very Poor	0.1	0.5	0.4	0.0

Cost estimates were also developed for each treatment type (Table 29). The cost of preservation activities (\$15/ft^2) was set equal to Colorado DOT's preservation cost for noise barriers. Maintenance activities were assumed to cost \$30/ft^2, which is double the cost of preservation activities. Replacements were assumed to cost \$70/ft^2, which is the cost estimate that the VDOT Environmental Division currently uses. Finally, rehabilitation activities were assumed to cost \$105/ft^2, which is approximately 50% more than replacement costs. A greater cost was assumed because rehabilitation activities are likely to be performed on smaller noise barrier areas, rather than entire noise barriers, so a larger portion of the cost would be incurred for mobilization.

A Markov chain analysis was conducted to simulate the condition of VDOT's noise barrier inventory over a 20-year period. An annual noise barrier asset management budget of \$11.0 million was assumed for this analysis, which is a unit cost of \$0.43/ft^2 of noise barrier area. This value is similar to the unit budgets of Minnesota DOT (\$0.34/ft^2) and Colorado DOT (\$0.41/ft^2) for their noise barrier and wall asset management plan budgets in terms of dollars per area. Within this \$11.0 million budget, \$1.0 million was assumed to be for noise barrier inspections, and \$10.0 million was assumed to be for noise barrier treatments.

Four different scenarios were considered in the Markov chain analysis (Table 31). The first scenario of "Do Nothing" considers that no treatment actions will be taken during the next 20 years and is used as a point of comparison. The other three scenarios consider how the inventory condition changes over 20 years as different percentages of the annual budget are allocated to rehabilitation versus replacement treatments. Other scenarios with preservation and maintenance were originally considered, but those two treatment types did not appear to be cost effective at improving the performance of the overall noise barrier inventory.

Table 31. Scenarios Considered for Markov Chain Analysis of VDOT's Noise Barrier Inventory

Scenario Name	Percentage of Annual Budget Allocation			
	Preservation	Maintenance	Rehabilitation	Replacement
Do Nothing	0%	0%	0%	0%
100% Replacement	0%	0%	0%	100%
80% Replacement + 20% Rehabilitation	0%	0%	20%	80%
50% Replacement + 50% Rehabilitation	0%	0%	50%	50%

A proposed performance target was also developed based on those used by Colorado and Minnesota DOTs as follows: less than 10% of VDOT's noise barriers may have an overall condition rating of poor or very poor.

Figure 14 through Figure 17 show the results of this analysis.

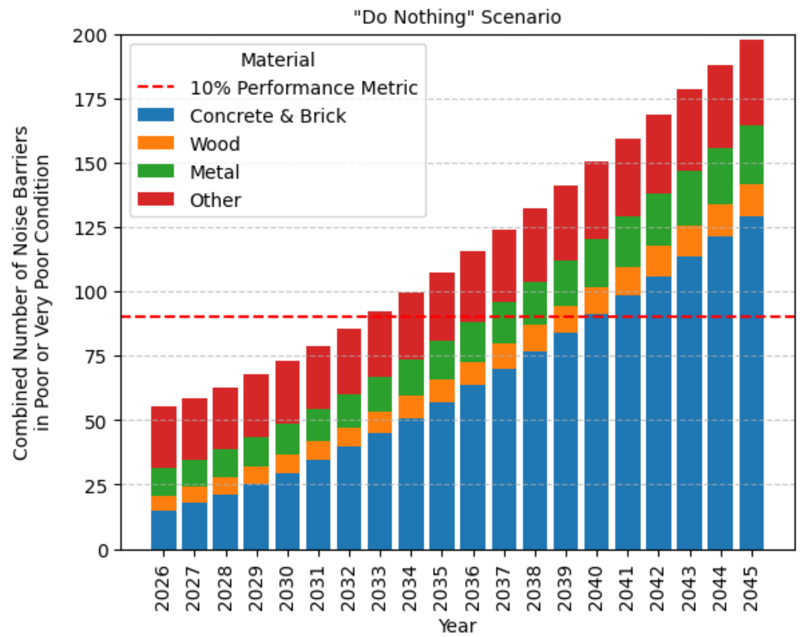

Figure 14. Markov Chain Analysis Results Showing Noise Barrier Inventory Condition After "Do Nothing" Scenario

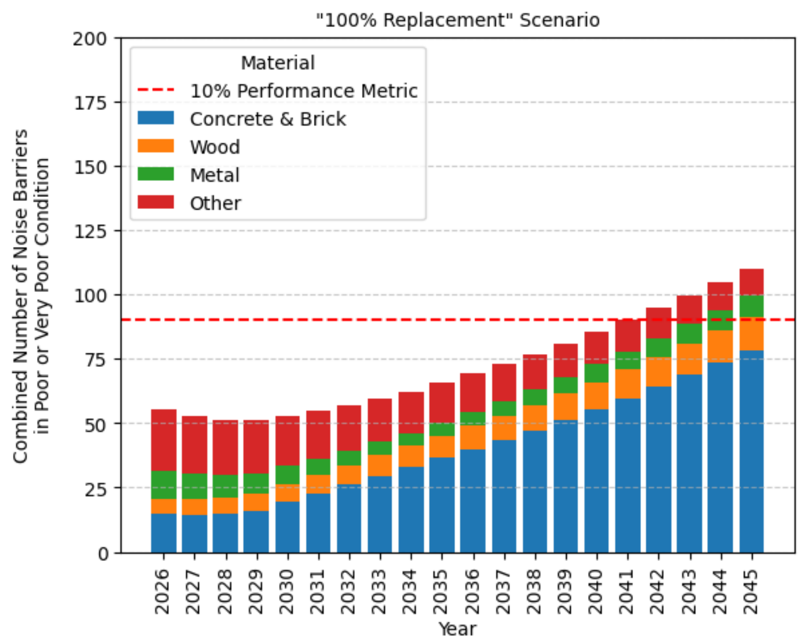

Figure 15. Markov Chain Analysis Results Showing Noise Barrier Inventory Condition After "100% Replacement" Scenario

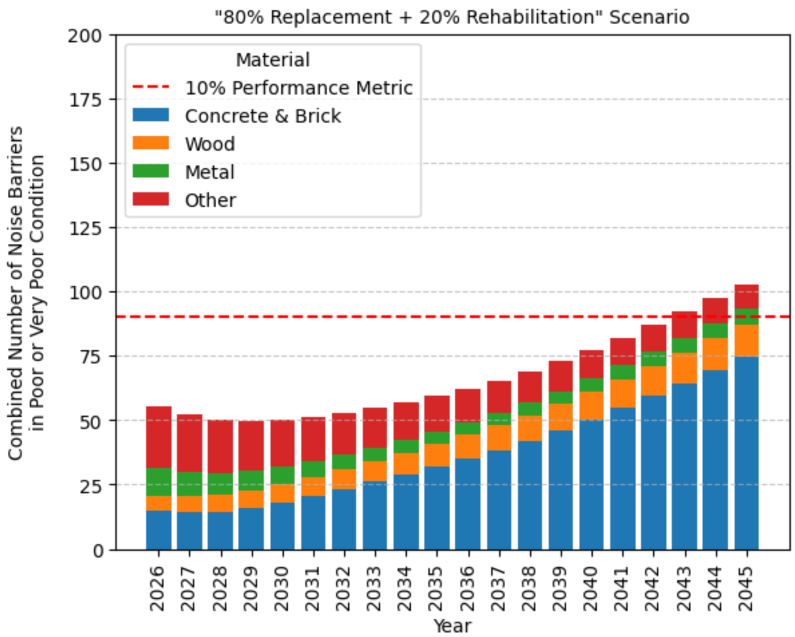

Figure 16. Markov Chain Analysis Results Showing Noise Barrier Inventory Condition After "80% Replacement + 20% Rehabilitation" Scenario

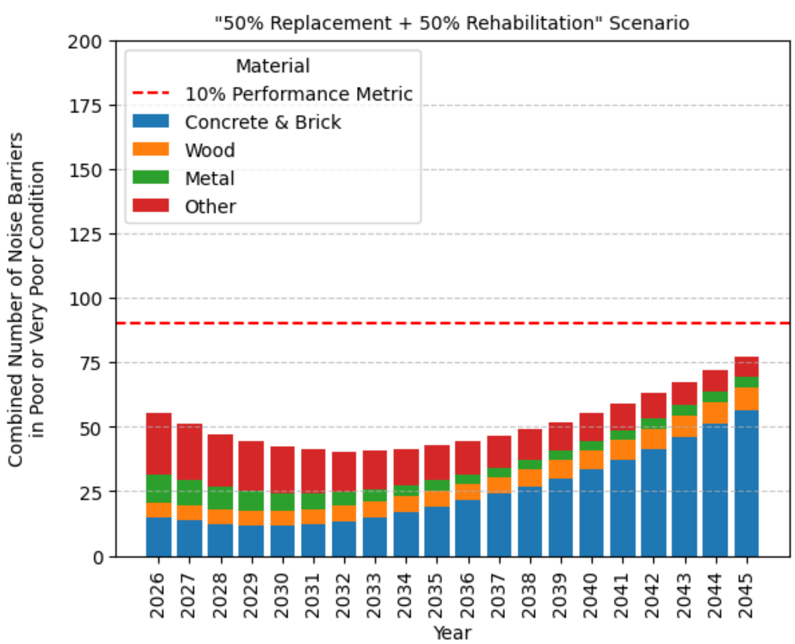

Figure 17. Markov Chain Analysis Results Showing Noise Barrier Inventory Condition After "50% Replacement + 50% Rehabilitation" Scenario

Based on Figures 14 through 17, applying a $10 million annual treatment budget has a large effect on the condition of VDOT's noise barrier inventory over a 20-year period. Under the "Do Nothing" scenario, the number of poor and very poor condition noise barriers was more than double the 10% performance metric. Under the "100% Replacement" scenario, the 10% performance metric was not exceeded until 2042, with similar results for the "80% Replacement + 20% Rehabilitation" scenario. However, under the "50% Replacement + 50% Rehabilitation" scenario, the 10% performance metric was not exceeded over the 20-year evaluation period. This result highlights the effectiveness of incorporating some proactive rehabilitation efforts alongside reactive replacement treatments within an asset management plan.

An economic burden analysis was conducted to evaluate the cost-effectiveness of each scenario over the 20-year period. This analysis includes both the money spent and the projected deferred replacement backlog in the inventory after 20 years. Although the "Do Nothing Scenario" required $0 in spending, the other three scenarios required $220 million in spending over the 20-year period. The deferred replacement backlog quantifies the cost required to restore all the noise barriers in poor and very poor condition to good condition. The unit replacement cost used in this analysis was $87.50/ft^2. This figure represents the previously used $70/ft^2 replacement cost increased by a 25% "failure premium." This multiplier accounts for the increased costs of reactive mobilization, maintenance of traffic, administrative overhead, potential liability, and so on of managing a failed asset. Table 32 shows the results of this analysis.

Table 32. Economic Burden Analysis Results Showing Cost-Effectiveness of Asset Management Scenarios [a]

Scenario Name	Money Spent on Treatments	Deferred Replacement Backlog	Total Economic Burden	Savings vs. "Do Nothing" Scenario	Return on Investment
Do Nothing	$0	$453 million	$453 million	N/A	N/A
100% Replacement	$220 million	$256 million	$476 million	– $24 million	– 11%
80% Replacement + 20% Rehabilitation	$220 million	$241 million	$461 million	– $8 million	– 4%
50% Replacement + 50% Rehabilitation	$220 million	$183 million	$403 million	$50 million	23%

N/A = not applicable. [a] Costs are in 2026 dollars.

As Table 32 shows, the "100% Replacement" scenario resulted in the greatest total economic burden over 20 years, even greater than the "Do Nothing" scenario. This result suggests that the total amount spent on replacements was insufficient to keep pace with the noise barrier deterioration. Figure 15 previously illustrated this outcome. The "50% Replacement + 50% Rehabilitation" scenario resulted in the least total economic burden after 20 years, suggesting that approach yields the most net economic benefit.

Table 32 also shows the cost savings of the last three scenarios versus the "Do Nothing" scenario and their return on investment. The return on investment was calculated by dividing the cost savings versus the "Do Nothing" scenario by the total money spent. The "50% Replacement + 50% Rehabilitation" scenario resulted in a return on investment of 23%. This result means that for every $1 spent in this scenario, $1.23 in economic value was received by preserving noise barriers within the inventory. In terms of actual dollars saved, this approach saved approximately $50 million during the 20-year period for an annual savings of $2.5 million per year. This analysis demonstrates that an asset management approach that includes a significant amount of funding toward proactive rehabilitation, and not just reactive replacement, can actually increase the economic value and condition of VDOT's noise barrier inventory.

Unmanned Aerial System Trial Inspections

The UAS trial inspections were successful at capturing condition data of both sides of all three noise barriers at both sites. Figure 18 shows some of the individual oblique-angle photos captured during the UAS flights over the PVC and concrete noise barriers at the Christiansburg site. Figure 18 includes photos from both the front and back sides of the noise barriers. Figure 19 shows an orthomosaic "top of wall" photo where the PVC and concrete noise barriers join.

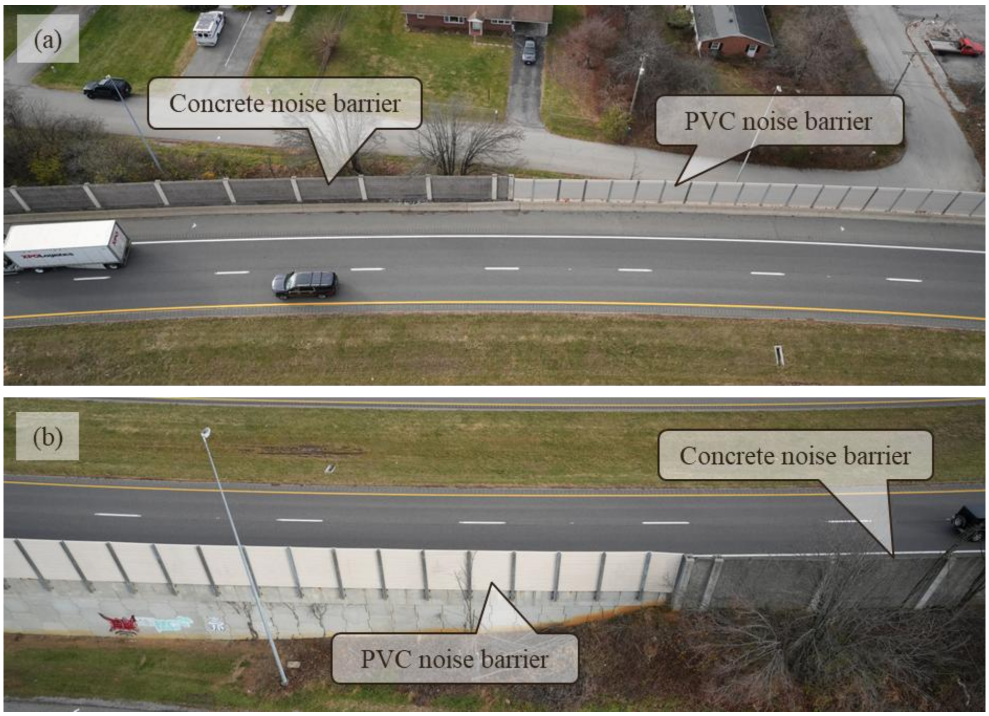

Figure 18. Oblique Imagery of PVC and Concrete Noise Barriers at Christiansburg Site: (a) Front Side of Noise Barriers; (b) Back Side of Noise Barriers. PVC = polyvinyl chloride.

Figure 19. Orthomosaic "Top of Wall" Photo Where the Polyvinyl Chloride and Concrete Noise Barriers Join at Christiansburg Site

The oblique imagery was used to generate a three-dimensional colorized mesh model of the noise barriers. Figure 20 shows screenshots of the colorized mesh model, highlighting features that could be seen in the model. As Figure 20 shows, the UAS data were able to clearly capture corroded flashing at the base of the PVC noise barrier, graffiti on the retaining wall below the PVC noise barrier, impact damage on the concrete noise barrier and concrete barrier, and vegetation growth behind the concrete noise barrier.

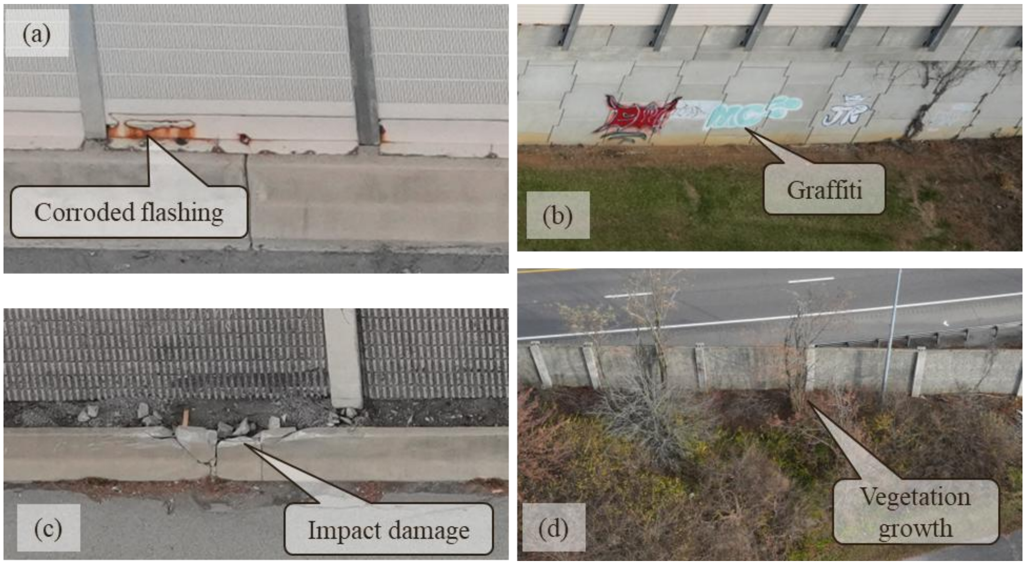

Figure 20. Screenshots of Colorized Mesh Model of Noise Barriers at Christiansburg Site: (a) Corroded Flashing at Base of PVC Noise Barrier; (b) Graffiti on Retaining Wall Below PVC Noise Barrier; (c) Impact Damage on Concrete Noise Barrier and Concrete Barrier; (d) Vegetation Growth Behind Concrete Noise Barrier. Photos were taken with a 61 megapixel camera at either 180 or 250 feet above ground level. PVC = polyvinyl chloride.

Figure 21 shows additional screenshots of the colorized mesh model at the Christiansburg site, including an overall view of the PVC noise barrier and general and closeup views of vine growth along the concrete noise barrier. These screenshots show the high resolution achievable with UAS imagery. Overall, these photos demonstrate that UASs can collect high-quality data from which to conduct a condition assessment of a noise barrier.

Figure 22 shows example screenshots of the LiDAR collected from the concrete noise barrier at the Christiansburg site. Figure 22b shows that the LiDAR data model can be used to view cross sections of the object. These data could be used to evaluate if a noise barrier was out of alignment. Additional data collected from future inspections could also be used to conduct a change analysis on the vertical alignment of the noise barrier to identify damage. One benefit of LiDAR is that it can travel through vegetation, so vegetation does not need to be cleared to develop an accurate LiDAR model.

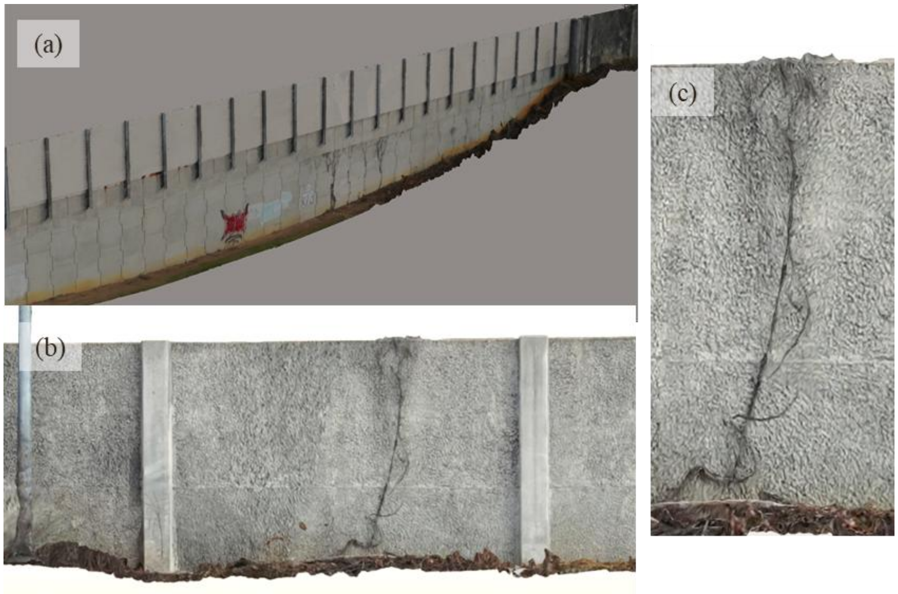

Figure 21. Screenshots of Colorized Mesh Model at Christiansburg Site: (a) Overall View of Polyvinyl Chloride Noise Barrier; (b) Overall View of Vine Growth Along Back Side of Concrete Noise Barrier; (c) Closeup of Vine Growth on Concrete Noise Barrier

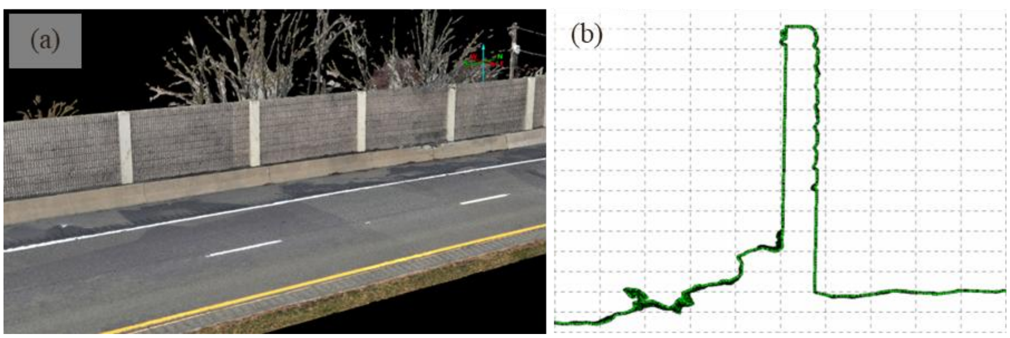

Figure 22. Screenshots of LiDAR Data from Concrete Noise Barrier at the Christiansburg Site: (a) Point Cloud Data; (b) Cross-Section Scan

Similar data were gathered from the metal noise barrier at the Fredericksburg site. As stated previously, the noise barrier was mounted to a bridge crossing over railroad tracks. A truss structure also crossed over the railroad tracks just south of the bridge. Figure 23 shows an oblique-angle image recorded from the UAS during the trial inspection. This site served as a likely use case for UAS inspection due to access difficulties associated with the railroad tracks. Access by other inspection tools, such as a bucket truck, would require additional railroad coordination and permits, in addition to a traffic lane closure to inspect the back side of the noise barrier without a UAS. All this effort would contribute to increased inspection delays and additional costs in equipment and resources.

Figure 23. Oblique Imagery from the Fredericksburg Site Showing Metal Noise Barrier, Railroad Tracks, and Truss Structure over Railroad Tracks

Figure 24 and Figure 25 show screenshots of the colorized mesh model of the metal noise barrier at the Fredericksburg site. Figure 24a shows that the bent panel on the noise barrier was captured through the UAS data, demonstrating its effectiveness at capturing condition data. Figures 24 and 25 display the high-resolution data that could be used to evaluate other noise barriers with potential damage.

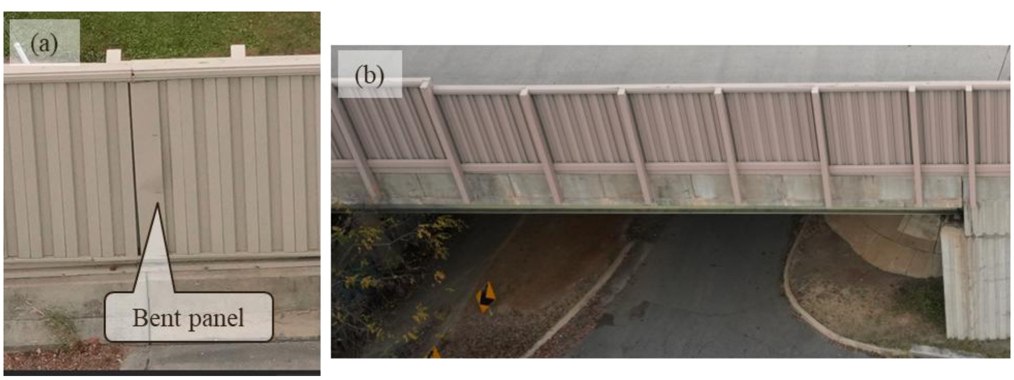

Figure 24. Screenshots from Colorized Mesh Model of Metal Noise Barrier at Fredericksburg Site: (a) Bent Panel on Front Side of Noise Barrier; (b) Back Side of Noise Barrier

Figure 25. Screenshots from Colorized Mesh Model of Metal Noise Barrier at the Fredericksburg Site: (a) Overall View of Back Side of Noise Barrier; (b) Closeup View of Noise Barrier

Overall, the UAS trial inspections successfully demonstrated the potential to evaluate noise barrier conditions. The UAS trial inspections also displayed significant safety benefits compared with a typical visual inspection. The UAS operator was able to stand in a single, safe location throughout the collection process without needing to interact with live traffic. In addition to the noise barrier data, the UAS consultant also provided draft performance-based specifications to VTRC and the VDOT Geospatial team for future noise barrier condition assessments using UASs as the collection technique. A report on these specifications can be found in the supplementary material for this report, entitled *Soundwall Condition Assessment Using UAS: Performance Based Specifications*.

In addition to condition evaluation, other potential UAS and LiDAR applications for noise barriers exist. Many noise barriers built in the 1970s and 1980s lack accurate geometry because the plans and records are no longer available. These noise barriers, and even newer ones, have become obscured by vegetation, making digitization from aerial imagery challenging. LiDAR scans of these locations would drastically improve the accuracy of the linework in VDOT’s noise barrier GIS databases.

UASs could also be used to more easily measure acoustic data along noise barriers. When a noise analysis is required for a project with existing noise barriers, accurate top-of-wall elevation data are critical for determining the acoustic performance of those barriers. Because as-built plans are not always available for older, existing noise barriers, these measurements could be taken using a UAS, and an acoustic sensor could be mounted to the UAS to record measurements at the top of the noise barrier.

Figure 26 shows some of the other VDOT assets that UASs captured during the trial inspections, including light poles, guardrails, and concrete barriers. A single UAS flight could collect data on multiple assets for future analysis. This capability could present a significant opportunity to minimize field site visits while maximizing the number of assets on which data were collected. This acheivement would be possible if UAS performance and collection standards were developed and the data collection process were centralized.

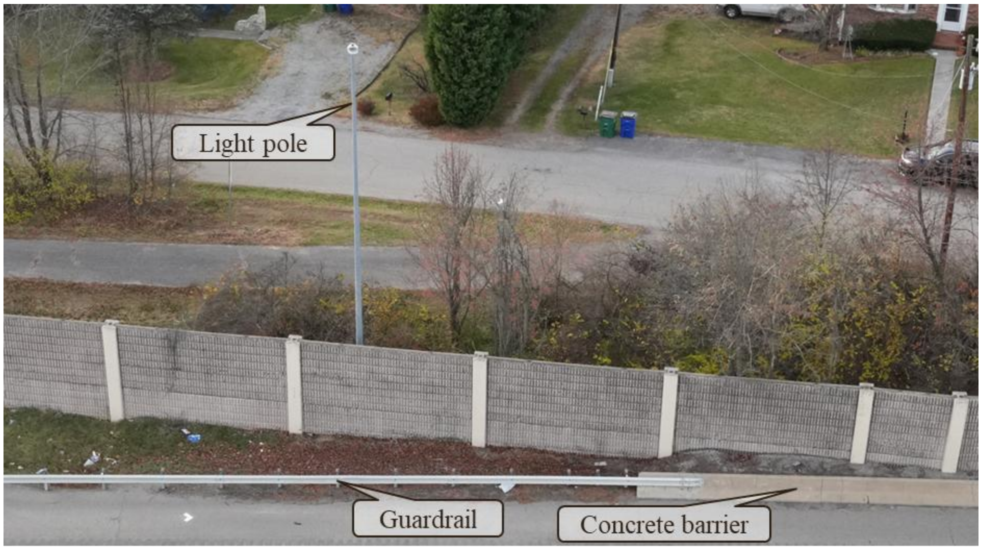

Figure 26. Other VDOT Assets Observed During Unmanned Aerial System Trial Inspections

Opportunities for additional cost savings are also possible by combining potential asset inspections with other VDOT divisions and business units like the VDOT Environmental Division, invasive species identification, vegetation encroachment, and photos or videos for VDOT's System Management and Allocation of Resources for Transportation (SMART) SCALE efforts. The VDOT Geospatial team could easily coordinate all such data collection efforts. Such a centralized effort would enable UAS data to be consistent and cohesive, thereby preventing data silos within separate VDOT Divisions. UAS technology has the potential to increase information sharing across VDOT through three-dimensional viewing tools, such as those shown in Figures 18 through 26.

CONCLUSIONS

- *Lightweight perforated metal noise barrier panels oriented horizontally exhibit poor durability, having an expected service life of approximately 10 to 15 years.*

- *Other types of lightweight noise barriers, including metal panels oriented vertically, composite, PVC, fiberglass, acrylic, and wood panels exhibit good durability, with all material types having an expected service life of at least 50 years.*

- *Anchor bolts connecting lightweight noise barriers to posts or foundations are susceptible to corrosion damage*. Better corrosion performance can be achieved if these anchor bolts are shielded from salt spray.

- *It was difficult to extract meaningful information about the durability of VDOT's noise barriers from reviewing the noise barrier databases*. More meaningful results could be reached in the future if these noise barrier databases were combined into a single authoritative inventory.

- *A noise barrier element-level inspection plan can be modeled after the FHWA and VDOT element-level bridge inspection guidance, with some modifications specific to noise barriers*.

- *An asset management plan with an annual budget of $11 million can maintain VDOT's noise barrier inventory with less than 10% of its noise barriers in poor or very poor condition over the next 20 years.* This conclusion depends on the noise barrier deterioration model, treatment effectiveness, and cost estimates determined in this report.

- *An asset management approach with a portion of the funding allocated toward proactive rehabilitation treatments can yield a greater net economic benefit with a positive return on investment compared with an approach with only reactive replacements*. This conclusion depends on the noise barrier deterioration model, treatment effectiveness, and cost estimates determined in this report.

- *UASs can successfully and safely be used for visually inspecting the condition of both sides of ground-mounted and structure-mounted noise barriers.*

RECOMMENDATIONS

1. *The VDOT Structure and Bridge Division should implement guidance prohibiting the use of lightweight perforated metal noise barrier panels oriented horizontally in the VDOT Road and Bridge Specifications*.

2. *The VDOT Maintenance Division and Environmental Division should establish a single authoritative source to house all noise barrier inventory data*.

3. *The VDOT Maintenance Division should establish an inspection program for noise barriers*.

4. *The VDOT Maintenance Division should establish an asset management program for noise barriers*.

5. *VDOT should evaluate the potential for using UASs for asset inspection*.

6. *The VDOT Location and Design Division should continue supporting all VDOT Divisions on geospatial workflows, collection specifications, and data governance programs*.

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding Recommendation 1, the Structure and Bridge Division will edit Section 519(c)1 of the VDOT Road and Bridge Specifications to restrict the use of perforated metal panels oriented horizontally within 2 years of the publication of this report.

Regarding Recommendation 2, the Maintenance Division and the Environmental Division will meet to discuss combining their noise barrier data into a single authoritative inventory within 1 year of publication of this report. Topics for discussion at this meeting will include establishing a unique wall identification for each noise barrier, assigning divisional ownership of fields within a shared database, and ensuring that a shared database continues to meet the business needs of both divisions. Both divisions recognize the value of having an authoritative data source but need to work through the details of how it will work in practice.

Regarding Recommendations 3 and 4, the Maintenance Division will hold internal discussions within 1 year of the publication of this report to determine the priority of establishing noise barrier inspection and asset management programs within its current business needs. The Maintenance Division recognizes the value of having these programs but acknowledges that manpower and funding resources are limited. The Maintenance Division will also have discussions with other stakeholders to gauge interest and identify the specific objectives they wish to see incorporated into noise barrier inspection and asset management programs.

Regarding Recommendation 5, VTRC will develop a research needs statement for presentation at the fall 2026 Bridge Research Advisory Committee meeting to evaluate the potential for using UASs to inspect VDOT assets. VTRC will partner with the VDOT UAS Section within the VDOT Location and Design Division to develop this research needs statement. Together, they will communicate with the VDOT divisions to determine which assets are of greatest priority for inclusion in this research needs statement. The research needs statement will include the need to develop a VDOT geospatial data workflow and governance guide to assist other VDOT divisions in managing UAS data collections.

Regarding Recommendation 6, the VDOT Location and Design Division already provides geospatial data support, but this recommendation serves as a reminder for all other VDOT divisions. The VDOT Location and Design Division is currently drafting an Instructional and Informational Memorandum to formalize this support on GIS-related products.

Benefits

Implementing Recommendation 1 would allow VDOT to eventually rid its inventory of a noise barrier material and design type that has extremely poor durability. Noise barriers with perforated metal panels oriented horizontally have a short service life and therefore require replacement more often, increasing the funding required. Implementing this recommendation would allow this funding to be spent on other high-priority noise barrier-related work. By eliminating this poorest performing noise barrier type, VDOT also reduces safety risks associated with potential failures.

Implementing Recommendation 2 would provide VDOT with a single, more information-rich dataset on its noise barrier inventory. Having a single, authoritative noise barrier database would make it clear where to find information regarding VDOT's noise barriers and may allow for more conclusions to be reached on the inventory once all data have been compiled and combined.

Implementing Recommendations 3 and 4 would allow VDOT to systematically manage its noise barrier inventory to maximize overall condition while minimizing limited funding. According to the analysis in this report, an asset management program with an annual budget of $11 million and portions of funding toward rehabilitation and replacement can result in cost savings of $50 million over 20 years when considering a reduced replacement backlog. This amount results in a 23% return on investment on the annual $11 million budget and is an annual savings of $2.5 million.

Implementing Recommendation 5 could yield safety, labor, access, and data quality benefits if UASs are used to demonstrate successful inspections of VDOT assets. UASs have the potential to limit workers' exposure to traffic or other unsafe conditions, capture images from difficult-to-reach vantage points, and take high-resolution aerial imagery from a distance that does not interfere with the traveling public.

Implementing Recommendation 6 will help to avoid divisional data silos within VDOT. Having unified geospatial data across VDOT divisions will allow for easier interpretation and better analysis of these data among all VDOT users.

ACKNOWLEDGMENTS

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