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RESEARCH REPORT

IMPROVING ROADWAY DEBRIS CLEARANCE FOR CHART RESPONDERS

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FINAL REPORT

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16. Abstract

This project evaluates LaneBlade® technology's feasibility and effectiveness in enhancing roadway debris clearance operations, focusing on improving safety for CHART responders and road users while optimizing operational efficiency. Through structured field experiments considering weather conditions, debris types, blade types, and operating speeds, LaneBlade® demonstrated the capability to effectively clear various debris types in the real-world operational environments, even under adverse weather conditions like snow and rain. Moreover, the use of this technology expedites debris clearance without necessitating lane closures, significantly reducing responder exposure to traffic hazards. Particularly, steel blades are more efficient, but rubber blades may minimize pavement damage in specific scenarios. Maintaining operational speeds between 5-10 mph balances effectiveness and safety. Challenges include equipment reliability, durability, and operational procedures, necessitating the development of standard operating procedures, training programs, and ongoing monitoring and evaluations. In conclusion, LaneBlade® shows promise in improving debris clearance efficiency and safety, offering potential benefits for SHA's CHART operations.

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Executive Summary

Ensuring the safety of the Coordinated Highways Action Response Team (CHART) responders while minimizing debris clearance time is a paramount objective for the Maryland Department of Transportation State Highway Administration (SHA). LaneBlade®, a specially designed blade mounted on the front of emergency response vehicles to improve debris removal capabilities, stands out as a compelling candidate to meet SHA's operational objectives. Therefore, this project aimed to evaluate the feasibility and effectiveness of the LaneBlade® technology in enhancing roadway debris clearance operations. It focuses on improving safety for responders and road users, while optimizing operational efficiency.

The literature review provided insights into existing technologies, best practices, and challenges associated with roadway debris clearance. Building on this foundation, field experiments were conducted to assess the performance of LaneBlade® systems in real-world scenarios. Key factors such as weather conditions, debris types, blade types, and operating speeds were considered during the experiments.

The findings revealed that LaneBlade® technology has the potential to effectively clear various types of debris in real-world operational environments. The system's performance was particularly noteworthy during adverse weather conditions, such as snow and rain. Capable of removing everything from stones and sand to crashed vehicles, the system demonstrated its ability to swiftly clear debris from roadways, thereby contributing to improved safety and minimized traffic disruption. It enables the expedited clearance of low-volume solid objects without the need for lane closures, significantly reducing the exposure of CHART responders to traffic hazards and improving their safety. Furthermore, steel blades were found to be more efficient than rubber blades in most scenarios. However, rubber blades might be preferable in certain situations to minimize pavement damage. Additionally, it was determined that the optimal operational speeds of the system range from 5 mph to 10 mph to balance effectiveness and safety, with higher speeds avoided to prevent equipment failures and safety risks.

While LaneBlade® demonstrated promising results in improving debris clearance efficiency and safety, challenges such as equipment reliability, durability, and operational procedures were identified. To address these issues, recommendations include developing standard operating procedures, implementing training programs for CHART responders, and establishing ongoing monitoring and evaluation processes.

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Chapter 1. Introduction

1.1 Background

Clearing roadway debris is a critical duty for the Coordinated Highways Action Response Team (CHART) responders within the Maryland Department of Transportation State Highway Administration (SHA). Despite its importance, this task presents substantial safety hazards to responders, who need to exit their vehicles to collect and dispose of the debris, which will expose them to high-speed traffic, particularly in low visibility conditions. Tragically, recent incidents serve as reminders of the dangers inherent in this duty. In 2022, two police officers, Chief Joe Carey of the Brodnax Police Department in Virginia (WRIC, 2022) and Sergeant Chris Jenkins of the Loudon County Sheriff's Office in Tennessee (WATE, 2022), lost their lives while performing this task. These incidents underscore the urgent need for enhanced safety measures to protect CHART responders and mitigate risks associated with their essential tasks.

Moreover, the clearance of roadway debris not only jeopardizes the safety of responders but also disrupts traffic flow and efficiency. Temporary lane closures are frequently needed to safeguard responders during debris removal, leading to significant delays for travelers. Additionally, the prolonged clearance times, exacerbated by limited responder availability, impede the timely removal of debris from multiple sites. Consequently, road users are subjected to prolonged exposure to potential hazards, thereby compromising overall traffic safety performance.

In response to these challenges, it is crucial to ensure the safety of CHART responders while also minimizing debris clearance time. This becomes a paramount objective for SHA. LaneBlade® from J-Tech (J-Tech, 2022) stands out as an excellent solution for achieving SHA's goals. This innovated system, depicted in **Figure 1**, is a specially designed blade to meet such an objective. Mounted on the front of emergency response vehicles, LaneBlade® effectively removes debris weighing up to 150 pounds at speeds of up to 20 mph. Its heavy-duty steel construction, coupled with a corrosion-resistant powder coating, ensures durability and longevity, even in challenging conditions. Additionally, the design includes a rubber contact surface and hydraulic hoses protected by sleeves, improving resilience, and reducing wear and tear.

Figure 1. The LaneBlade® Installed on a Truck [Adopt from (J-Tech, 2023)**]**

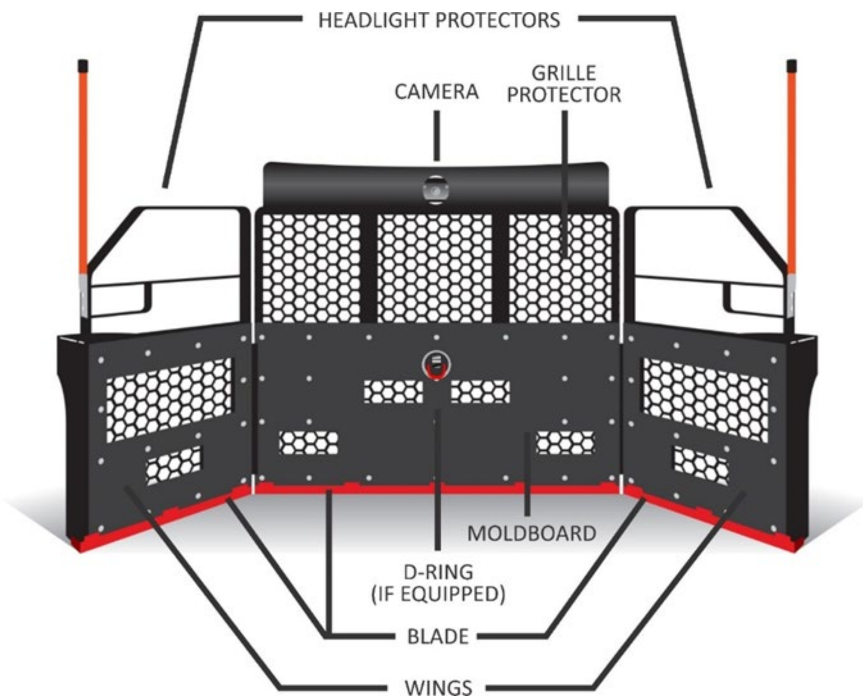

Figure 2. Diagram of the LaneBlade® [Adopt from (J-Tech, 2022)**]**

The LaneBlade® serves a dual purpose: it swiftly removes debris to restore normal traffic flow while prioritizing the safety of first responders. With its distinctive winged design, illustrated in **Figure 2**, the LaneBlade® advances, effectively containing and pushing debris toward the road shoulder, away from passing vehicles. Moreover, with its wings retracted, the LaneBlade® can assist in relocating disabled vehicles out of live traffic lanes, further enhancing traffic management. To boost responder efficiency and safety, the LaneBlade® is equipped with an advanced camera system. This includes a multi-view camera mounted on the blade itself and an in-vehicle video monitor, enabling responders to locate and manage debris without needing to exit their vehicles or expose themselves to high-speed traffic. By allowing responders to remain inside their vehicles, this system significantly reduces the risks associated with oncoming traffic, ensuring their protection while effectively clearing debris. Additionally, the LaneBlade® proves to be particularly beneficial for routine debris clearance tasks, eliminating the need for temporary lane closures. This capability substantially cuts down debris clearance time, boosting operational efficiency and enhancing overall safety for road users.

1.2 Objectives

Despite its potential to enhance the safety of CHART responders while minimizing the time required for debris clearance, LaneBlade® has yet to be deployed on CHART emergency response vehicles. Therefore, this project intends to investigate:

1) The feasibility of employing LaneBlade® on CHART vehicles under various scenarios such as multiple debris on roadways, low visibility conditions, etc.

2) The effectiveness of LaneBlade® in reducing debris clearance time compared to current CHART operations, in scenarios where its deployment is feasible.

1.3 Report Organization

All research results and primary findings from this study are organized into five chapters and presented in this report. Chapter 2 provides a comprehensive review of literature related to roadway debris clearance. It discusses various state and federal policies and programs aimed at ensuring the safety of responders and the efficient removal of debris. Additionally, the chapter evaluates existing technologies for debris removal and introduces LaneBlade® as a promising solution to overcome current limitations. Chapter 3 presents CHART's current roadway debris clearance procedures, the expectations regarding the integration of LaneBlade® technology, and the initial impressions of CHART responders with LaneBlade®. Chapter 4 discusses the field evaluation of the LaneBlade® system's effectiveness and efficiency in clearing various types of debris under diverse environmental conditions, including the experiments design, evaluation schedule, and the evaluation results. And Chapter 5 concludes the report and recommended several guidelines for using the LaneBlade®.

Chapter 2. Literature Review

2.1 Introduction

This literature review chapter begins by providing an overview of roadway debris and its general clearance process. Then, the current practices employed in the United States for roadway debris removal, along with the evaluation measures used to assess performance will be elaborated. Subsequently, the chapter explores existing technologies utilized by other state transportation agencies to improve debris clearance, highlighting their respective performance characteristics. Finally, the potential benefits of implementing LaneBlade® will be briefly discussed according to the review results.

2.2 Roadway Debris and Its General Clearance Process

Roadway debris encompasses a wide array of objects and materials that are found on or adjacent to roadways, constituting a potential hazard to drivers, pedestrians, and other users of the road. The nature and size of this debris can vary significantly, encompassing small items such as glass shards, nails, or screws, which can puncture tires or become projectiles, to larger and potentially more hazardous objects like tree branches, parts of vehicles, or construction materials that can obstruct paths or cause accidents. The sources of roadway debris are diverse and numerous. One primary source is vehicular accidents, where collisions or incidents can result in parts of vehicles, personal belongings, or cargo being scattered across the road. These remains not only pose immediate dangers to other road users but can also lead to secondary accidents if not promptly cleared. Natural occurrences, particularly storms, intense winds, or severe weather conditions, are also significant contributors to roadway debris. These conditions can bring down trees, branches, and other natural materials onto the roadways, creating obstacles and hazards for traffic. Seasonal changes, such as autumn leaves or winter snowfall, further add to the variety and amount of debris encountered on roads. Construction and maintenance activities near or on roadways are another prevalent source of debris. These activities often involve the use of a wide range of materials, some of which may inadvertently end up on the road due to mishandling or accidents. Construction debris not only includes materials directly used in construction projects but also waste and discarded items from the construction process. Lastly, littering by pedestrians and drivers contributes significantly to the accumulation of debris along roadways. Despite public awareness campaigns and penalties for littering, trash ranging from food wrappers to larger items like electronic devices or household trash is routinely disposed of improperly, adding to the clutter and posing risks to safety and environmental health. **Figure 3** and **Table 1** provide examples of various types of roadway debris.

Table 1. Examples of Different Types of Roadway Debris (Wikipedia, 2023)

Type	Examples
Particulates	Dust, dirt, sand, mud, road salt
Solid objects	Asphalt, concrete, pebbles, rocks/stones/boulders
Sharp objects	Broken glass, nails, screws
Crash debris	Disabled vehicles, car parts, tire tread
Animal corpses	Roadkill
Objects dropped from moving vehicles	Litter, food waste, furniture, electrical appliances, bicycles, roof racks, luggage, lumber
Plants and their parts	Branches, leaves, sticks, twigs, seeds, or grass clippings.

Figure 3. Illustration of Roadway Debris [Particulates, Rock (Utah Department of Transportation, 2013)**, Food Waster, Tire Debris** (Versageek, 2008)**, fallen trees]**

Roadway debris can cause punctured tires, damage to vehicle components, or lead to loss of control, resulting in accidents or collisions. Additionally, debris may obstruct visibility or create hazards that require sudden evasive maneuvers, endangering the safety of drivers and pedestrians alike. According to the American Automobile Association Foundation for Traffic Safety (American Automobile Association, 2016), an alarming number of over 200,000 crashes in the United States occurred due to debris on roadways between 2012 and 2016. Shockingly, this led to approximately 39,000 injuries and more than 500 fatalities between 2011 and 2014 alone. The prevalence of accidents involving vehicle-related debris has risen by 40% since 2001, as highlighted by the Foundation's initial study on the matter. Consequently, it is imperative to promptly remove roadway debris to ensure the safety of all road users.

The process of clearing and removing roadway debris on highways involves a coordinated effort between various agencies and personnel. It is important to note that the specific process may vary depending on the jurisdiction, nature of the incident, and resources available. The following presents a general overview of the steps involved:

- Detection, Reporting and Initial Assessment: Roadway debris is detected and reported through patrols, driver reports, or monitoring systems. Responsible agencies assess the situation upon receiving reports.

- Traffic Control: Measures such as cones, barriers, or signage are deployed to ensure safety for responders and road users.

- Debris Removal and Clean-up: Methods range from manual labor with tools like brooms, shovels, or rakes for small debris to heavy equipment like loaders or tow trucks for larger items or disabled vehicles.

- Restoration of normal traffic flow: Adjustments or removal of traffic control measures allow for normal traffic flow once the roadway is safe.

Figure 4. First Responders Using Unmanned Aircraft Systems for Traffic Crash Investigation and Reconstruction (LEXIPOL, 2017)

Figure 5. Removal of Smaller (left) and (larger) Debris

Roadway debris removal is a critical yet hazardous task that involves responders exiting their vehicles to manually collect and dispose of objects that pose potential hazards on or alongside roadways. This process is particularly perilous due to the exposure of workers to high-speed traffic, significantly increasing the risk of injury or fatality. According to the National Institute for Occupational Safety and Health (NIOSH) Surveillance System data published by the National Institute for Occupational Safety and Health in 1997, between 1980 and 1992, there were 450 fatalities among workers aged 16 or older involved in refuse collection and disposal activities. A staggering 67% (303) of these deaths were vehicle related. Notably, 36% (110) of the vehicle-related fatalities resulted from workers slipping or falling from refuse collection vehicles, being struck, or run over by these vehicles, or falling and subsequently being struck or run over. Among these incidents, 18% (20) occurred while the refuse collection truck was in reverse, highlighting the particular dangers of maneuvering vehicles in close proximity to workers on foot.

Beyond the immediate dangers to responders, the process of debris clearance can significantly disrupt traffic flow and efficiency. The necessity for temporary traffic control measures to safeguard workers during debris removal operations often results in considerable delays. Furthermore, with a finite number of responders available to address debris across various locations, extended clearance times exacerbate the challenge of timely debris removal. Consequently, road users are subjected to increased exposure to potential hazards, prolonging the risk of accidents or incidents on the road. This extended exposure not only endangers road users but also diminishes the overall safety performance and efficiency of the transportation network.

The intricate balance between ensuring the safety of responders during debris removal and maintaining traffic efficiency underscores the need for innovative solutions and strategies. Enhancing safety protocols, employing technology to minimize direct exposure to traffic, and improving operational efficiency are critical steps towards mitigating these risks. Addressing the challenges of roadway debris removal is essential for safeguarding both the workers tasked with this duty and the general public who rely on safe and efficient roadways.

2.3 Current Practices and Performance Measures

There are several laws and policies concerning the clearance of roadway debris, aiming to ensure public safety and efficient traffic flow. Since 2003, at least 14 states in the United States have enacted authority removal (hold harmless) laws (U.S. Department of Transportation, 2021). These laws grant designated public agencies, such as Departments of Transportation (DOTs), state, county, and local law enforcement, the authority to remove or facilitate the removal of certain items, including driver-attended disabled or wrecked vehicles, spilled cargo or personal property obstructing a travel lane, and any other items posing a hazard to the smooth flow of adjacent traffic. The objective of these laws is to empower authorities and first responders to proactively and expeditiously eliminate vehicles and debris, without concerns about potential liability claims for damages incurred during the removal process. By providing indemnification to the agency for damages incurred during the removal process, these laws enable swift and decisive action by authorized personnel.

Furthermore, "move over" laws are implemented to safeguard responders. These laws typically require motorists to change lanes and/or reduce speed when approaching an authorized emergency vehicle that is parked or stopped on a roadway. This measure aims to protect the safety of responders working at the scene.

Another policy relevant to debris clearance is the implementation of "open road" policies. These policies serve as formal guidelines outlining the objectives of collaborative efforts among various agencies involved in removing vehicles, cargo, and debris from roadways following motor vehicle crashes and other incidents. The primary goal is to restore safe and orderly traffic flow within specified timeframes, beginning from the arrival of the first responding officer. These policies prioritize minimizing risks to responders, secondary crashes, and incident-related delays. While recognizing that vehicle or cargo damage may occur during roadway clearance, the primary focus remains on promptly returning traffic conditions to normal. The underlying principle of open road policies is to minimize road closures or restrictions, ensuring they last only for the necessary duration.

The Federal Highway Administration (FHWA) has introduced a comprehensive Traffic Incident Management (TIM) program. This program encompasses a planned and coordinated multi-disciplinary approach to effectively detect, respond to, and clear traffic incidents, with the overarching objective of restoring traffic flow as safely and swiftly as possible. The primary goal of the TIM Program is to continually enhance the safety of both responders and road users, improve travel reliability, and optimize the efficiency of incident and emergency response through the establishment and integration of TIM programs (U. S. Department of Transportation, 2023). An integral component of the TIM program is the expeditious removal of roadway debris following a traffic incident. Recognizing the hazards posed by debris, the program emphasizes the importance of promptly clearing the affected area to restore safe conditions for motorists. By prioritizing the timely removal of debris, the TIM program seeks to minimize the risk of secondary incidents and facilitate the smooth flow of traffic. The performance of TIM can be assessed through the evaluation of various time-based components within the incident timeline. This timeline provides a comprehensive depiction of a typical incident and outlines the stages involved in its management by responders. To visualize this breakdown, **Figure 6** presents a detailed illustration of the entire incident timeline.

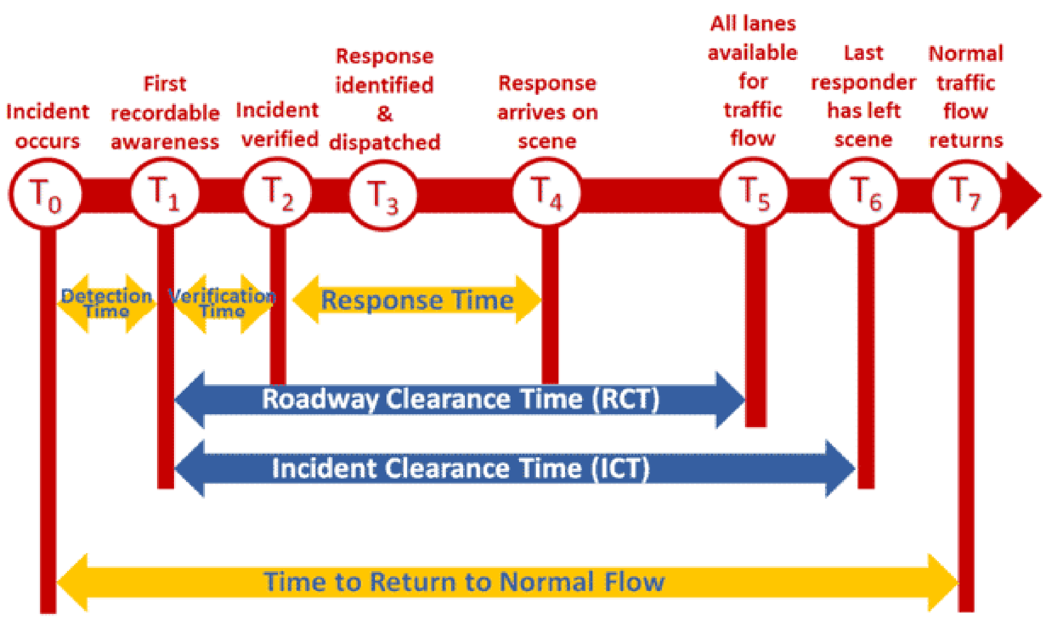

Figure 6. Incident Timeline [Adopt from (Pecheux, 2016)**]**

To ensure consistency in measuring TIM performance on a national level, the FHWA collects three key performance measures, including roadway clearance time (RCT), incident clearance time (ICT), and secondary crashes. Several other metrics are utilized to evaluate TIM effectiveness. These measures include incident detection time, incident verification time, incident response time, and time to return to normal traffic flow.

Regarding the current practices of roadway debris clearance, the National Work Zone

Safety Information Clearinghouse (American Road & Transportation Builders Association, 2023) provides summaries of litter and debris removal procedures for eight states, including Maryland, Minnesota, New York, Florida, California, Arkansas, and Colorado. Each state follows its own unique protocol for cleaning its roads. In Maryland, for instance, a maintenance vehicle, typically a dump truck, is assigned to a section of the roadway. This vehicle is staffed with workers who are individuals performing community service. The supervisor of the crew is an SHA maintenance employee. The crew disembarks, picks up litter and debris, and deposits them in the truck. This process is repeated until the entire section is cleaned. If a large piece of debris is spotted in the travel lane, the supervisor waits for traffic to clear and retrieves it. Minnesota follows the same procedure as Maryland, with one notable exception.

Minnesota does not deploy Special Transportation Services (STS) personnel onto the roadway. Instead, the state relies on its own maintenance workers to remove debris from the lanes. New York does not have a formal program for litter and debris removal. However, some informal arrangements are made at the local level. Despite this difference, the state's overall approach to debris management is also similar to Maryland's. Florida utilizes inmate labor for litter and debris pickup, with the Department of Transportation providing the necessary transportation in the form of a truck bed. A Department of Corrections officer supervises the inmate crew. Four-wheel vehicles with mounted amber strobe lights and trailers are often used. The Arkansas DOT employs multiple strategies to combat litter on state highways. Contracted mowing crews and state employees are responsible for the majority of litter removal, while some counties utilize prisoner labor or hire external organizations for the task. Colorado has litter and debris guidelines that require personal protective equipment and Shoulder Work Ahead signs for roadside cleanup, with litter collected in bags and transported to the maintenance yard by trash compactor or dump trucks. The state also has a contract for the Corporate Sponsorship Adopt-A-Highway program. Litter and debris removal are also managed by CDOT forces.

As for measures of effectiveness (MOEs) used to evaluate the roadway debris clearance, the Missouri DOT, (Hasson, 2019), as mentioned in a Safety Service Patrol Idea Sharing Network webinar, selects “Safe”, “Quick”, and “Clearance”. Specifically, reducing exposure to traffic and the risk of being struck, as well as expediting the removal of debris to reduce traffic impact are approaches to achieve the goals.

2.4 Existing Technologies

2.4.1 Automated Roadway Debris Vacuum

The California Department of Transportation (CalTrans) has implemented an innovative solution known as the Automated Roadway Debris Vacuum (ARDVAC) (Church et al., 2014) to address the challenge of debris removal on roads. This system integrates a long-reach robotic device with an internal vacuum into a full-sized truck, providing an efficient and versatile debris collection capability. The ARDVAC eliminates the need for on-site setup and can be operated by a single operator with minimal complexity.

The ARDVAC is specifically designed to assist responders in clearing light debris such as paper, cups, and aluminum cans, as well as denser debris like glass bottles and surface soil from roadways. The key advantage of the ARDVAC system is that it allows the operator to control the articulating nozzle from within the truck's cab, eliminating the need to expose themselves to ongoing traffic. This significantly enhances safety and minimizes the risk to responders.

The ARDVAC system is particularly suitable for deployment in areas such as median dividers, roadway shoulders, and embankments adjacent to roadways. These locations often accumulate debris and require effective removal to maintain roadway safety. It is worth noting that the initial capital cost for implementing an ARDVAC system is approximately $381,000. CalTrans also employs a similar device known as the Automated Litter Bag/Debris Collection Vehicle to effectively address debris accumulation. This specialized vehicle is equipped with a retractable basket mechanism that allows for efficient collection of various types of debris. Unlike the ARDVAC, the Automated Litter Bag/Debris Collection Vehicle is capable of handling larger debris such as tires and mufflers. However, it is designed to operate at low speeds. The upfront capital cost for this device is comparable to that of the ARDVAC system.

CalTrans has undertaken a series of field tests to assess the performance of the ARDVAC in various deployment scenarios. These tests were conducted over a duration of four years, from July 2010 to June 2014. However, before delving into the test results, it is important to highlight the challenges encountered by CalTrans during the deployment of the ARDVAC. Introducing novel equipment like the ARDVAC posed a learning curve for both operators and planners within CalTrans. Operators had to familiarize themselves with the operation, inspection, and maintenance procedures specific to the device. Additionally, obtaining special driving licenses, such as Class B or A, was necessary to operate heavy equipment like the ARDVAC. On the other hand, planners had to adapt the debris removal work plan to accommodate the implementation of the ARDVAC and carefully evaluate the potential positive and negative impacts associated with its use. These learning processes demanded significant effort and perseverance from all stakeholders involved.

In addition to the learning curve, concerns arose regarding the reliability of the ARDVAC. Frequent failures of various components not only frustrated CalTrans but also caused challenges for the operators. Addressing these reliability issues became a priority to ensure the efficient and effective use of the ARDVAC in debris removal operations. Despite these challenges, CalTrans persevered and conducted rigorous tests to evaluate the performance of the ARDVAC for different purposes. The initial testing of the ARDVAC focused on its application for litter collection, which was its primary intended purpose. However, during this test, certain challenges arose when the ARDVAC operated near power poles, which posed threats and obstacles. To monitor the potential impact of the ARDVAC on these power poles, a crew member had to exit the vehicle and walk alongside the road.

The ARDVAC demonstrated a litter collection rate of 300 feet per hour, which was relatively slow. Given the unsatisfactory efficiency and the continued exposure of one operator to traffic risks, CalTrans made the decision that the ARDVAC was unlikely to be extensively deployed for litter collection purposes. Currently, CalTrans still relies on low-risk probation workers to manually pick up litter along roadways.

The ARDVAC underwent additional testing in CalTrans District 3 for sand collection by the Northgate maintenance stormwater crew. Each winter, CalTrans needs to collect remaining sand to prevent its intrusion into waterways. During sand collection, the ARDVAC's nozzle can be rotated around the vertical axis, allowing the nozzle tip to break up packed sand using its articulation feature. The ARDVAC demonstrated exceptional performance in this task, effectively collecting sand that normal street sweepers often miss. Consequently, there have been suggestions to utilize the ARDVAC regularly for sand collection to significantly reduce the amount of sand remnants entering the drainage system.

Figure 7. ARDVAC and A Standard Vacuum Truck for Drain Inlet Cleaning

Following ARDVAC's successful performance in sand collection, the Northgate stormwater crew further deployed it for drain inlet cleaning. However, due to the absence of specialized tubing, ARDVAC was unable to reach the area below the gate in drain inlets, which is typically accessible by standard vacuum trucks. A comparison between the ARDVAC and a standard vacuum truck is depicted in **Figure 7**.

The crew discovered that, thanks to the ARDVAC's high airflow rate and large opening, it efficiently removed dirt compared to the standard vacuum truck. The need for manual effort was eliminated as its nozzle effectively broke up the dirt. Additionally, the ARDVAC has the capability to spray water in the airstream at the base of the elbow above the nozzle, minimizing the release of dust into the air. Based on the crew's experience, debris collected by the ARDVAC can be directly dumped at a dry dump site since the debris already contains some water. The crew recommended that the addition of a spray line and specialized tubing to the ARDVAC would allow it to completely replace the standard vacuum truck, offering a more efficient and effective solution for drain inlet cleaning operations. The evaluation of the ARDVAC revealed both successes and challenges. In terms of litter collection, the ARDVAC demonstrated limitations in efficiency and operator safety, leading to the decision that it is unlikely to be widely deployed for this purpose. However, in the tasks of sand collection and drain inlet cleaning, the ARDVAC showed impressive performance. It effectively collected sand that normal street sweepers missed and proved more efficient than standard vacuum trucks in removing dirt from drain inlets. Reliability issues and operator training were identified as areas that require improvement to ensure ARDVAC's efficient and effective use.

2.4.2 Gator Getter

The use of ARDVAC has proven effective in reducing responders' exposure to dangerous situations during debris removal. However, these systems are expensive and operate at low speeds. In contrast, the Colorado Department of Transportation (CDOT) implemented a cost-effective solution called Gator Getter (World Sweeper, 2021) for rapid debris removal. The Gator Getter consists of a metal cylinder attached to the front of a truck, with a scraping blade that directs debris into a barrel. The force of the vehicle redirects the debris into a catch tray. The pick-up scope is determined by the diameter of the drum, typically 48" × 72". The cost of a standard Gator Getter unit is $15,995, with an additional $600 for a frontal camera system if needed. Compared to ARDVAC, adopting the Gator Getter has minimal impact on operation costs due to existing vehicle requirements and the ease of attachment to trucks. The Gator Getter provides a cost-effective option for rapid debris removal.

Figure 8. Gator Getter

The CDOT conducted field tests (Strong & Vasques, 2014) to evaluate the performance of the Gator Getter. The results of these tests are summarized in **Table 2**. The evaluation of the Gator Getter revealed several important findings. Firstly, it was observed that the Gator Getter performs optimally at higher operating speeds (above 45 mph), indicating that its effectiveness diminishes at lower speeds. This implies that the device may not be suitable for use in urban or congested traffic conditions where higher speeds are not feasible. Additionally, the field tests highlighted potential negative and safety hazards associated with the Gator Getter. Instances were recorded where debris was reflected into oncoming or adjacent traffic, presenting a significant danger to nearby vehicles. This raises concerns about the safety of the device, as it could potentially create more hazards for other vehicles on the road.

Furthermore, the Gator Getter demonstrated a susceptibility to frequent damage, which could result in increased costs. The angled blade used by the device is prone to getting hung up on uneven surfaces, leading to potential damage. The fourth test of the first field test specifically revealed that hard and heavy debris, such as concrete, can cause damage to the blade, strip, drum, and camera components of the system. These findings suggest that while the Gator Getter may have certain advantages in terms of cost and ease of attachment to vehicles, it also presents limitations and potential risks that need to be addressed before considering its widespread adoption.

Table 2. Results of Field Tests of Gator Getter (Strong & Vasques, 2014)

#	Speed	Debris Composition	Outcome
1	45 mph	Large tire tread, 10 gal. bucket, bag of trash, short lumber lengths.	All debris was picked up aside from bucket. Tire peal did not make it to the hopper.
2	45 mph	Lumber, bag of trash, 10-gallon bucket, tire treads.	All pieces picked up.
3	25 mph	Lumber, tire treads, bag of trash, 10-gallon bucket.	Only one piece made it into hopper.
4	75 mph	Two chunks of concrete and a tire tread.	Everything picked up. Lead blade dented, composite strip broke, camera cable broke
5	65 mph	Chain, lumber, tire treads, bag of trash, 10-gallon bucket.	All debris was picked up. Some debris fell back out.
6	45 mph	Lumber, bag of trash, 10-gallon bucket, tire treads	All pieces picked up (aside from light bag).
7	35 mph	Lumber, tire treads, bag of trash, 10-gallon bucket	All pieces picked up. Small tire tread fell out.
8	30 mph	Lumber, tire treads, bag of trash, 10-gallon bucket	Debris held in the bottom of the drum.
9	40 mph	Tire tread and 3 concrete chunks	Tire picked up. Damage to tip lip, one piece of concrete not picked up.

2.4.3 Other Technologies

Another technology that shows potential for road and highway maintenance is the Piranha Magnetic Sweeper (**Figure 9**) (Bluestreak Equipment, 2022). One of its key advantages is its ability to sweep up debris at high speeds. The magnet integrated into the sweeper has the capability to pick up a two-and-a-half-inch nail when positioned ten and a half inches above the ground. The sweeper's height can be adjusted between 2 and 3 inches to accommodate different conditions. Equipped with two rows of 4.5" x 4.5" magnetic housing and three layers of closely packed magnets, the Piranha Magnetic Sweeper delivers enhanced pickup performance. It also features onboard debris bins for convenient cleaning of large areas. The price range for the Piranha Magnetic Sweeper is typically between $9,099.99 and $9,599.99.

Figure 9. Piranha Magnetic Sweeper

In 2004, a tragic incident occurred when Julie Love, an employee of the Missouri Department of Transportation (MoDOT), lost her life while retrieving debris from the roadway. In remembrance of Julie, MoDOT developed Julie's Automated Waste-Removal System (JAWS) (Missouri Department of Transportation, 2018). This equipment enables employees to safely remove roadway debris without exiting the vehicle. The truck is fitted with a joystick-controlled down skid plate and a camera that activates whenever the skid plate is lowered. This setup allows the operator to visually locate and identify debris before effectively scooping it off the road. By employing the JAWS system, MoDOT not only prioritizes the safety of their employees but also streamlines the debris collection operation, as a single responder can operate the equipment.

Figure 10. JAWS [Adopt from (American Association of State Highway and Transportation Officials, 2018)**]**

2.5 Summary and Discussion

2.5.1 Summary

The literature review reveals that, despite the variety of types, roadway debris can generally be classified into two weight classes for removal practices. Lighter debris is typically removed through manual clearance by response personnel, while the removal of heavier debris requires specialized equipment. Furthermore, hazardous debris, such as nails and metal parts like nuts and bolts, can become projectiles upon contact with moving vehicle tires, causing significant damage and injuries. Therefore, immediate actions are necessary to remove them.

While different states may have slightly different procedures for debris removal, most of them have enacted move-over laws and established authority removal laws and "open road" policies to ensure the safety of responders and facilitate the swift removal of debris. At the federal level, debris removal is an integral part of the TIM program. Performance evaluation of TIM can be achieved through various time-based measures such as RCT and ICT. Each state has its own unique protocol for debris removal, but in many cases, personnel need to exit their vehicles to collect and dispose of debris, particularly when dealing with smaller objects. This exposes them to the inherent risks associated with high-speed traffic, making the task significantly hazardous.

Consequently, several state highway agencies have started to implement innovative technologies aimed at streamlining the efficient and prompt removal of roadway debris while enhancing the safety of both responders and road users. A summary of the performance of two major technologies, ARDVAC and Gator Getter, is provided in **Table 3**. However, it is important to note that these technologies have significant limitations that hinder their practical application in daily debris clearance operations.

Table 3. Performance of ARDVAC and Gator Getter

Name	Pros	Cons
ARDVAC	● Suitable for shoulders and medians ● Effective on sand and dirt ● Can clean drain inlet	● Ineffective on larger debris or lighter debris other than sand or dirt ● Long learning process ● Frequent failures ● Continues exposure to traffic ● High cost
Gator Getter	● Operates at high speed ● Low cost	● Less effective at low speed ● Debris can be reflected into traffic ● Threats nearby vehicles ● Frequent damages ● Ineffective on hard and heavy debris

To summarize, the literature review highlights the challenges and complexities associated with roadway debris clearance. State transportation agencies are actively seeking innovative solutions to mitigate risks and improve the efficiency of debris removal processes. The performance evaluations of existing technologies underscore the need for further exploration and development of effective strategies to ensure the safe and effective management of roadway debris.

2.5.2 Discussions

One important conclusion of this literature is that existing technologies for debris removal have significant limitations that hinder their practical application in daily debris clearance operations. However, LaneBlade® shows promise in overcoming these limitations. For example, ARDVAC requires the operators continuously exposing to traffic to monitor the potential impact of the ARDVAC's long tube on power poles. Due to the differences in structure, LaneBlade® is unlikely to impact power poles, which may reduce the dangerous exposure. It also demonstrates potential effectiveness in handling large and heavy debris, where other technologies like ARDVAC and Gator Getter fall short.

While LaneBlade® offers several advantages, it is important to address issues such as durability, potential debris reflection, and operator training, which have been observed in other technologies. These factors will be carefully considered in designing the evaluation.

Chapter 3. Current Operation and Expectations of the New Technology

3.1 Introduction

To assess the potential advantages LaneBlade® can offer to CHART responders, a comprehensive understanding of their current roadway debris clearance practices is needed. As such, the research team discussed with CHART personnel, including two emergency responders, to gain insights into their operational procedures and obtained documentation outlining the Standard Operating Procedure (SOP) for CHART operations. This facilitated the collection of vital information pertaining to their daily operational procedures, key performance metrics utilized for process evaluation, challenges associated with debris clearance, and anticipated benefits from the LaneBlade® system. Furthermore, the research team conducted interviews with the two CHART responders whose vehicles were equipped with LaneBlade® systems, aiming to capture their initial perceptions and expectations regarding the technology.

3.2 Current CHART Operation on Debris Clearance

As the first line of defense in maintaining safe freeway conditions for travelers, CHART responders are tasked with promptly responding to emergency situations and swiftly restoring normalcy to affected travel lanes after traffic incidents. This includes the removal of a wide array of debris types found on travel lanes, spanning from remnants of crashes to debris scattered by storms, as well as miscellaneous items like loose bumpers or discarded trash resulting from other incidents. The presence of debris on highways poses a significant hazard to motorists, often leading to accidents as vehicles maneuver to avoid obstacles or sudden stops.

Regardless of the nature of the debris, the primary objective remains consistent: to expedite its removal and facilitate the resumption of uninterrupted travel along affected roadways. Under no circumstances are CHART personnel permitted to merely report debris and continue patrolling without taking action.

Given the diverse nature of these debris, the removal procedure is adapted to accommodate varying circumstances, taking into account factors such as debris size, roadway characteristics, and incident severity. **Figure 11** illustrates the duties of CHART responders during the debris removal process. Typically, CHART responders are tasked with closing the lane affected by the debris, exiting their vehicles, and manually collecting the debris. Trash and routine debris removed from the travel lanes will be placed well off the travel lanes to be picked up by SHA Maintenance later. This manual approach is standard practice for most scenarios, especially those requiring lane closures. But removing debris from the travel lanes is a potentially dangerous activity and every precaution must be taken.

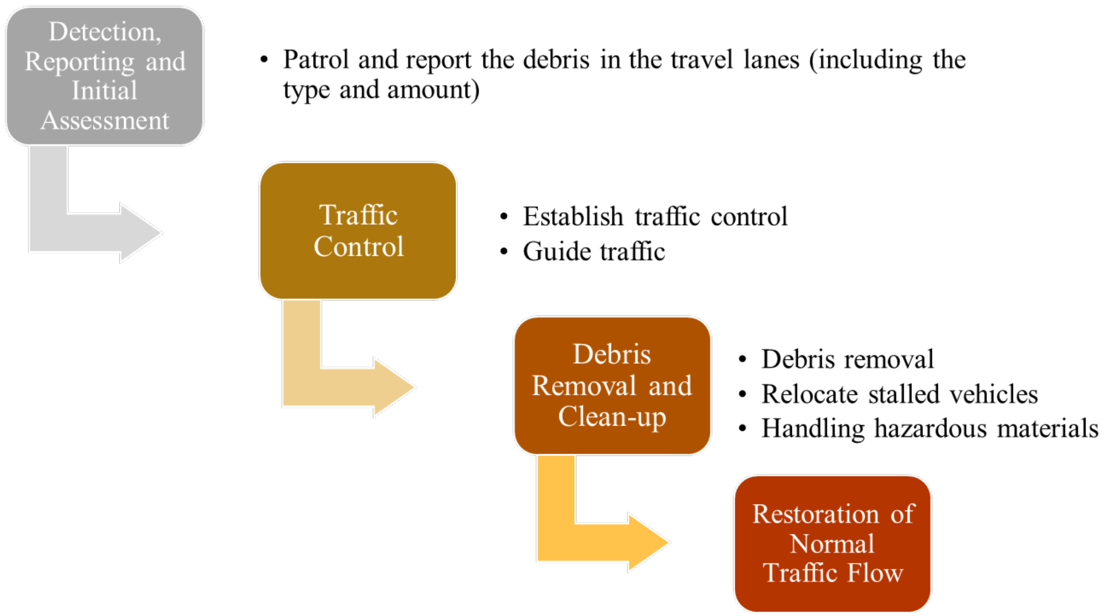

Figure 11. CHART SOP: Duties During Debris Removal Process

When a CHART responder observes objects or debris in the travel lanes during patrol, they promptly notify the Traffic Operations Center/Statewide Operations Center (TOC/SOC) and provide the dispatcher with crucial information, including: (a) the precise location (nearest mile marker, crossroads, or landmarks); (b) which lane(s) are affected, specifying lane numbers; and (c) whether they can remove the debris unassisted or if backup is necessary. If assistance is required, the TOC/SOC coordinates with other CHART Patrol Personnel, law enforcement, and/or SHA Maintenance Personnel for safe debris removal. Meanwhile, the CHART responder sets up traffic control to safeguard the scene until assistance arrives, minimizing potential incidents.

However, the debris removal process may vary depending on specific circumstances encountered. Moreover, on less congested roadways, temporary traffic stops may be instituted to facilitate the safe and efficient removal of debris obstructing a single lane. Valuable items discovered on the freeways are to be surrendered to the supervisor, who will then tag them with the date and location found before turning them over to CHART management. These items are held for 90 days, after which they are disposed of properly if unclaimed. Additionally, the collection of spilled loads necessitates collaboration with the driver. If a spilled load poses a hazard to traffic, the responder will promptly halt and initiate cleanup procedures.

3.3 Expectations and Perceptions of CHART

In anticipation of integrating LaneBlade® technology into the CHART debris clearance process, certain expectations have been outlined. Foremost among these is the goal to optimize debris clearance operations while aligning with the core principles of the CHART framework. LaneBlade® is anticipated to revolutionize debris removal by enabling responders to execute their tasks without necessitating lane closures, thereby minimizing traffic disruption and enhancing overall roadway safety. By allowing CHART responders to remain within the safety of their vehicles, LaneBlade® aims to mitigate the risk of injury and streamline the clearance process, ultimately saving valuable time and resources. Moreover, the technology is expected to demonstrate performance on par with or surpassing the efficiency of existing manual practices, offering a faster and more effective solution for debris removal on roadways.

The interview with CHART responders also provided valuable first impressions of the LaneBlade®'s performance under real-world traffic conditions. Responders encountered a diverse array of debris on highways and roads, ranging from dirt and stones to crashed cars and bikes. Findings indicated that two types of blades used in the LaneBlade® system, namely rubber blade and steel blade (**Figure 12**), exhibited comparable overall performance, albeit with distinct strengths in specific scenarios. For instance, the rubber blade proved more effective in clearing dirt amid rainy conditions, whereas the steel blade demonstrated superior efficacy in scraping off debris, particularly during fire hazard incidents.

Figure 12. Different Types of Blades (Left: Steel; Right: Rubber)

Responders highlighted several positive aspects of the LaneBlade®, such as its smooth and efficient operations, enhanced safety features, and the capability to swiftly clear most debris. Additionally, they found that the LaneBlade® could remove cars and bikes with minimal cosmetic damage, which was a significant benefit. Notably, the LaneBlade® demonstrated rapid operation, typically requiring only 15-20 seconds to clear debris in the majority of cases.

However, responders encountered certain challenges during deployment. Sensor calibration issues were reported, affecting the system's effectiveness. Moreover, in some instances, multiple passes were necessary to fully clear debris, potentially impeding operational efficiency. Nonetheless, these experiences informed the evaluation process, prompting the development of diverse testing scenarios customized to address SHA's unique requirements.

Chapter 4. Field Evaluation

4.1 Introduction

Drawing from insights from both the literature review and SHA's current practices, the LaneBlade® system is expected to not only enhance the safety of CHART responders and road users but also optimize the efficiency of debris clearance operations. While initial feedback from CHART responders offers valuable insights into real-world scenarios, a comprehensive structured field evaluation of its feasibility and effectiveness is needed. This evaluation also includes identifying potential challenges associated with deploying the LaneBlade® system, including considerations of reliability and durability. Carefully designed to incorporate variables such as debris type, weather conditions, and operational speeds, these experiments were conducted in collaboration with CHART and SHA maintenance staff from October 2023 to January 2024.

4.2 Experiment Design and Schedule

Two CHART emergency patrol vehicles, each equipped with a LaneBlade® system – one featuring the steel blade and the other the rubber blade – were utilized in the experiments. The drivers of these vehicles are CHART responder supervisors, each having over twenty years of experience in the field. Throughout the experiments, CHART responders were instructed to clear debris as they would on the highway that they routinely patrol. The debris utilized in the experiments was primarily provided and prepared by SHA maintenance staff and CHART.

Various factors were taken into account during the development of experimental scenarios to ensure a diverse range of debris types and environmental conditions were considered. Given that a comprehensive evaluation across diverse operational conditions is essential for informing guidelines under complex real-world scenarios, which aligns with one of the project objectives, if the LaneBlade® system proves beneficial for CHART operations. Through consultation with the CHART team, several key factors impacting operational conditions were identified, including blade type, debris type, operating speed, weather conditions, and roadway geometry. Blade type was selected based on initial observations by CHART responders, who noted distinct strengths of different blade types in specific scenarios, as discussed in Chapter 3. Debris type was also considered significant, given its potential influence on the system's effectiveness, as highlighted by the responders. Operational speed emerged as another crucial factor, supported by findings from the literature review, as other debris clearance technologies operate optimally at either lower or higher speeds, and the LaneBlade® system may exhibit similar characteristics. Furthermore, adverse weather conditions such as rain and snow can alter the physical properties of debris or impede responders' visibility, posing additional challenges to clearance efforts. Finally, the presence of vertical curves in roadway geometry may present obstacles to debris clearance, necessitating consideration during experimentation.

A structured experimental design was implemented to thoroughly account for these factors. **Table 4** outlines the specific scenarios considered for each factor. It is important to note that certain types of debris may not have been tested under all controlling factors due to constraints such as limited material availability or personnel resources. Additionally, due to scheduling limitations, rainy weather conditions were simulated by manually wetting the debris.

Table 4. Test Scenarios

Factor	Scenario
Blade Type	Steel and rubber.
Debris Type	Dirt, sand, stone, tires, branches, wood pieces, metal pieces, plastic pieces, and crashed vehicles such as motorbikes and cars.
Operational Speed	5mph, 10mph, and higher speeds (e.g., 15/20 mph).
Weather Condition	Sunny, rainy and snowy.
Roadway Geometry	Level grade and downhill.

The experiments were conducted over three days spanning from October 2023 to January 2024. **Table 5** shows the schedule, testing locations, and a brief summary of the experiments conducted. The “Joppa Rd Facility” (333 W Joppa Rd, Timonium, MD 21093) was utilized to simulate two highway sections, each approximately 80 feet in length. Section one is level, allowing for the closure of multiple lanes, while section two features a slight grade, and the closure of close multiple lanes is not allowed. During testing on section two, drivers were instructed to drive downhill. The “Falls Rd Facility” provided water for wetting the debris and simulated a 50-feet roadway section with a slight grade. Drivers navigated downhill to clear small particles and uphill to clear larger debris on this section.

Table 5. Test Schedules

Date	Site	Experiment Summary
10/16/2023	Joppa Rd Facility	Three-hour experiments for sunny weather except crashed vehicles.
11/17/2023	Falls Rd Facility	Three-hour Experiments for rainy weather and heavy debris clearance for sunny weather.

01/19/2024	Joppa Rd Facility	One-hour experiments for snowy weather.

The evaluation experiments were recorded, and the videos will be provided to SHA as references for review.

4.3 Results

The field evaluation experiments comprised a total of sixty-six scenarios. **Table 6** presents the summaries of the experiment results under both sunny and adverse weather conditions. It is crucial to note that throughout the entire field evaluation process, the responders remained in their vehicles. This signifies a significant reduction in responders' exposure to moving traffic, thereby enhancing their safety.

Table 6. Summary of Experiments Results

No.	Weather	Section	Debris	Blade	Speed	Effective
1	Sunny	Downhill	High Volume Sand/Stone	Steel	5 mph	No
2	Sunny	Downhill	High Volume Sand/Stone	Steel	15 mph	Yes
3	Sunny	Downhill	High Volume Sand/Stone	Rubber	5 mph	Yes
4	Sunny	Downhill	High Volume Sand/Stone	Rubber	15 mph	Yes
5	Sunny	Downhill	High Volume Sand/Stone	Rubber	20 mph	No
6	Sunny	Downhill	Low Volume Sand/Stone	Steel	5 mph	Yes
7	Sunny	Downhill	Low Volume Sand/Stone	Steel	10 mph	Yes
8	Sunny	Downhill	Low Volume Sand/Stone	Rubber	5 mph	Yes
9	Sunny	Downhill	Low Volume Sand/Stone	Rubber	10 mph	Yes
10	Sunny	Level	Low Volume Sand/Stone	Steel	5 mph	Yes
11	Sunny	Level	Low Volume Sand/Stone	Steel	10 mph	Yes
12	Sunny	Level	Low Volume Sand/Stone	Rubber	5 mph	Yes
13	Sunny	Level	Low Volume Sand/Stone	Rubber	10 mph	Yes
14	Sunny	Level	Tires and Tire Debris	Steel	5 mph	Yes
15	Sunny	Level	Tires and Tire Debris	Steel	10 mph	No
16	Sunny	Level	Tires and Tire Debris	Rubber	5 mph	Yes
17	Sunny	Level	Tires and Tire Debris	Rubber	10 mph	Yes
18	Sunny	Level	Wood Pieces	Steel	5 mph	Yes
19	Sunny	Level	Wood Pieces	Steel	10 mph	Yes
20	Sunny	Level	Wood Pieces	Rubber	5 mph	Yes
21	Sunny	Level	Wood Pieces	Rubber	10 mph	No
22	Sunny	Level	Small Metal Pieces	Steel	5 mph	Yes
23	Sunny	Level	Small Metal Pieces	Steel	10 mph	Yes
24	Sunny	Level	Small Metal Pieces	Rubber	5 mph	Yes
25	Sunny	Level	Small Metal Pieces	Rubber	10 mph	Yes
26	Sunny	Level	Sign	Steel	5 mph	Yes
27	Sunny	Level	Sign	Steel	10 mph	Yes
28	Sunny	Level	Sign	Rubber	5 mph	No
29	Sunny	Level	Sign	Rubber	10 mph	Yes
30	Sunny	Downhill	Dirt	Steel	5 mph	Yes

No.	Weather	Section	Debris	Blade	Speed	Effective
31	Sunny	Downhill	Dirt	Steel	10 mph	Yes
32	Sunny	Downhill	Dirt	Steel	20 mph	Yes
33	Sunny	Downhill	Dirt	Rubber	5 mph	Yes
34	Sunny	Downhill	Dirt	Rubber	10 mph	Yes
35	Sunny	Downhill	Dirt	Rubber	20 mph	No
36	Sunny	Uphill	Large Metal Pieces	Rubber	5 mph	Yes
37	Sunny	Uphill	Large Metal Pieces	Rubber	10 mph	Yes
38	Sunny	Uphill	Large Metal Pieces	Steel	5 mph	Yes
39	Sunny	Uphill	Large Metal Pieces	Steel	10 mph	Yes
40	Sunny	Uphill	Motorcycle	Rubber	5 mph	Yes
41	Sunny	Uphill	Motorcycle	Rubber	10 mph	Yes
42	Sunny	Uphill	Motorcycle	Steel	5 mph	Yes
43	Sunny	Uphill	Motorcycle	Steel	10 mph	Yes
44	Sunny	Uphill	Passenger Car (front push)	Rubber	5 mph	Yes
45	Sunny	Uphill	Passenger Car (side push)	Rubber	5 mph	Yes
46	Rainy	Downhill	Dirt (Mud)	Rubber	5 mph	No
47	Rainy	Downhill	Dirt (Mud)	Rubber	10 mph	No
48	Rainy	Downhill	Dirt (Mud)	Steel	5 mph	Yes
49	Rainy	Downhill	Dirt (Mud)	Steel	10 mph	Yes
50	Rainy	Downhill	Stone	Rubber	5 mph	No
51	Rainy	Downhill	Stone	Rubber	10 mph	No
52	Rainy	Downhill	Stone	Steel	5 mph	Yes
53	Rainy	Downhill	Stone	Steel	10 mph	Yes
54	Rainy	Downhill	Wood Pieces	Rubber	5 mph	Yes
55	Rainy	Downhill	Wood Pieces	Rubber	10 mph	Yes
56	Rainy	Downhill	Wood Pieces	Steel	5 mph	Yes
57	Rainy	Downhill	Wood Pieces	Steel	10 mph	Yes
58	Snowy	Level	Wood Pieces	Rubber	5 mph	Yes
59	Snowy	Level	Wood Pieces	Rubber	10 mph	Yes
60	Snowy	Level	Wood Pieces	Rubber	15 mph	Yes
61	Snowy	Level	Small Metal Pieces	Rubber	5 mph	Yes
62	Snowy	Level	Small Metal Pieces	Rubber	10 mph	No
63	Snowy	Level	Small Metal Pieces	Rubber	15 mph	Yes
64	Snowy	Level	Plastic bottles	Rubber	5 mph	Yes
65	Snowy	Level	Plastic bottles	Rubber	10 mph	Yes
66	Snowy	Level	Plastic bottles	Rubber	15 mph	Yes

Overall, the LaneBlade® system demonstrates effectiveness in clearing debris across various weather conditions. Particularly noteworthy is its capability to handle snow, as the blade efficiently gathers snow along with debris and pushes it to the shoulder of the roadway, as depicted in, as shown in **Figure 13**. Across the 80-feet long section, smaller debris types, such as solid objects tested in experiments 14 to 39, were typically cleared in a single run, taking only 10 to 20 seconds depending on operational speed. Moreover, the system proves capable of clearing larger debris, such as crashed motorcycles weighing approximately 800 pounds in the deployed position (**Figure 14. Experiment**

No. 40: Clearing A Crashed Motorcycle Figure 14) and passenger cars weighing around 3,000 pounds when pushed from both the front and side in the stowed position (**Figure 14**). However, it is essential to operate the system in a certain manner to maximize effectiveness. In instances like experiments 15, 28, and 62, clearing metal pieces, wood pieces, and tires, respectively, improper pushing angles may cause pipes to roll away, leave behind small wood pieces, or deflect tires, posing hazards to nearby traffic. Additionally, in experiment 15, a small piece of wood was inadvertently crushed during the clearing process, leading to more scattered debris.

Figure 13. Experiment No. 61: Clearing Metal Pieces in Snowy Conditions

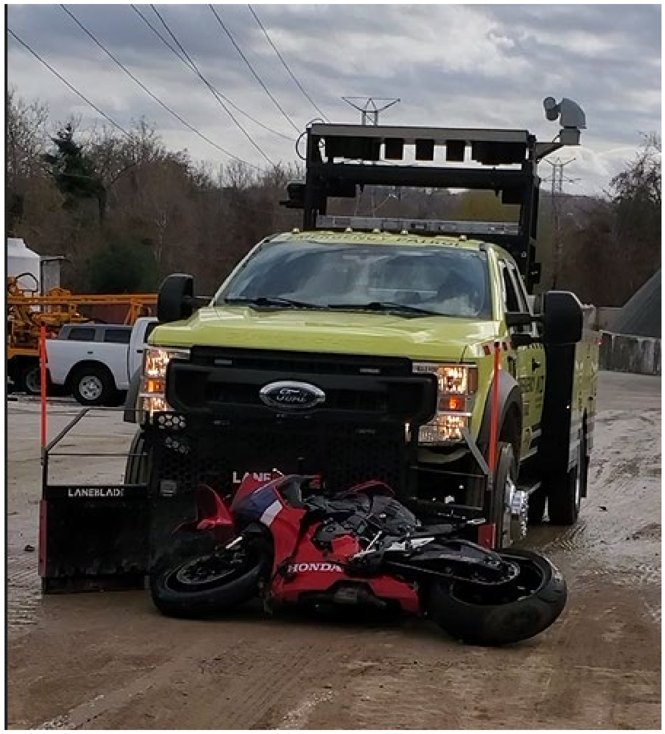

Figure 14. Experiment No. 40: Clearing A Crashed Motorcycle

Figure 15. Experiment No. 44: Clearing A Crashed Passenger Car

While LaneBlade® systems remain effective for clearing smaller and more dispersed debris particles in various scenarios, such as stones, sand, dirt, and mud – commonly associated with spilled loads – the clearance process can present challenges. Clearing spreading particles typically cannot be accomplished in a single run, necessitating lane closures. In cases of high debris volume, particles may accumulate and form bumps, further complicating the clearance process. However, when debris volume is relatively low, a single CHART emergency vehicle can clear them through multiple runs, potentially obviating the need for assistance from SHA maintenance staff and reducing clearance time. It is important to note that at higher vehicle operating speeds, the clearing process may generate flying dust, as depicted in **Figure 16**, diminishing visibility for nearby traffic and posing a potential safety hazard to the public.

Figure 16. Experiment No. 34: Clearing Dirt

When considering blade type, the steel blade consistently demonstrates superior effectiveness and efficiency compared to the rubber counterpart across various parameters. It removes debris more swiftly in nearly all experimental scenarios. Conversely, the rubber blade exhibited limitations, particularly in removing mud (especially in rainy conditions) and stone, likely due to inherent structural properties. Nonetheless, the rubber blade may prove advantageous in specific scenarios where pavement preservation is a priority, such as on bridges, as it inflicts less damage to the pavement.

In summary, the field evaluation underscores the effectiveness and efficiency of the LaneBlade® system in clearing a diverse range of debris on freeways, even under varying environmental conditions. This highlights its potential as a viable solution for enhancing the safety of CHART responders and the traveling public, while also improving traffic efficiency.

4.4 Discussions

Operating at higher speeds can indeed reduce debris clearance time, but it also introduces risks of equipment failures and safety hazards. For instance, during experiments 5 and 35, the rubber blade experienced shaking when the vehicle operated at 20 mph, hindering its effectiveness in clearing sand, stone, and dirt. Additionally, higher speeds can cause larger debris like tires and stones to deflect across lanes, while smaller debris may create flying dust, posing safety risks for nearby traffic. This trade-off between safety and effectiveness suggests that LaneBlade® should ideally be operated at lower speeds, typically ranging from 5 mph to 10 mph, to mitigate these concerns.

While the field evaluation provided valuable insights, it was too short to conclusively determine the reliability and durability of the LaneBlade® system. However, several potential operational issues were noted during the experiments. Firstly, heavy rain and snowfall could obstruct the system's camera lens, affecting visibility. Secondly, a mechanical failure occurred on the first day of the experiment, although it was promptly addressed by the CHART team. Lastly, moderate wear of the rubber blade was observed by the end of the evaluation period. While these incidents may not directly reflect on the system's reliability or durability, long-term observations and monitoring are recommended if the system is to be adopted.

Finally, given the specific operational requirements identified during the evaluation, it is crucial to develop a standardized operating procedure for LaneBlade® operation if SHA decides to integrate this technology. Additionally, comprehensive training should be provided to less experienced CHART responders to ensure safe and efficient use of the system.

Chapter 5. Conclusion and Recommendation

5.1 Conclusion of the Research Findings

The deployment of innovative technologies in roadway maintenance and debris clearance operations holds significant promise for enhancing safety, efficiency, and effectiveness. Throughout this project, the research team has explored the feasibility and potential benefits of integrating the LaneBlade® system into SHA's CHART operations.

Drawing upon insights from the literature review, current practices of SHA, and extensive structured field evaluations under various operational conditions, several key findings have emerged. Overall, the LaneBlade® system demonstrated remarkable effectiveness in clearing various types of debris under diverse environmental conditions, showing its potential to improve responder safety, traffic safety, and traffic efficiency. From stones and sand to crashed vehicles, the system exhibited capability in swiftly removing debris from freeways, thereby contributing to improved safety and traffic operations. Additionally, the system's performance during adverse weather conditions, such as snow and rain, was notable, with the steel blade proving particularly effective in such scenarios. The system is able to expedite clearance of low volume solid objects without necessitating lane closures, significantly reducing the exposure of CHART responders to traffic hazards, thereby improving responders' safety.

However, the field evaluation also identified several operational considerations that warrant attention, such as blade type selection, operating speed, and potential equipment failures. These factors underscore the importance of developing standardized operating procedures and providing comprehensive training for CHART responders. These measures aim to equip responders with the knowledge to safely and efficiently manage debris clearance while addressing the system's use under diverse conditions. Moreover, the evaluation calls for further research to assess the long-term reliability and durability of the LaneBlade® system, suggesting that continuous monitoring and evaluation are crucial for identifying and rectifying any issues that may arise with prolonged use. Implementing a holistic approach that encompasses standardized procedures, in-depth training, ongoing research, and continuous feedback mechanisms will be vital in ensuring the LaneBlade® system remains an effective, safe, and sustainable solution for roadway debris clearance, thereby enhancing both traffic safety and operational efficiency.

5.2 Recommended Guidelines of Using LaneBlade®

The implementation of the LaneBlade® technology for roadway debris clearance necessitates a set of comprehensive guidelines to optimize its usage while ensuring safety and efficiency. These recommendations are designed to maximize the potential of the LaneBlade® system across various operational scenarios:

- **Debris Classification**: It is crucial to categorize debris encountered on roadways based on its type, size, and volume. This classification aids in devising customized clearance strategies that are specific to the nature of the debris. By understanding the characteristics of the debris, responders can select the most appropriate method and tools for its removal, thereby enhancing the efficiency of clearance operations.

- **Blade Selection**: The choice of blade plays a pivotal role in the debris clearing process. While the steel blade is recommended for its superior performance in clearing a wide range of debris types, it's important to consider the use of the rubber blade in certain contexts, such as on bridge surfaces, to prevent damage to the pavement. This dual-blade approach allows for a flexible response to different debris challenges while preserving infrastructure integrity.

- **Operating Speed**: Maintaining an operational speed range between 5 mph to 10 mph strikes a delicate balance between effective debris clearance and the safety of the operating crew and surrounding traffic. Speeds within this range are optimal for ensuring thorough debris removal without compromising the stability of the LaneBlade® system or increasing the risk of accidents due to equipment malfunction or debris deflection.

- **Debris Clearance Process**: Implementing specific operating procedures is essential for managing the removal of larger debris items. These procedures should be designed to prevent debris from deflecting into adjacent lanes, which could pose hazards to nearby traffic. Strategic maneuvering and careful handling of debris can mitigate these risks, ensuring a safer environment for both responders and road users.

- **Adverse Weather Conditions**: The efficiency of the LaneBlade® system can be affected by heavy precipitation, which may obscure the camera lens and reduce visibility. Anticipating and planning for adverse weather conditions is necessary to ensure that the system remains effective. Measures such as regular lens cleaning and the adjustment of operational tactics in response to weather changes are recommended to maintain high levels of performance and safety.

- **Long-Term Monitoring**: To guarantee the long-term reliability and durability of the

LaneBlade® system, establishing a regimen for continuous evaluation and maintenance is imperative. This involves routine checks, performance assessments, and the timely addressing of any wear and tear or operational issues. A proactive approach to monitoring and maintenance will help in identifying potential problems before they escalate, ensuring the system remains a viable and effective tool for debris clearance over time.

- **Training and SOP for Operators**; A brief training for operators will be necessary for proper and safe operation and longevity of the equipment.

By adhering to these guidelines, SHA and other relevant entities can leverage the LaneBlade® technology effectively, enhancing the safety and efficiency of roadway debris clearance operations while minimizing impacts on traffic flow and infrastructure.

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Appendix - LaneBlade® Owner's Manual

A COPY OF THIS SAFETY SHEET SHOULD BE LEFT WITH THE VEHICLE AT ALL TIMES

SAFETY MESSAGES

Do not exceed 20mph with the LaneBlade® deployed.
Do not attempt to push debris weighing more than 150lbs.
Do not attempt to push a vehicle with the LaneBlade deployed.

Read Owner's Manual before operating or servicing LaneBlade®.

Operator must comply with all Federal, State, or any other applicable governing oversight requirements.

Consult your own company's/agency's recommended operation procedures for this device which will take into account your particular operating environment.

Always exercise safe vehicle operating practices and maintain situational awareness when operating the LaneBlade®

Lower the LaneBlade® when vehicle is parked. Keep 8' clear of the LaneBlade® drop zone.

NOTICE The LaneBlade® is not intended to be used as a snowplow or grader moving excess amounts of snow, dirt, or gravel.

Always push debris with the wings in their fully deployed position.

Always power off controller and return it to its cradle after use.

Do not operate the LaneBlade® if the Unstowed indicator is not working.

Ensure camera is showing the correct field of view as described in the owner's manual before attempting to push debris.

Never operate LaneBlade® if the camera system is not working or if the camera is not showing the moldboard.

Avoid any obstructions and uneven pavement while using the LaneBlade®.

Do not use LaneBlade® if the Safe Deployment Speed Control is not working.

The LaneBlade® must be in the stowed position when using the D-ring.

Never exceed the rating of either the D-ring or your tow strap.

Use extreme caution when towing a vehicle.

Tow only on hard surfaces for a short distance and at low speed.

Do not use the D-ring to pull a vehicle out of the mud, sand, or other conditions from which the vehicle cannot be driven out under its own power.

Attach a tow strap to the D-ring only.

Use only a tow strap specifically intended for use in vehicle towing.

Securely fasten the tow strap to the D-ring.

Do not jerk the D-ring. Apply steady and even force.

To avoid damaging the D-ring or the LaneBlade®, do not pull from the side or at a vertical angle. Always pull straight back.

PRE- AND POST-USE INSPECTIONS

Always support the LaneBlade® with appropriate jack stands when performing inspections.

Always park the LaneBlade® vehicle in a safe and level area when performing inspections.

Always be aware of and avoid pinch points when working on the LaneBlade®.

1. Make sure vehicle is in a safe and level location for inspection.
2. Visually inspect the LaneBlade® looking for damaged, bent, loose, missing or broken bolts, pins, and snaps.
3. Visually inspect LaneBlade® components and frame for damage, rust, or broken welds.
4. Visually ensure all the cylinder and wing pivot pins are free from damage.
5. Carefully inspect the LaneBlade® blade. Use the inspection standards in the Owner's Manual to determine if the blade is due for replacement.

6. Run the LaneBlade® through its total movement and look for complete movement or evidence of hydraulic leaks.
7. Visually inspect the moldboard, blade, and face for damaged, frayed, or missing pieces.
8. Visually inspect all wiring harnesses for exposed wires, corrosion, or damaged insulation, including the controller cable and wiring harness.
9. Visually inspect the hydraulic lines, seals, and components.
10. Check the camera for proper operation, clean lense, and acceptable field of view using the standards given in the Owner's Manual.
11. Inspect the hydraulic fluid level following the steps listed in the Owner's Manual. Ensure the hydraulic fluid is at a proper level.
12. As needed, lubricate all moving parts for ease of operation.
13. With the LaneBlade® deployed, verify the Unstowed indicator flashes red.
14. With the LaneBlade® stowed, verify the Unstowed indicator extinguishes.
15. While driving in a safe location over 20mph, attempt to deploy the LaneBlade®. It must not deploy while vehicle is traveling over 20mph.
16. If equipped with the optional D-ring, inspect the D-ring assembly for cracks, damage, or wear that may affect strength and operation.
17. Any deficiencies must be corrected before use.

OPERATION

⚠ **Every agency will have its own process to be followed to provide safety for its unique environment. Always check with your safety department and local authorities for vehicle operation and use of the LaneBlade® in your work zone.**

⚠ **See the Owner's Manual for Deploying and Stowing the LaneBlade® with the Hand-Held Controller**

DEPLOYING THE LANEBLADE® AUTOMATICALLY WITH THE TOUCHSCREEN CONTROLLER

1. Press and release the Sleep Mode button once to awaken the system.

2. Press and release the Deploy button once to deploy the LaneBlade®. The Unstowed indicator will flash red and the LaneBlade® will deploy into its float mode.

STOWING THE LANEBLADE® AUTOMATICALLY WITH THE TOUCHSCREEN CONTROLLER

1. If necessary, press and release the Sleep Mode button to awaken the system.

2. Press and release the Stow button once to stow the LaneBlade®. The system will return to the stowed position and the Unstowed indicator will extinguish.

DEPLOYING THE LANEBLADE® MANUALLY WITH THE TOUCHSCREEN CONTROLLER

1. Press and release the Sleep Mode button once to awaken the system.

2. Press and hold the Wings FWD button. The wings will swing from their stowed position to their deployed position.

3. With the wings deployed, press and hold the Float Down button. The LaneBlade® will lower into its deployed position and the Unstowed indicator will flash red.

STOWING THE LANEBLADE® MANUALLY WITH THE TOUCHSCREEN CONTROLLER

1. If necessary, press and release the Sleep Mode button to awaken the system.

2. Press and release the UP button to raise the LaneBlade® into its stowed position. The Unstowed indicator will extinguish once the LaneBlade® reaches its stowed position.

3. Press and release the Wings Back button once to return the wings to their stowed position.

⚠ **To prevent accidental activation, turn LaneBlade® off when not in use.**

(Scan for latest version)

For parts, service, technical assistance or replacement of Owner's Manual or In-Cab Safety Sheet CONTACT J-TECH AT 610-458-4334.

PN LaneBladeSheet Updated August 17, 2023