MITIGATING STORM DRAINAGE SYSTEM IMPACTS FORM LITTER AND DEBRIS

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16. Abstract

The objective of this research is to analyze current best practices for collecting/removing litter and debris from the highways; and provide recommendations on efficient, more productive and cost-effective ways to keep litter/debris from clogging the urban highway drainage system. Currently, ODOT collects litter from the highways manually. The manual collection process is expensive, and labor intensive. Analysis of data provided by ODOT concluded that at current prices, the cost of collecting a litter bag is $31.38/bag. The research concluded that there are many challenges associated with roadside litter that prevents the use of a single general purpose litter removal machine. The roadside litter collection machines commercially available typically use vacuum action to lift the litter. The research evaluated several types of vacuum based machines and recommends that ODOT further evaluate the tractor-pulled Trilo S8. Although the S8 is not effective in all situations, it was found to be the machine that is more capable of dealing with the challenges associated with roadside litter. However, a conclusive evaluation of the cost effectiveness of the Trilo S8 will require additional research. The research also recommended that ODOT field tests various types of drain inlet screens to assess their performance at different locations in Ohio. Such screens have environmental and economic benefits. The preliminary cost benefit analysis has determined that the payback period of screen installation can be as low as 1.2 years.

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Executive Summary

The objective of this research is to study, document and analyze current best practices for collecting/removing litter and debris from the highways; and provide recommendations on efficient, more productive and cost-effective ways to keep litter/debris from clogging the urban highway drainage system while enhancing safety for both the traveling public and ODOT maintenance forces. Currently, ODOT collect litter from the highways manually. The manual collection process is expensive, and labor intensive. Data provided by ODOT concluded that at current prices, the cost of collecting a litter bag is $31.38/bag. Furthermore, workers collecting litter from the roadsides manually are on foot and exposed to the hazards of high-speed traffic since road shoulders are not usually closed. The proximity to this traffic increases the risk of launched debris or an errant vehicle hitting ODOT workers. The workers are also subject to physical injuries such as those associated with lifting and tripping. ODOT seeks to improve the working conditions of these manual operations through the possible use of automated litter collection machines and/or process improvement. The research has concluded that there are many challenges associated with roadside litter that prevents the use of a single general purpose litter removal machine. These challenges include: (1) the composition of the roadside litter is highly variable, (2) the location of the roadside litter is highly variable; where as some litter tends to collect in "hotspots" against curbs, barriers, fences and other difficult to reach areas, other litter is widely distributed on roadside grass, (3) the roadside terrain is rugged and is not compatible with many existing litter collection machines. The roadside litter collection machines commercially available typically use vacuum action to lift the litter. The research evaluated several types of vacuum based machines and recommends that ODOT further evaluates the tractor-pulled Trilo S8. Although the S8 is not effective in all situations, it was found to be the machine that is more capable of dealing with the challenges associated with roadside litter described above since it can collect different types of litter from both widely distributed areas and hotspots, and it can operate on the rugged roadside terrain. However, a conclusive evaluation of the cost effectiveness of the Trilo S8 will require additional research. The research team also recommends improving the current manual process by letting ODOT workers use small all-terrain utility vehicles (e.g. John Deere Gator) when collecting litter rather than collecting litter on foot. The West Central Region (WCR) of Alabama DOT (ALDOT) adopted this process improvement in 2018 and was able to double the productivity of its roadside trash collection activities.

Currently, ODOT does not use any devices to prevent litter and debris from entering the storm drainage systems. The use of such devices has environmental and economic benefits. The environmental benefits result from the ability of the devices to keep gross pollutants out of bodies of water to stop harm to marine life, wildlife and humans. During the research, 2 inlet screens were installed on a median barrier inlet and on a curb inlet to test the ease of installation. Observations of the installation process confirmed manufacturers' claims that installation is quick and simple. The economic benefits of the inlet screens result from the reduction in required catch basin maintenance. Feedback from inlet screen manufacturers have indicated that a minimum 50% reduction in catch basin maintenance should be expected when the screens are installed. The preliminary cost benefit analysis has determined that the payback period of screen installation depends on the original required catch basin cleaning frequency and can be as low as 1.2 years for screens installed on inlets of catch basins that require cleaning twice per year. However, a conclusive evaluation of the cost effectiveness of the inlet screens will require further research. There are different types of inlet protection devices and each has its advantages, disadvantages and optimal application. It is recommended that in future ODOT research, the various types are field tested to assess their performance and effectiveness in preventing trash from entering the storm drain system at different locations in Ohio. The performance of the devices should be tested at different conditions such as different terrains where the devices will be used, presence of different types of debris and different quantities of debris.

Project Background

The Ohio Department of Transportation (ODOT) county maintenance forces are tasked with collecting/removing litter and debris from the highway berms and medians. While this process is labor and time intensive, it is necessary to keep Ohio's roads safe and clean and to minimize the adverse effects that litter and debris have on roadway storm drainage systems.

Some ODOT counties use state prisoners to remove litter from roadways. Under such programs, state prisoners would collect litter along the side of the road under the watchful eyes of guards. However, these programs are getting expensive since separate police guards have to be employed to guard the prisoners. Furthermore, restrictions that prevent prisoners from working near schools or businesses limit the number of miles of road they could clean.

Other ODOT counties are relying on their workers to remove the litter. Also in this case, ODOT workers manually collect the litter in bags and deposit the bags at the road edge. They will then use a dump truck to collect the bagged litter deposited at the road edge. The manual collection process is very time-consuming and labor intensive. Furthermore, personnel are on foot and exposed to the hazards of traffic since road shoulders are not usually closed. The workers are also subject to physical injuries such as those associated with lifting and tripping. For these reasons, ODOT is seeking safer and more efficient methods for the collection of roadway litter and debris.

Another problem that ODOT is trying to solve is minimizing the entry of roadway litter and debris into highway storm drainage systems in urban areas. If not properly removed, litter and debris will be carried by wind and rain runoff to the storm water drainage structures. In a short amount of time the road litter and debris build up in the storm water drainage structures causing blockage and restricting the flow in the roadway drainage system. A roadway drainage system is an important component of a roadway. Roadway drainage systems are used to remove storm water from the roadway to prevent vehicles from hydroplaning and to eliminate flooding. Roadway drainage systems also extend the service life of the roadway especially in freeze-thaw environment (AASHTO 1996). Water that does not drain away properly due to blockage will soak the base material of the road bed causing pavement breakup, potholes, cracking, shoulder disintegration, base saturation, and eventually total pavement failure. Furthermore, the removal of litter and debris and preventing it from clogging the urban highway drainage systems has aesthetic and water quality benefits, including reducing foul odors, reducing suspended solids, and reducing the load of oxygen-demanding substances that reach receiving waters (EPA 1999).

Currently, ODOT does not use any device to prevent litter and debris from entering the storm drainage systems. As a result, catch basins in urbans areas fill up with trash and debris quickly and if not maintained on a regular basis cause flooding. The predominant equipment used in Ohio for cleaning catch basins is a Vactor-Jet (sewer cleaner). The Vactor-Jet is expensive and in many cases shared between garages which limits its availability. Furthermore, the maintenance of many catch basins (particularly those on interstates) may require lane closures and thus can only be done at night. For these reasons, ODOT would like to evaluate the use of devices that minimize the entry of litter and debris into catch basins.

It is anticipated that the installation of such devices will generate cost savings to ODOT by reducing the required frequency of catch basin cleaning and will reduce pollution of Ohio water bodies. As environmental regulations continue to become more and more stringent, installing those devices will increase ODOT's capacity to meet such regulations.

Research Context

Goals and Objectives of the Project

The objective of this research is to study, document and analyze current best practices for collecting/removing litter and debris from the highways; and provide recommendations on efficient, more productive and cost-effective ways to keep litter/debris from clogging the urban highway drainage system while enhancing safety for both the traveling public and ODOT maintenance forces. The research aims to identify and field-test new technologies and practices that are promising and available for both removing of litter/debris and minimizing litter/debris from entering the storm drainage system.

To achieve these objectives, the following tasks were completed as shown in Figure 1:

(1) Evaluate the current ODOT process for debris/litter removal and minimizing litter/debris from entering the storm drainage system.
(2) Evaluate nationwide best practices for debris/litter removal and minimizing litter/debris from entering the storm drainage system.
(3) Develop matrices of practices used for debris/litter removal and minimizing litter/debris from entering the storm drainage system.
(4) Document and provide alternatives for dealing with additional secondary issues resulting from roadway litter.
(5) Provide an interim report detailing the findings from all the above steps. Recommend solutions for infield testing and analysis.

A detailed explanation of all the research's tasks and subtasks is provided in the Appendix.

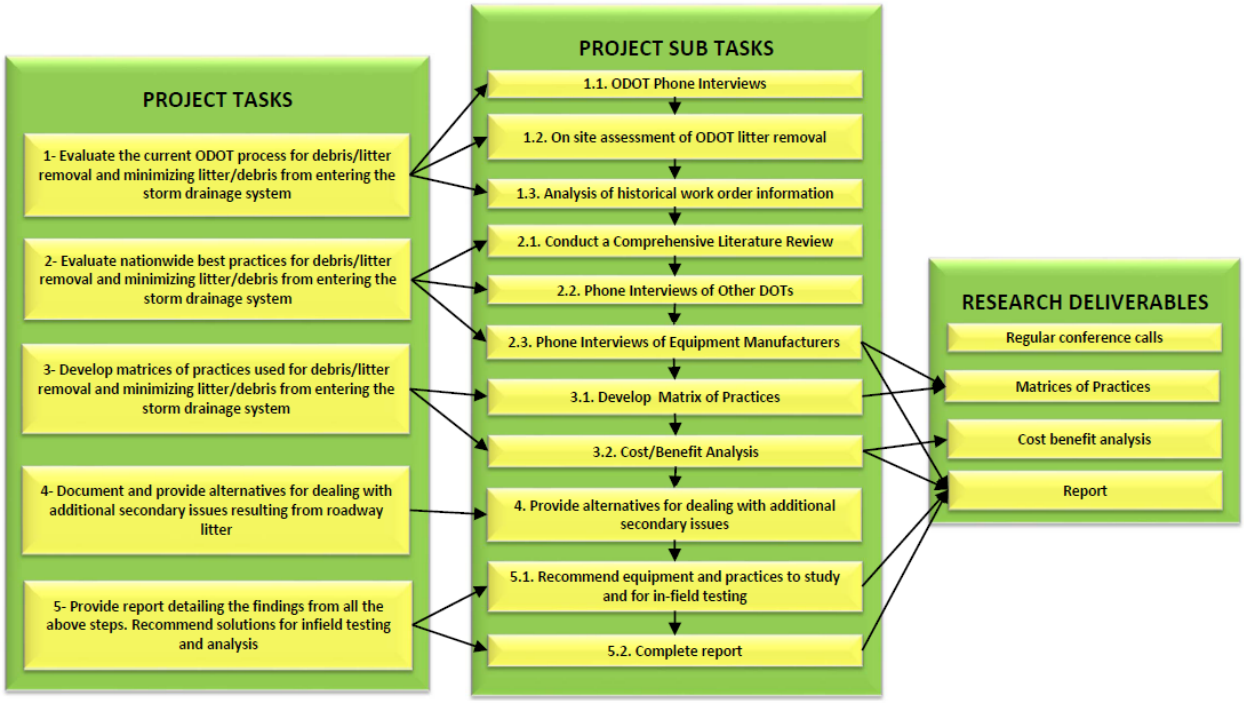

Figure 1. Research Tasks, Subtasks and Deliverables

Summary of Literature Search

The literature review has revealed that many states are spending a significant amount of money on their litter collection programs. Many of these states are still relying on manual collection programs using their own workers, state prisoners, Adopt-A-Highway volunteers and/or contractors. Traditional manual methods for the collection and removal of roadway litter as discussed above, are labor and resource intensive. "New" methods of litter collection and removal are now available that can significantly increase productivity, worker safety, speed, and cost effectiveness of the debris removal operation. Examples of these methods/equipment include the use of debris removing vehicles, compact vacuum cleaners, and raking machines. Several of these equipment are fully operated from the cabin which eliminates exposure of worker to traffic travelling at high speed, increase productivity, reduces required labor resources and allows DOTs work crews more time to devote to their core functions, including road maintenance and construction projects.

The literature review also revealed that to effectively prevent litter from getting into the drainage system it is important to perform the following activities simultaneously:

1. Collecting and removing litter and debris from Ohio roads on a regular basis since capturing the litter early in the process greatly reduces environmental damage.
2. Preventing litter from entering the roadway storm drainage system
3. Cleaning drainage infrastructure in case litter ends up in them

Several devices are currently available to prevent litter from entering the roadway storm drainage systems. These include protection bars, outlet pipe protection screens and hoods, fixed inlet screens, and automatic retractable screens (ARS). ARS prohibit most trash and debris from entering storm drains during the dry season, while opening automatically during specific water flow conditions to prevent street flooding. Municipalities worldwide have learned that until human habits change, these devices must be used in conjunction with a regular roadway debris collection program to keep gross pollutants out of bodies of water to stop harm to marine life, wildlife and ultimately humans (WWI 2010). The literature review identified several benefits of installing such devices including environmental benefits, reduction in required labor resources and cost savings due to decreased frequency of required catch basin cleanings since street sweeping is enough to collect the litter blocked by the devices.

Research Approach

The research team conducted phone interviews with ODOT garage managers. The results of the phone interviews showed that while litter is collected off the pavement manually by hand, street sweepers are used for collecting debris on the pavement. Sweepers can only collect debris less than 6", large debris is collected by ODOT crew manually before using the sweeper. As to practices used to prevent litter/debris from entering the storm drainage system, the phone interviews indicated that no devices are currently used by ODOT with an exception of steel bars being used at curb inlets in Cleveland. The phone interviews also revealed that cleaning of storm water system components such as catch basins and underdrains is expensive but important. Improper maintenance leads to flooding of the roadways.

The research team coordinated with ODOT staff in the Hamilton County Garage (District 8) and the Northwood Outpost (District 2) to conduct 6 site visits as listed in Table 2 in the Appendix. The objective of these site visits is to witness firsthand current ODOT procedures, provide recommendations on how to increase efficiency and decrease labor hours, demonstrate the equipment and devices researched, take measurements of the inlets where devices will be installed and install sample devices to assess the ease of installation. The field site visits have demonstrated that some of the equipment were ineffective

in performing their intended functions while others were promising and should be further evaluated in future research. The field site visits also confirmed the ease of installation of the devices used to prevent litter from entering the catch basins.

The research team also analyzed historical work order information provided by ODOT District 2. The analysis confirmed that the current process of manual collection is labor intensive and expensive. 2019 work order data puts the cost of collecting a single litter bag at $26.62/bag in District 2. Statewide, ODOT calculated the 2-year average cost per bag to be $31.38/bag. The research team conducted an online survey of other DOTs. Details of survey results and follow up phone interviews are included in the Appendix. The survey revealed that manual collection is still the predominant method of collecting litter/debris off the pavement nationwide and that safety of crews from traffic is the biggest safety concern while collecting road litter. Safety concerns increase when hazardous items such hypodermic needles, pipe bombs, urine bottles and guns are found among the debris. Follow up interviews with the survey respondents were conducted to inquire about best practices to deal with above safety concerns. Best practices include providing all workers with gloves, hard hats, eye protection, high visibility garment, puncture resistant gloves, and litter pickers.

All respondents agreed that safety hazards can be reduced through the use of mechanical equipment that decrease the direct involvement of labor with road litter particularly if the equipment can be fully operated from the cabin of the vehicle. Several respondents reported satisfactory experiences with devices used to prevent road litter from entering storm water systems. These devices included inlet screens and Snouts. A Snout is a hood that is placed against the outlet pipe in a catch basin to prevent the debris from entering the outlet pipe.

Manually collecting litter debris off the pavement had negative health impacts on ODOT technicians. In many cases the workers have to travel on rugged steep slopes for long distances to collect the trash. Data provided by ODOT have indicated that such a rugged and harsh work environment has caused several injuries/incidents including tendon rupture, syncope (temporary loss of consciousness caused by a fall in blood pressure), open wounds, scrapes and/or bruises resulting from being hit with flying rocks, injuries to lower back and/or internal derangement of the knee due to falling and rolling down a steep hill. Such accidents result in lost work days, put stresses on ODOT employees and their families, reduce employees' moral and increase ODOT liability.

The research proposes several methods to be field tested in future research that if implemented can increase productivity and worker safety by removing workers from the roadside. These methods include:

- Installation of devices that prevent litter from entering the catch basins. Such devices will reduce the frequency of required catch basin cleaning.
- Use of vacuum machines to collect trash and litter off the road. This will not only remove workers from the treacherous conditions associated with collecting litter but will make them available to complete other necessary operations needed in their garages.
- Use of the automated drop-down skid plate (JAWS) that scoops up large debris on the pavement and move it to the shoulder out of traffic, where it can be handled more safely.

Implementing these proposed strategies can result in additional secondary benefits to ODOT including lower costs and reduced pollution of Ohio water bodies. As environmental regulations continue to become more and more stringent, implementing the strategies above will increase ODOT's capacity to meet such regulations.

Matrices of practices

Three matrices of practices were developed to summarize findings related to the following 3 research areas:

- Devices for preventing litter from entering the roadway storm drainage system
- Equipment for collecting debris off the pavement
- Equipment for collecting large debris on the Pavement

Devices for preventing litter from entering the roadway storm drainage system

As shown in the Matrix of practices (Figure 2), there are several devices that can be used to minimize litter and debris entering the roadway storm drainage system. These can be categorized in two main categories (1) inlet protection and (2) outlet pipe protection. Each of these two types of devices can be used in a standalone configuration or they can both be installed together. Installing them together has a significant environmental benefit as it will significantly reduce the amount of litter traveling via the stormwater conduits and eventually reaching and harming receiving water bodies. However, installing both devices together will increase the amount of maintenance needed and associated resources and costs. In a combined installation, although the inlet screen reduces the amount of debris entering the catch basin, whatever debris does enter is prevented by the connector pipe screen from travelling via the stormwater conduit and thus retained in the catch basin requiring more maintenance. On the other hand, just installing an inlet screen reduces the catch basin's maintenance required provided that an effective sweeping program is used to regularly collect the debris blocked by the inlet screen. There are different inlet protection devices (screens) and each has its advantages, disadvantages and optimal installation as previously discussed and as summarized in Figure 2. It is recommended that in future research, the various types are tested to confirm their applicability at different locations in Ohio.

Equipment for collecting debris off the pavement

As shown in Figure 3, the matrix of practices provides information on manufacturers, model numbers, applicability, size and length of hose, hopper capacity, cost, impact on traffic, advantages and disadvantages of the various researched equipment. The information was collected based on phone interviews, literature reviews and site visit as was previously discussed.

The research has concluded that there are many challenges associated with roadside litter that prevents the use of a single general purpose litter removal machine. These challenges include: (1) the composition of the roadside litter is highly variable, (2) the location of the roadside litter is highly variable; where as some litter tends to collect in "hotspots" against curbs, barriers, fences and other difficult to reach areas, other litter is widely distributed on roadside grass, (3) the roadside terrain is rugged and is not compatible with many existing litter collection machines. The roadside litter collection machines commercially available typically use vacuum action to lift the litter. The research evaluated several types of vacuum based machines and recommends that ODOT further evaluates the tractor-pulled Trilo S8. Although the S8 is not effective in all situations, it was found to be the machine that is more capable of dealing with the challenges associated with roadside litter described above since it can collect different types of litter from both widely distributed areas and hotspots, and it can operate on the rugged roadside terrain. The tractor-pulled S8 has a large hopper capacity (10.5 cy) which reduces the time of driving back and forth from and to an unloading location. Additionally, with the S8, it is possible to easily exchange the work shaft to mow and collect debris in one pass. When only collecting litter an "event cleaning" brush shaft can be used for quick and easy collection. Furthermore, the S8 comes with an optional wander hose that can be controlled from the cabin to collect trash from hard to reach places. However, a conclusive evaluation of the cost effectiveness of the Trilo S8 will require additional research.

Devices for Preventing Litter from Entering the Roadway Storm Drainage System

	Type	Description	Manufacturers	Model		Applicability (where it is installed)	Type of pollutants captured	Ease of Installation	Equipment Cost	Ease of Maintenance	Material used to manufacture	Advantages	Disadvantages
Inlet Protection	Fixed Inlet Screen	Fixed inlet screens are used to prevent the litter from entering the catch basin.	SOP Technologies	Curb Inlet Filter		Drain inlets (median barrier and curb)	larger than 1/2"	5- 10 minutes	$750 for 4"x10' inlet #3, $550 for 4'9"x6" CB#3	Street sweeping is enough to collect the litter blocked by screens	Aluminum and High Density Polyethylene	Patented upward flow allows maximum water flow rate through the screen	Potential for flooding if a regular sweeping program is not performed
	Automatic Retractable Inlet Screen	Automatic retarctable screens are the updated versions of fixed inlet screens. These screens open automatically during storm events to prevent flooding.	Hydra TMDL Systems	Hydra ARS Storm drain gate		Drain inlets (median barrier and curb)	larger than 1/2"	5 to 10 minutes	$600 for 4"x10' inlet #3, $440 for 4'9"x6" CB#3	Street sweeping is enough to collect the litter blocked by screens	Plastic	The screen design is expected to open to curb flow in order to reduce the potential for flooding during wet weather. Lower cost	Due to the absence of locking mechanism, trash enters into catch basin when a street sweeper is used
			United Storm Water Inc.	Wing Gate ARS		Drain inlets (median barrier and curb)	larger than 1/2"	20 minutes	$1000 for 4"x10' inlet #3, $600 for 4'9"x6" CB#3	Street sweeping is enough to collect the litter blocked by screens	Stainless Steel	Can be calibrated to open for different water levels.	Moving parts (i.e. springs may not withstand harsh Ohio environment
	Protection Bars	Protection bars can be used to prevent large debris from entering storm water systems.	Long Beach Iron Works	LB409F and LB409G		Drain inlets (median barrier and curb)	Large debris	10 minutes	$300 for 4"x10' inlet #3, $150 for 4'9"x6" CB#3		Stainless Steel	Can be used at any location	Only prevents large debris from entering the catch basin
Outlet pipe protection	Connector Pipe Screen	Placed against outlet pipe in catch basin to prevent the debris from entering the outlet pipe.	United Storm Water Inc.	Connector Pipe Screen		Inside catch basin over the outlet pipe.	All types of debris larger than 5 mm will be trapped.	25 minutes	$500	A Vac Truck should be used to clean the catch basin.	Stainless Steel	Can be used at catch basins with no sumps	More frequent maintenance
	Snout	Snout is a catch basin hood which is placed against the outlet pipe in a catchbasin to prevent the debris from entering the outlet pipe.	Best Management Products Inc.	Snout		Inside catch basin over the outlet pipe.	Debris, Total Suspended Solids and Hydrocarbons	Within an hour	$ 437.7 for 18" pipe	A Vac Truck should be used to clean the catch basin.	Marine fiberglass	Maintenance of pipes decreases.	Can only be used at catch basin with sumps.

Figure 2. Matrix of practices - Devices for preventing litter from entering the roadway storm drainage system

Debris Collection Equipment - Off Pavement

	Type	Description	Manufacturer	Model	Picture	Hose Diameter	Hose Length	Hose Features	Hopper Capacity	Hopper Features	Engine Power	Applicability	Cost	Impact on Traffic	Advantages	Disadvantages
Traditional Method	Manual Collection	People collect litter into plastic bags on foot	N/A			N/A					N/A	Debris can be collected from all locations where a person can reach	$26/bag	Minimal	No initial investment	Time consuming, expensive and highly dangerous procedure
Researched Methods	All Terrain Compact Vacuum Units	These vehicles can be used on both on and off pavement.	Neptune Wash Solutions	Trash Vac		12"	10'	Controlled from cabin	4 CY	It can be hydraulically raised and tilted to dump load	64 hp	Litter can be collected off the pavement.	$104,000	Minimal	4.5" vertical range. High engine power helps to control on slopes	Need to be tested for suitability for rugged environment
			Madvac	LR50		8"	15'	Controlled from cabin	0.6 CY	Single heavy duty disposable/ Re-usable bag	24.8 hp	Litter can be collected using either suction head or vacuum hose.	$75,000	Minimal	Fully robotic arm and 48" suction head	Small Hopper Capacity. Fragile
	All Terrain Mid Size Vacuum Units	These vehicles can be used on both on and off pavement.	Trilo	S8		9.84" and 13.8"	26.25'	Joystick controlled and can be used on both left and right sides	10.5 CY	Hydraulic back door with conveyer	70-110 hp (required power takeoff from the tractor attached)	Can be used to collect litter off the pavement using both suction hood and vacuum hose.	$93,500	Minimal	Compact in size when compared to other equipment in its class. Availability of wander hose	Requirement of external power source such as tractor.
	Large Vehicles	Can only be used on pavement, but can collect litter adjacent to roadway by an automatic vacuum hose	Pik Rite	Debris Collector Vehicles		18"	10'	Three axis hose boom with joystick control	19 CY	Internal Hydraulic Compactor		Used to collect litter adjacent to the road (Shoulders, berms, medians)	$200K +	Moderate: vehicle operate on pavement at a lower speed than traffic	Availability of safety sensors. Option of roll off units.	Reach is limited. High Cost

Figure 3. Matrix of practices - Debris collection – off pavement

Equipment for collecting large debris on the Pavement

Since street sweepers are not able to collect and remove large debris from the roadway, there is a need to separately collect such large debris before the sweeper is used on a particular segment of the road. The current method of removing large debris from the roadway is manually. This current method has a large impact on traffic. As shown in Figure 4, the matrix of practices provides information on alternate researched methods for collecting large debris ahead of sweeper activities and their advantages and disadvantages. The information was collected based on phone interviews, literature reviews and site visits. Based on the matrix of practices, the site visits and the phone interviews, the research team is recommending that ODOT further tests the JAWS debris collection attachment developed by MoDOT in future research.

Research Findings and Conclusions

Manually collecting litter is expensive and labor intensive. Analysis of data provided by ODOT concluded that at current prices, the cost of collecting a bag of litter is $26.31/bag in District 2. Statewide, ODOT calculated the 2-year average cost per bag to be $31.38/bag. The research has concluded that vacuum cleaners can potentially be used to more efficiently collect debris off the pavement. The use of vacuum cleaners would also increase the safety of the cleaning operation and would free limited labor resources allowing ODOT work crews more time to devote to its core functions, including road maintenance and construction projects. The preliminary cost benefit analysis detailed in the Appendix has calculated the breakeven production rate of the proposed Trilo S8 vacuum cleaner to be 0.86 CY/ hour. In cases when the proposed equipment is more productive than this break even rate, the equipment will generate savings to ODOT. A conclusive evaluation of the cost effectiveness of the Trilo S8 will require additional research.

The use of devices such as inlet screens to minimize litter and debris entering the roadway storm drainage system has environmental and economic benefits. The environmental benefits result from the ability of the devices to keep gross pollutants out of bodies of water to stop harm to marine life, wildlife and humans. The economic benefits result from the reduction in required catch basin maintenance. Feedback from device manufacturers have indicated that a minimum 50% reduction in catch basin maintenance should be expected when the screens are installed. The cost benefit analysis detailed in the Appendix has determined that the payback period of screen installation depends on the original required catch basin cleaning frequency. The required cleaning frequency varies from one catch basin to another and depends primarily on the amount/type of trash, location of catch basin and surface area of watershed drained by the catch basin. Table 1 shows expected payback for catch basins that are typically cleaned every 6 months, 1 year and 2 years before the screen is installed and assuming that the installation of the screen will double the time between required cleaning. As shown in Table 1, installing screens on inlets of “problem” catch basins that require more frequent cleaning has shorter payback periods.

Table 1. Payback periods for installing screen

Original Cleaning Frequency (years)	Estimated Cleaning Frequency with Screen Installed (years)	Annual Savings ($) from reduced cleaning	Pay back period (Years)
0.5	1	$ 905.30	1.2
1	2	$ 452.65	2.4
2	4	$ 226.33	4.8

Large Debris Collection - On Pavement														
	Type	Description		Manufacturer	Model	Hopper Capacity	Hopper Features	Applicability	Safety	Cost	Performance	Impact on Traffic	Advantages	Disadvantages
Traditional Method	Manual Collection	Working crew collects large debris manually in front of sweepers and place it in dump truck		N/A	N/A	N/A	N/A	All the debris that can be picked by an ordinary person can be collected.	High Risk	Labor intesive	Good since all debris can be collected	High since safety vehicles should be used behind the crew collecting litter	No initial investment	Time consuming, expensive and highly dangerous procedure
Researched Methods	Debris Collector Attachment	Used to safely move the large debris present on the road to the shoulder where it can be safely collected		Modot	JAWS	N/A	N/A	Can be used to bring large debris to the shoulder ensuring safety of crew	Safer as person sits in the cabin.	$2900 (Material Cost)	Good according to MoDOT	Moderate since Highway technician doesn't leave cabin	Saves money by reducing the number of workers and increase safety.	None reported by MoDOT
	Raking Machines	These machines are used to collect the large debris which cannot be collected by a sweeper		Barber	Road Rake	4 CY	Can be hydraulically raised and dumped	Before using a sweeper on the road, Road Rake is used to collect the large debris.	Safer as person sits in the cabin.	$81,800	Leaving behind large debris such as tire treads.	Moderate since Highway technician doesn't leave cabin	Saves money by reducing the number of workers and increase safety.	Not effective in removing large debirs

Figure 4. Matrix of practices - Large debris collection equipment – on pavement

Recommendations for Implementation of Research Findings

The research team recommends that ODOT conducts future research to do the following:

1. Test the performance of devices installed to prevent litter from entering the catch basins.
2. Test the use of debris collection equipment and/or improving the current manual process.

Each of the above recommendations are discussed in more detail in the following sections.

Test the performance of devices installed to prevent litter from entering the catch basins.

The research proposed several devices to be installed and tested in future research. Such devices will reduce the frequency of required catch basin cleaning. As previously discussed, there are different types of devices and each has its advantages, disadvantages and optimal application. It is recommended that the various types are field tested to assess their performance and effectiveness in preventing trash from entering the storm drain system at different locations in Ohio. The performance of the devices should be tested at different conditions such as different terrains where the devices will be used, presence of different types of debris and different quantities of debris.

The impact of the following factors on the performance and durability of the installed devices should be identified:

- Weather conditions (dry vs wet) since floatable materials are more likely to be mobilized and transported to the CB during rain events.
- Debris/litter type and its potential to clog the opening of the installed devices.
- Amount of Debris.
- Terrain (flat vs rolling terrain): Steep slopes can interfere with successful operation of some automatic retractable screens resulting in a screen that would remain in a fixed position most of the time.
- Size of watershed area drained by the catch basin where the screen is installed.
- Installation location: previous studies have shown that in some locations, screens are more prone to theft and/or to tampering by individuals determined to pushing trash inside the catch basin.
- Potential to cause flooding.
- Impact on street sweeping activities: Previous studies have shown that the placement of the catch basin curb opening screen cover (flush with the curb or recessed) may affect the sweeper's ability to collect trash and debris that accumulated directly in front of the screen. Some automatic retractable screen covers have a locking mechanism that prevent the screen from being pushed in by the operation of the sweeper and will only retract during the presence of storm water flow.
- Impact on snow plowing activities.

To determine the impact of the above factors on the performance of the screens, field observations should be performed during dry weather, after major storms and during sweeping operations. The scope and duration of the research should be long enough to allow for a range of field observations during various rain events to comprehensively verify the performance of the installed devices.

It is anticipated that the installation of such devices will generate cost savings to ODOT by reducing the required frequency of catch basin cleaning and will reduce pollution of Ohio water bodies. As environmental regulations continue to become more and more stringent, installing those devices will increase ODOT's capacity to meet such regulations.

Test the use of debris collection equipment and/or improving the current manual process

The research proposed the tractor-pulled Trilo S8 for further testing to determine its cost effectiveness. Several productivity studies should be conducted to determine the production rate of the Trilo S8 under different project conditions. The impact of the following factors on the production rate should be identified:

- Weather conditions (dry vs wet).
- Debris/litter type.
- Amount of Debris.
- Terrain (flat vs rolling terrain).
- Size of area to be cleaned.

The research team also recommends improving the current manual process of collecting litter off the pavement. The current manual process had negative health impacts on ODOT workers. In many cases the technicians have to travel on rugged steep slopes for long distances to collect the trash. The workers are also subjected to physical injuries such as those associated with lifting and tripping.

Based on discussion with the technical liaison team, the current strenuous manual process can be potentially improved by letting ODOT workers use small all-terrain utility vehicle (e.g. John Deere Gator or similar vehicles) when collecting litter rather than collecting litter on foot. It is anticipated that with this method, ODOT can remove litter from longer stretches of the road in a shorter time. There are different types of small all-terrain vehicles (ATVs) with different power capacities that are suitable for different terrains and these have to be further researched to determine the most applicable model. The West Central Region (WCR) of Alabama DOT (ALDOT) adopted this process improvement in 2018 and was able to double the productivity of its roadside trash collection activities. Below is the information received through a phone interview with WCR.

- WCR employs a 5-person full-time crew for trash collection. Each person has an ATV for a total of 5 vehicles.
- During the 12 months in which WCR implemented the process improvement (10/2018 to 10/2019), the 5-man crew collected 113 tons of trash.
- Before the use of the ATVs, the same crew collected 60 tons of trash/year. In other words, the productivity almost doubled.
- The crew uses litter pickers to collect the trash and place it in a trash can attached to the ATV.
- The process improvement has first been piloted only in Tuscaloosa since it experiences a large amount of trash compared to other areas in Alabama
- After the success of the process improvement, other ALDOT districts are planning to implement it

APPENDIX

The Appendix contains detailed explanation of all the research's tasks and subtasks as shown in Figure 1.

1- Evaluate the current ODOT process for debris/litter removal and minimizing litter/debris from entering the storm drainage system.

1.1 ODOT Phone Interviews

The research team conducted phone interviews with ODOT garage managers. The interviews collected several categories of data that focus on the following:

- Existing debris/litter removal methods including equipment and technologies used and their effectiveness.
- Existing products used to minimize litter/debris from entering the storm drainage system and their effectiveness.
- Existing equipment/methods used to clean debris from drainage infrastructure and their effectiveness.
- Impact of different procedures on safety, productivity, and traffic
- Durability of equipment used
- How are debris removal activities typically initiated?
- Process of selecting areas for debris removal
- Frequencies of debris removal
- Best practices for debris/litter removal and minimizing litter/debris from entering the storm drainage system
- Additional issues caused by debris and litter on the highway and alternative ways ODOT can proactively address those issues.

The sections below highlight information obtained from the phone interviews

<u>George Holloway, County Manager, Cuyahoga</u>

- Large litter is picked manually.
- Mobile sweeper units are used to clean paved streets.
- Cuyahoga County has 3 sweeper units.
- Sweeping is carried out daily. Areas with large shoulders are cleaned during day and nighttime. Whereas, small shoulders are cleaned during nighttime.
- Large debris is picked up by crews. Paper and blown trash are picked by volunteers as part of various litter programs.
- Road rake was used for certain period. But the results are unsatisfactory.
- Litter crews are sent to site every day to clean the debris. In cases of emergencies when traffic is blocked, litter crews are sent immediately.
- Complaints about litter are common during winter season.
- The main concern about debris is it blocks the catch basins.
- They had few incidents of collision of vehicles while collecting litter on roads. To prevent this warning vehicles and signs are used.
- Catch basins are inspected once a year. They had problems with catch basins nearer to construction sites as the construction debris blocks the catch basin.

Ron Sharpe, Youngstown

- Existing debris removal method includes contract with sheriff.
- All interstates debris cleaning activities are performed in coordination with sheriff.
- 4 to 5 people working for 6 to 7 hours, collects on an average 60 to 100 bags.
- Steel protection bars are used on curb inlets in larger cities such as Cleveland.
- Trailer mounted pressure washer is used to clean underdrain (4" to 6" width). For large underdrains a Jet Vac is used. Big machines may be too strong for the underdrains and small machines fills up too fast, waste should be dumped for continuous use.
- A Jet Vac should be replaced every 4 to 5 years.
- 10 to 12 catch basins can be cleaned in a day if they are not so dirty. The cleaning rate depends on size of the system and the condition of the system.
- MOT (Maintenance of Traffic) is required during catch basin cleaning operation as machine sits on the road.
- Sweeper is rented once or twice in a year. The maintenance costs of sweeper are very high. The rent of a sweeper per month varies between $12000 to $15000. Sweepers are rented for 2 weeks and is used round the clock. A sweeper covers 7 to 10 miles a day. Sweepers have a broom which kicks the debris to the center.
- Interstates are the hardest to clean.
- Anything larger than pop cans are collected by hand.
- Sweeping is done at median walls, curb and gutters (80 miles) and bridges. Median walls take 4 days (15 to 18 miles). You can't blow the debris as it is considered hazardous waste by EPA.
- Median walls have small holes in the bottom which are harder to clean.
- Some median walls are very old and should be reconstructed.
- The major amount of trash is due to garbage trucks carrying garbage to landfills. There is a landfill in the county. Law enforcement not really keen on pulling them out all the time for unsecure loads.

Dan Wise

- Skid loader in front of sweeper is used to collect large stuff.
- Sweeper is very slow (1-2miles/hour).
- A study was carried on high speed street sweeping, but the results are not effective.
- Not worried about pop cans or anything less than 6" x 6". Catch basin clogging and flooding usually occurs because of larger debris such as wheel covers and hubcaps.

Analysis of Interview Results

The results of the phone interviews showed that while litter is collected off the pavement manually by hand, street sweepers are used for collecting debris on the pavement. Sweepers can only collect debris less than 6", large debris is collected by ODOT crew manually before using the sweeper.

As to practices used to prevent litter/debris from entering the storm drainage system, the phone interviews indicated that no devices are currently used by ODOT with an exception of steel bars being used at curb inlets in Cleveland.

The phone interviews also revealed that cleaning of storm water system components such as catch basins and underdrains is expensive but important. Improper maintenance leads to flooding of the roadways.

1.2 On site assessment of ODOT debris/litter removal operations

The research team coordinated with ODOT staff in the Hamilton County Garage (District 8) and the Northwood Outpost (District 2) to conduct 5 site visits as listed in Table 2. The objective of these site visits is to witness firsthand current ODOT procedures and to provide recommendations on how to increase efficiency and decrease labor hours, demonstrate the equipment and devices and to take measurements of the inlets where devices will be installed.

Table 2. Summary of Site Visits and Demonstrations

Date	District	County	Description
08/21/2019	8	Hamilton	• Tour of several ODOT installations of median barrier inlets and curb inlets
09/16/2019	2	Lucas	• Evaluate the use of Barber Road Rake and Madvac LP61G
10/10/2019	8	Hamilton	• Measurements of a median barrier inlet and a curb inlet are taken to send them to device manufacturers
10/30/2019	2	Lucas	• Evaluate the use of Trilo S3
11/08/2019	8	Hamilton	• Presentation on United Storm Water's "Wing Gate" screen and site visit to take measurements of inlets.
12/02/2019	8	Hamilton	• Installation of SOP technologies filters on a median barrier inlet and a curb inlet

The following sections summarize the findings from the site visits

Demo of a Barber Road Rake

A Barber Road Rake as shown in Figure 5, is a piece of equipment which can be used to clear roadway debris. This equipment is intended to ensure the safety of the ODOT crew as it is attached to a pickup truck and doesn't require ODOT crew to manually collect large pieces of trash in hazardous conditions. The rake collects the debris on a conveyor which dumps it to the hopper of the equipment. When full, the hopper can be hydraulically lifted and dumped into a dump truck. The gutter brushes located on both sides of the equipment pulls debris to the center of the machine. Field observations of the rake indicated that the rake was successful in collecting medium size debris but was unable to effectively collect larger debris. In many cases, the ODOT technicians had to go out of their truck in order to manually put large debris in the rake's hopper which puts the technician in harm's way.

Figure 5. Barber Road Rake

Demo of a Madvac LP61G

A Madvac LP61G, as shown in Figure 6 is a portable vacuum litter collector which can be towed using any towing vehicle. It is powered by a Honda engine and has an 8-inch diameter hose. The litter is collected into a reusable collector bag that has a capacity of 80 gallons. Field observations of the Madvac indicated that its performance was unsatisfactory. Its disposable litter collection bag got filled up very quickly not only with trash but with grass as well. Once filled up, the litter bag was heavy and difficult to handle manually to put on the bed of a dump truck. When the suction power of the Madvac was decreased, less grass was collected. ODOT technicians who were trying the Madvac noted that it requires a considerable amount of manual effort to move the hose around.

Figure 6. Madvac LP61G

Demo of the Trilo S3 Vacuum Sweeper

Trilo is a company based in the Netherlands that produces several types of vacuum sweepers for different applications. These sweepers are a popular choice for collecting roadway debris in Europe. The demoed Trilo S3 Vacuum Sweeper as shown in Figure 7 has a hopper capacity of over 100 cubic feet and has large air filled tires to allow for effective operation in cases of low soil pressure. The S3 is driven by a PTO drive shaft attached to a tractor and requires an output of 70 – 110 hp. (Trilo 2019). The demoed Trilo S3 had an optional wander hose that has a reach of nearly 20 feet and is equipped with a sturdy end pipe with handgrip. Although the testing day was rainy and some of the debris was suppressed into the soil due to the wet conditions, ODOT personnel were satisfied with the equipment but decided that a Trilo S8 will be more suitable and recommended that a cost benefit analysis of the S8 be performed to determine its feasibility for testing in future research.

Figure 7. Trilo S3

Demo of United Storm Water Automatic Retractable Screens

United Storm Water Inc. demoed the Wing gate inlet screen shown in Figure 8. The Wing-Gate™ is an automatic retractable screen (ARS) that prohibits most trash and debris from entering storm drains during the dry season, while opening automatically during specific water flow conditions to prevent street flooding. The device's screened gate remains in a closed position during the dry season or low water flow, and the retained pollutants can be removed using routine street sweeping.

During periods of increased or heavy water flow, the Wing-Gate™ screen will open with the pressure of water on the screen face, allowing water to flow into the catch basin. The device is capable of opening for a calibrated amount of water flow. As a storm subsides the spring-activated screen gate will automatically return to the closed position.

The Wing-Gate is fabricated from perforated S-304 stainless steel with 3/4 inch diameter holes. It is custom-made and calibrated for each individual catch basin. It can be calibrated to open when subjected to water flow levels of approximately 1 inches to 4 inches. It can be manually pinned in the open position as needed during catch basin cleaning or extreme storm conditions. Gates with double or single wings can be installed in series based on catch basin length and flows to the site (United Storm Water 2019). The county of Los Angeles has over 10,000 installations of these devices.

Figure 8. United Stormwater Automatic Retractable Screen

Installation of SOP technologies filters

The main objective from installing the screens manufactured by SOP Technologies is to assess the ease of installation and determine installation time. The installation time is needed to perform the cost benefit analysis as further discussed in a following section.

Two screens were installed. The first screen as shown in Figure 9 was installed on a median barrier inlet located at mile marker 49, on I-275 West bound. The installation time took 25 minutes including un-packaging. Feedback from ODOT personnel indicated that the installation time will be significantly reduced with experience.

Figure 9. Installed screen on a median barrier inlet

Although ODOT personnel overall were satisfied with the product, they the following suggestions for improvement:

- The bottom mounted brackets might get uplifted during snow plowing. An alternative to this problem is that the brackets can be mounted to the top of the barrier.
- The height of the screen should be increased to reduce the gap currently present between the top of the screen and the median barrier wall.
- It is better that the entire screen be made of Aluminum to increase the strength and reduce the likelihood that the screens break hit by a hard object (e.g. hubcaps).
- It is suggested that the bottom-mount brackets be shortened. During this installation, the extra lengths of the brackets were cut to protect the screens during snow plowing.

The second screen as shown in Figure 10 was installed in Colerain Ave in front of (O' Reilly Auto Parts). Installation took only 5 minutes and the screen fit nicely to the opening with a ½" gap on the sides.

Figure 10. Installed screen on a curb inlet

1.3 Analysis of historical work order information.

ODOT District 2 collects its litter internally using its own crews. It has provided cost information for collecting litter. In 2018 District 2 spent around $315,000 on collecting litters. The majority of this cost ($242 K) is labor cost since litter is manually collected. The litter collecting crew consists of 4 persons and a 1 ton dump truck that is used to transport the ODOT crew to the site and haul away the collected litter from the site.

The Northwood Garage also provided the unit cost for collecting a single litter bag which currently is $26.62/bag. Statewide, ODOT calculated the 2-year average cost per bag to be $31.38/bag. The information provided by District 2 were used to conduct the cost benefit analysis of the proposed equipment as discussed later in the report.

2- Evaluate nationwide best practices for debris/litter removal and minimizing litter/debris from entering the storm drainage system

2.1 Conduct a Comprehensive Literature Review

Cost of collection and removal of roadway litter

The literature review has revealed that many states are spending a significant amount of money on their litter collection programs. For example, the California Department of Transportation spends more than 50 million dollars every year cleaning up litter along California's roads and highways (AHMCT 2007). The North Carolina Department of Transportation spent nearly $19 million annually to pick up roadway litter along North Carolina's roads and highways (News Observer 2018). Research is needed to identify more cost effective alternative to current collection methods to reduce burden on State DOT's limited financial resources.

Approaches to reduce litter impact on roadway drainage systems

To effectively prevent litter from getting into the drainage system it is important to perform the following activities simultaneously:

1. Collecting and removing litter and debris from Ohio roads on a regular basis since capturing the litter early in the process greatly reduces environmental damage.
2. Preventing litter from entering the roadway storm drainage system
3. Cleaning drainage infrastructure in case litter ends up in them

Methods for collecting and removing roadway litter

<u>Manual collection by ODOT crews</u>

In many instances roadway litter is collected and removed using manual labor. This is usually done just before the grass along the road is mowed. As shown in Figure 11, litter collection crews collect the litter in bags using trash grabbers and deposit the bags at the road edge. ODOT technicians will then use a dump truck to collect the bagged litter deposited at the road edge. The truck pulls over next to the bags and a worker exits the vehicle to throw the bags into the back of the truck. The manual collection process is very time-consuming and labor intensive. Furthermore, personnel are on foot and exposed to the hazards of traffic since road shoulders are not usually closed. The workers are also subject to physical injuries such as those associated with lifting and tripping (AHMCT 2011).

Figure 11. Manual collection of trash

Adopt-A-Highway Program

The public distress over roadside litter prompted ODOT to begin its "Adopt-a-Highway" program to enlist volunteers in the cleanup in 1989. Since 1989, thousands of volunteers have joined the program to help keep Ohio's roadways clean. As part of the program, a group of volunteers commits to cleaning up a two-mile stretch of highway, at least four times a year (ODOT 2019). ODOT places green signs on the section of highway that has been "adopted". These signs are inscribed with the adopting group's name and placed at each end of their two-mile section. Each group that adopts a highway saves ODOT approximately $800 in litter pick up costs per year. The program also allows ODOT work crews more time to devote to its core functions, including road maintenance and construction projects (ODOT 2019).

State Prisoners

Many states have implemented large programs that used state prisoners to remove litter from roadways. These programs are sometimes very expensive. For example, in 2010, NCDOT paid the state Department of Correction $11.3 million a year to clean up a total of 80,000 miles of road (News Observer 2018). Under such programs, state prisoners would collect litter along the side of the road under the watchful eyes of guards. Recently however some states have found that prison closings and restrictions that kept prisoners from working near schools or businesses helped eat away at the number of miles of road they could clean. Because of this, some states have recently decided to stop the state prisoners program for litter cleanup which put more burden on the state DOT's work crews.

Contractors

States that are eliminating their prisoners' program are hiring more and more contractors to pick up litter. These states are finding that even paying prisoners $1 a day, contractors are more cost-effective in part because they don't have to remain clustered within sight of prison guards and are thus able to clean up more trash (News Observer 2018).

New methods for the collection and removal of roadway litter

Traditional manual methods for the collection and removal of roadway litter as discussed above, are labor and resource intensive. "New" methods of litter collection and removal are now available that can significantly increase productivity, worker safety, speed, and cost effectiveness of the debris removal operation. Examples of these methods are discussed in the following subsections.

Debris Removing Vehicles

A debris removing vehicle (DRV) such as the Xtreme Vac shown in Figure 12, is a truck mounted debris collector that utilizes an automated arm vacuum to remove the debris. The Xtreme Vac only requires one operator who control the automated arm with a joystick safely and comfortably from within the cab.

Figure 12. Extreme VAC (Xtremevac 2019)

Another example of a DRV is the ARDVAC machine shown in Figure 13. The ARDVAC is designed to operate in median divider areas, roadway shoulders, around guardrails, and on some embankments adjacent to roadways. It is capable of sucking denser trash such as glass bottles, sections of rubber tires, surface soil and loose vegetation as well as removing light debris such as aluminum cans, paper, cups fast food packaging (AHMCT 2007). The machine is also controlled from within the safety of the vehicle's cab.

Figure 13. ARDVAC (AHMCT 2007)

Compact vacuum cleaners

Compact vacuum cleaners such as those shown in Figure 14 are easy to use and control and have small width that allows them to clean any pavement or narrow passage. The suction speed of the vacuum can be easily controlled to enable the collection of all types of waste without pulling in soil or surrounding gravel. They can also be safely used for cleaning areas with high pedestrian traffic such as sidewalks, walkways, plazas, public markets, and alleyways.

Figure 14. Compact vacuum cleaners

Carry on vacuum cleaners

A carry on vacuum cleaner such as that shown in Figure 15, can pick small pieces of plastic, cigarette butts and other small garbage out of the sides of the roads. Although they do not increase productivity and worker safety as much as DRVs and/or compact vacuum cleaners, they are cheap to purchase, maintain and operate and they can be easily and readily implemented to improve the current manual trash collection process particularly in areas where a large percentage of the trash is comprised of cigarette butts such as in urban interchanges.

Figure 15. Carry on vacuum cleaner

Raking machines

Raking machines such as those shown in Figures 16 and 17, can be used for the safe and efficient removal of roadway debris. Different models are available for different ground surfaces. The Litter Picker as shown in Figure 16, can be used to remove debris from grass, and dirt surfaces. The Road Rake as shown in Figure 17**,** combines the raking technology of the litter picker with rotating brushes to remove large debris from the sides of roads, highway medians, shoulders, parking lots, and other paved surfaces that are too large and potentially damaging for street sweepers (Barber 2019).

Figure 16. Litter picker (Barber 2019)

Figure 17. Road rake (Barber 2019)

Bulky debris removal

A grapple truck is a truck as shown in Figure 18, that has a grapple loader mounted to its frame and has a dump body. It can be used to safely and efficiently remove bulky waste. The grapple truck can be operated by a single operator who can load, haul, and dump the bulky debris.

Figure 18. Grapple-truck

Prevent litter from entering the road way storm drainage systems

Among the products being used today to prevent litter from entering the roadway storm drainage systems are inlet screens, protection bars, and snouts. Municipalities worldwide have learned that until human habits change, these devices must be used in conjunction with a regular roadway debris collection program to keep gross pollutants out of bodies of water to stop harm to marine life, wildlife and ultimately humans (WWI 2010).

Inlet screens

A curb inlet screen as shown in Figure 19, prevents debris and litter from entering roadway stormwater systems' inlets. Inlet screens should have flat mounting brackets to make them tire-safe and compatible

with street sweeping operations. Inlet screens are easy to remove and are available in different sizes to retrofit existing curbs.

Figure 19. Inlet screen

Snout

The “Snout”, as shown in Figure 20 consists of a vented hood that traps pollutants such as floatables, trash and sediments.

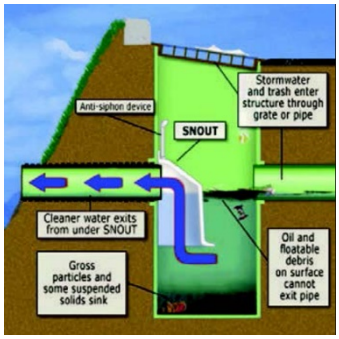

Figure 20. The Snout: a catch basin hood (BMP 2019)

Protection Bars

Protection bars as shown in Figure 21, are devices used to prevent large debris from entering catch basins. These can be installed at both median barrier inlets and curb inlets. Protection bars can be used along with screens to protect the screens from theft and vandalism. The other main purpose of protection bars is to prevent large debris to get in contact with the screens to prevent further blockage of inlets with large debris.

Figure 21. Protection Bars

2.2 Survey of Other DOTs

A survey was created and sent to members of other DOTs. The survey form consisted of the following questions:

1. What equipment is used for the collection of litter on the pavement?
2. How often are paved street swept?
3. What method/equipment is used for the collection of litter off the pavement (on the berm, shoulder of the road, grass, etc)?
4. How are the litter removal activities initiated?
5. What are the biggest safety concerns while collecting road litter?
6. What products have been used to prevent road litter from entering the storm water system?
7. How satisfied are they with the products used to prevent litter from entering the storm water system and the advantages and limitations of these products?
8. Are there any best practices for debris/litter removal and minimizing litter/debris from entering the storm drainage system?

8 responses were received. The details of the respondents are shown in the table below:

Name	Title	Organization
Sandi Sauter	Deputy Director, Operations	Maryland Department of Transportation's State Highway Administration
Theresa Drum	Safety and Training Liaison	California Department of Transportation (Caltrans)
William	District Maintenance Engineer	VDOT
Andrew Morse	Statewide Litter Coordinator	Caltrans Division of Maintenance
Tim Jones	Roadside Operations Specialist	Michigan Department of Transportation
Scott Malone	operations engineer	Idaho transportation dept.
Dewayne E. Jones	Superintendent	MnDOT
Jeff Wilson	Superintendent of Neighborhood Operations	City of Cincinnati, Department of Public Services

The results the survey are discussed below:

Equipment used for collecting road litter (on the pavement)

As shown in Figure 22:

- 4 out of 8 respondents stated the use of vacuum street sweeper.
- 5 out of 8 respondents stated the use of mechanical street sweeper.
- 2 out of 8 respondents stated the use of manual collection.

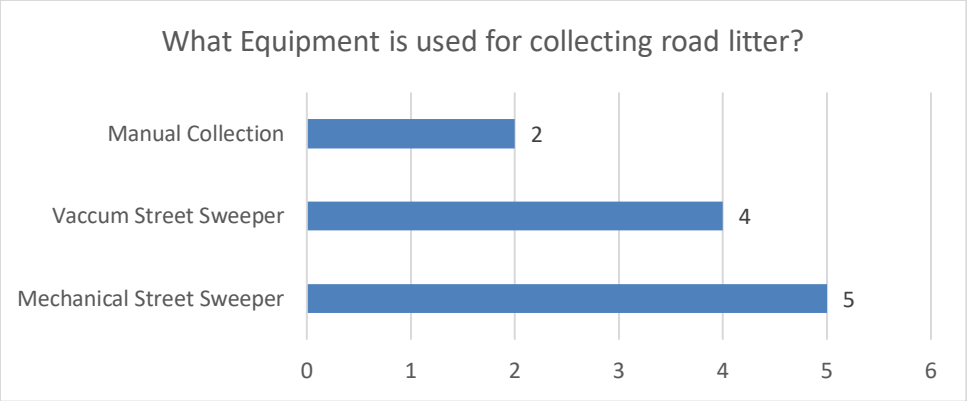

Figure 22. Survey response: equipment used for collecting litter on the pavement

All 8 respondents stated safety of labor from traffic as a concern while collecting road litter.

Frequency of sweeping the paved streets

The frequency of sweeping the paved streets varies considerably from once a week to once a year. The main factors which affect the frequency is the type of area to be swept and the budget available.

- The Maryland Department of Transportation sweeps pre-identified routes every two weeks to reduce the sediment load to the Chesapeake Bay. In most areas across the state, roadways are swept approximately 6 times per year. They deploy state-owned or contract sweepers on an as-needed basis.
- 1 respondent from California Department of Transportation stated that paved streets are swept once a week. The other respondent from California Department of Transportation stated that the frequency depends upon other assignments.
- The Virginia Department of Transportation stated that the frequency depends on budget and area to be swept. Some areas are swept monthly and some annually.
- The Michigan Department of Transportation stated that the frequency varies from none to two per year depending on the region of the state.
- The Idaho Transportation Department stated that streets are usually swept annually and typically for sand accumulation and rarely for litter.
- The Minnesota Department of Transportation stated that paved streets are swept once in fall and once in spring, and occasionally once during the summer.
- The City of Cincinnati stated that paved streets are swept once a month.

Collection of litter off the pavement
As shown in Figure 23:

- 8 out of 8 respondents stated that manual collection is used to collect litter off the pavement. Only 1 respondent from California Department of Transportation indicated the use of road rake for collecting litter off the pavement.
- In Michigan, off-the pavement litter removal is performed as part of the mowing contract in some areas.
- The Idaho DOT mostly relies on the Adopt-A-Highway program for litter removal activities.

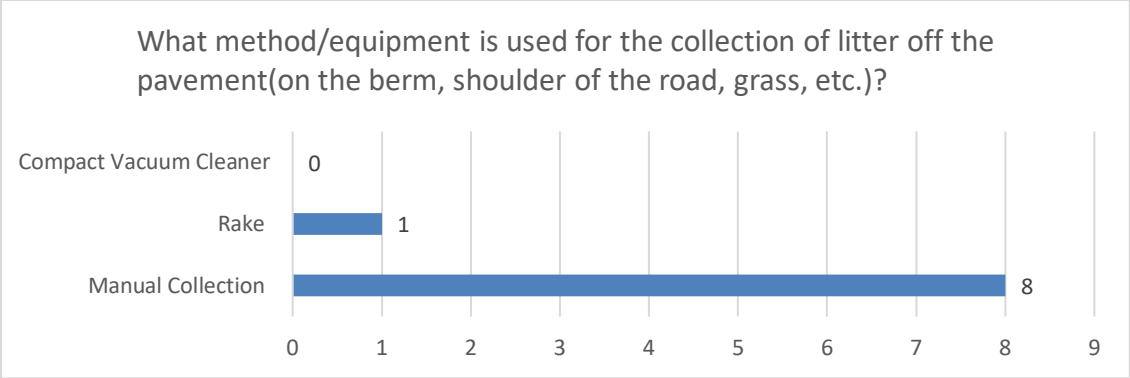

Figure 23. Survey response: methods used for collecting litter off the pavement

Initiation of litter removal activities

- 6 out of 8 respondents stated litter removal activities are initiated based on a formal plan.
- 5 out of 8 respondents stated that they are initiated based on complaints.
- One respondent from the California Department of Transportation stated that litter removal activities are initiated based on inspections performed by area superintendents.
- Minnesota DOT initiates a litter removal program after 2 weeks of snow and ice. Later they contract with counties STS program (STS is a sentencing alternative for courts that put nonviolent offenders to work on community improvement projects) for weekend picking. 8 to 10 members in a group are deployed in an area. Minnesota DOT indicated that using the STS program is not economical as separate police guards have to be employed to guard the prisoners.

Biggest safety concerns while collecting road litter

- 8 out of 8 respondents stated safety of crews from traffic is the biggest safety concern while collecting road litter.
- One respondent from the California DOT indicated that hypodermic needles is one of the biggest safety concerns while collecting road litter. The other respondent from the California DOT stated that hazardous items such as pipe bombs, urine bottles and guns are the biggest safety concerns while collecting road litter.
- All respondents agreed that safety hazards can be reduced through the use of mechanical equipment that decrease the direct involvement of labor with road litter particularly if the equipment can be fully operated from the cabin of the vehicle.

Products used to prevent road litter from entering storm water systems:

- 5 out of 8 respondents indicated the use of products to prevent road litter from entering storm water systems.
  - 4 out of those 5 respondents stated the use of fixed curb inlet screens.
  - 3 out of the 5 respondents stated the use of snout.
- The participants were requested to give a rating from 1 to 5 of the products that they used for preventing road litter from entering the storm water system. 1 refers to totally dissatisfied and 5 refers to totally satisfied.
  - 2 respondents gave a rating of 2 for fixed curb inlet screens and 2 respondents gave a rating of 3 for the same.

- 2 respondents gave a rating of 3 for snout and 1 respondent gave a rating of 2 for the snout.
- All the respondents using the fixed curb inlet screens stated that the screens block the litter from entering the inlet. They mentioned the issue of flooding when the debris clog the screens when timely cleaning is not done.

2.2.1 Phone Interviews of Other DOTs

Follow up phone interviews with survey respondents were conducted to clarify and get more information on their surveys. The following are the results of the phone interviews.

Tim Jones, Operations Field Services, Michigan DOT

The main objective of this phone interview is to get additional information related to the Snout and to manual litter collection.

- The snout is only used on new installations.
- The installation of a snout increases the maintenance cost of catch basins but reduces the maintenance requirement of storm water pipes.
- Manual litter collection is performed either by hand or using a litter picker hand tool.
- Manual collection operations are not carried out during the winter season due to snow.
- Manual collection is carried out by both MDOT crews and volunteers as part of the Adopt-a-highway program.
- Safety vests, Hard hats and safety shoes are compulsory when manually collecting litter.

Jeffery Wilson, Superintendent of Neighborhood Operations, City of Cincinnati

The main objective of this phone interview is to get additional information related to products used to prevent litter from entering the storm water system.

- Fixed inlet screens and Snouts are used.
- Maintenance of catch basins increases when a snout is used but reduces the maintenance of pipes
- Debris blocked by the screen is removed either through regular sweeping or manually. Manual cleaning of the screen does not require expensive equipment and can be conveniently performed when it rains to ensure no flooding is occurring and since city crews can't usually perform other road maintenance and/or construction operations during the rain.

Theresa Drum, Safety and Training Liaison, CalTrans Division of Maintenance

The main objective of this phone interview is to get details on safety equipment used during manual collection of litter.

- Hardhats, eye protection, high visibility garment, and puncture resistant gloves are used.

Dewayne E. Jones, Superintendent, Minnesota Department of Transportation (MnDOT)

The main objective of this phone interview is to get information about safety equipment used during manual collection and procedures followed for manual collection of litter.

- Hardhats, high visibility garment, and gloves are used.
- A truck follows the crew collecting litter. All the litter bags are placed on the truck after collecting litter.

Sandi Sauter, Deputy Director, Operations, Maryland DOT

The main objective of this phone interview is to get information about safety equipment used during manual collection and procedures followed for manual collection of litter.

- All employees working on manual litter operations are provided gloves, hard hats, ANSI Class 3 garments or safety vest, and ASTM F 2412 or 2413-11 safety footwear. Employees are also provided litter pickers.
- All of our litter crews are supported by a dump truck which follows them closely while they are walking on the roadside. If the posted highway speed is 55 MPH or greater, then a crash attenuator is also provided and follows the dump truck at a distance of 50 to 100 feet.
- Litter is placed in 33 gallon trash bags which are loaded into the dump truck and then taken to the local landfill. Recyclables are placed into a clear or different colored trash bag and taken back to the recycling bin at the Maintenance Shop.
- At the end of the day, all litter accumulations (# of bags filled) are tallied up and entered into the Team Activity Card (eTAC) along with labor, equipment, and materials. 50 filled 33-gallon trash bags are considered equivalent to one dump truck load. The weight of litter is approximately 7 pounds per bag.

2.3 Phone Interviews of Equipment Manufacturers

Various manufacturers of different types of equipment and devices were contacted and interviewed. Only a limited number of reviewed products which were deemed applicable to ODOT are included in the subsequent sections.

2.3.1 Phone Interviews of equipment manufacturers

MAD-VAC LR 50

Mad-Vac LR 50 is a vacuum litter collection vehicle with a robotic arm as shown in Figure 24. It has a wander hose which can collect litter 15 feet away. The wander hose can be controlled using a joystick. It can be used to pick up dry, humid and wet debris. An optional 48” wide vacuum head can be installed for collecting litter in front of the vehicle with a greater coverage. The maximum speed of the vehicle is 12 mph. The hopper capacity of this vehicle is 100-120 gallons. (Madvac 2019)

Figure 24. Mad-Vac LR 50

Advantages:

1. 270-degree arm movement.
2. High operation seating for good visibility.

Disadvantages:

1. Vehicle should be trailed to the site.
2. Small hopper capacity
3. Fragile. Not suitable for rugged or sloped terrain.

Trash Vac by Neptune Wash Solution

The IES TRASH VACUUM shown in Figure 25, is designed to mount on a Bobcat Tool Cat chassis. The Bob Cat Tool CAT 5600 was chosen as the platform as it offers the correct combination of features that makes the TRASH VACUMN an effective and safe machine even on sloped or rugged terrain. The Tool Cat offers, 4-wheel independent suspension, Hydrostatic 4-wheel drive, high flow hydraulics traction control, and a hydraulic dump bed which are all needed to effectively drive, vacuum and dump the collected debris.

The Articulating Suction Snout of the Trash Vac has a 10' foot of reach with 6' of vertical range and 180-degree range of movement from left to right. The Suction Snout utilizes a 12" diameter intake hose to facilitate picking up large debris, provided the debris constitutes blown trash. It has a 4 cubic yard aluminum collection box that utilizes the Toolcat's integrated dump mechanic for easy debris removal. The hydraulic dumb bed is activated by a single lever in the cab. The maximum speed of the vehicle is 17 mph (Neptune Wash 2019)

Figure 25. Trash Vac by Neptune Wash Solution

Advantages:

1. The trash vac has a pass-through impeller designed to help shred litter for compaction.
2. Effective on slopes and rugged terrain.

Disadvantages:

1. This vehicle should be trailed to the site.
2. Manufacturer doesn't have units to demo in Ohio.

Trilo

Trilo is a manufacturing company which develops different types of vacuum units for different purposes. After describing the project objective to them during the phone interview, they have suggested that S-

series vacuum units would be the best solution for the current research work. The S-series are available with different hopper capacities ranging from 4 CY to 15.7 CY. Despite their compact size, they have a large loading capacity that reduces the time of driving back and forth from and to an unloading location. a powerful fan ensures a great suction power and is mounted in a housing fitted with a replaceable lining. The vacuum unit is driven by a PTO drive shaft attached to the tractor and requires an output of 70 – 110 hp. (Trilo 2019). With the Trilo S-Series, it is possible to easily exchange the work shaft. Depending on the work shaft, the TRILO® S-Series vacuum sweepers can not only collect leaves but can also mow and collect or verticut and collect grass in one pass. When collecting litter, an event cleaning brush shaft can be used for quick and easy collecting.

As previously described, a demo of a Trilo S3 was conducted in ODOT District 2, ODOT personnel were satisfied with the equipment but decided that a Trilo S8 shown in Figure 26, will be more suitable and recommended that a cost benefit analysis of the S8 be performed to determine its feasibility for testing in future research.

Figure 26. Trilo S8

Advantages:

1. Compact in size when compared to other equipment in its class.
2. Optional wander hose can be used on both sides.
3. Availability of suction hood.
4. Different work shafts for different applications
5. Hi Tip hopper that can empty into a trailer or waste disposal.
6. It can be used to cut grass and collect debris simultaneously there by reducing operation time.

Disadvantages:

1. This vehicle should be trailed to the site.
2. Needs a tractor for operation

Pik Rite Truck Mounted Debris Collector

The Pik Rite Debris Collector as shown in Figure 27, comes complete with an independent diesel engine, heavy duty suction fan and internal hydraulic compactor. The three-axis hose boom eliminates the need for an entire crew to wrangle the suction hose by hand. Single operator function with in-cab joystick controls maximize safety and efficiency. It has a hopper capacity of 19 CY and it has a 10’ long vacuum hose of 18” diameter (PikRite 2019)

Figure 27. Pik Rite Truck Mounted Debris Collector

Advantages:

1. Single operator function
2. Large capacity

Disadvantages:

1. Can only collect litter close to the edge of pavement.
2. High cost

JAWS by Missouri Department of Transportation

Missouri Department of Transportation developed JAWS (Julie's Automated Waste-removal System). JAWS is mounted on the front of the pickup truck as shown in Figure 28. It is operated from inside the truck using a joystick, so workers don't have to enter the road to remove debris. It is an automated drop-down skid plate that can scoop up debris and move it to the shoulder out of traffic, where it can be handled more safely (Figure 29). A mounted front facing camera is used to provide a clear view of the debris.

Figure 28. JAWS mounted on the front of a pickup truck

Figure 29. JAWS mounted truck removes debris to shoulder

Advantages:

1. This device increase productivity and worker safety by removing workers from the roadside

2.3.2 Phone Interviews of devices manufacturers

Snout

Snout is a patented product manufactured by Best Management Products Inc. that has already been installed in more than 80,000 locations all over the US. The snout is made up of marine fiberglass which makes it very strong and durable. The snout can only be used in a catch basin with a sump. The minimum depth of sump required to install a snout is 36" or 2.5 times the inner diameter of the outlet pipe whichever is larger. The maintenance frequency decreases as the sump depth increases. The snout comes in different sizes and shapes for use in different applications, catch basin shape and outlet pipe sizes.

In addition to snouts, and as shown in Figure 30, Best Management Products Inc. manufactures screens installed around the Snout for additional protection, and Bio-Skirts used to in addition to the Snout, to reduce hydrocarbons that get into the stormwater network.

Figure 30. Snout and accessories

Advantages:

1. Proven effectiveness in removing pollutants from the stormwater system
2. High durability of 25 to 50 years as the snout is made of marine fiberglass. In past 20 years, less than 100 snouts are replaced out of 80,000 installations.
3. Can be installed within an hour.

Disadvantages:

1. Can only be used in a catch basin with a sump.
2. Increased maintenance/inspection of catch basin is required
3. A Vac Truck should be used for cleaning operations.

Hydra TMDL

Hydra TMDL Systems manufactures a patented product called Hydra "Automatic Retractable Screen" (ARS) Storm Drain Gate shown in Figure 31. The hybrid retractable screen design moves away from a perforated screen cover shielding the catch basin curb opening and instead, relies on a series of flat-angle wedges installed across the curb opening. The plastic wedges are held in place by a cable and slide in a longitudinal direction of the CB opening. The hybrid retractable wedges act independently from each other, thus only those being subjected to a force by flowing water retract inwards to allow flow of water. Those wedges not being subjected to a force remain in the closed position, theoretically preventing trash from entering the storm drain system during wet weather. Two horizontal pre-tension cables are provided one at the top and the other at the center to provide resistance.

Figure 31. Hydra ARS Storm Drain Gate

A recent research study was conducted for the City of Los Angeles to evaluate the performance of the Hydra ARS. The study concluded that the Hydra ARS is a promising alternative to the typical stainless steel automatic retractable screen for trash deflection. Based on the visual observations and data collected through this study, it has been shown that the hybrid retractable screen cover is 92.64% effective year-round in preventing trash from entering the storm drain system. The study indicated that this represents a six percent (6%) improvement from the stainless steel automatic retractable screens tested by the City of Los Angeles in the 2005/06 wet season. Though the performance improvement is small, the hybrid retractable screen cover's cost for fabrication and installation is assumed to be considerably lower, when comparing stainless steel versus plastic material costs, making them financially attractive. The study noted a potential limitation of the Hydra ARS in that it does not have a locking mechanism like the older ARS model screen covers and is designed to slide open longitudinally to allow storm water flow into the CB. As a result, the hybrid design may allow trash and debris to be introduced into the CB by the street sweeper's brush during cleaning activities (Advtech Environmental 2015).

Advantages:

1. Fast installation (5 to 10 minutes). Faster than other automatic retractable screens.
2. Cost of fabrication and installation is lower.

Disadvantages:

1. These screens do not have a locking mechanism. As a result, these screens allow trash and debris to enter into the catch basin by the street sweeper brush during cleaning activities.

United Storm Water

As shown in Figure 32, the Wing-Gate is an automatic retractable curb inlet screen cover (ARS) that prohibits most trash and debris from entering storm drains during the dry season, while opening automatically during specific water flow conditions to prevent street flooding. The device's screened gate remains in a closed position during the dry season or low water flow, and the retained pollutants can be removed using routine street sweeping.

During periods of increased or heavy water flow, the Wing-Gate™ screen will open with the pressure of water on the screen face, allowing water to flow into the catch basin. The device is capable of opening for a calibrated amount of water flow. As a storm subsides, the spring-activated screen gate will automatically return to the closed position.

The Wing-Gate is fabricated from perforated S-304 stainless steel with 3/4 inch diameter holes. It is custom-made and calibrated for each individual catch basin. It can be calibrated to open when subjected to water flow levels of approximately 1 inches to 4 inches. It can be manually pinned in the open position as needed during catch basin cleaning or extreme storm conditions. Gates with double or single wings can be installed in series based on catch basin length and flows to the site (United Storm Water 2019). The county of Los Angeles has over 10,000 installations of these devices.

The wing gate can come both with and without a locking mechanism. 3.5 ‘ screen without lock costs $450 and a 3’ to 5’ screen with lock costs $600. This cost doesn’t include the installation costs. A warranty of 5 to 10 years is provided for these screens. United Storm Water sends their teams to take the measurements and install the devices.

Figure 32. United Storm Water’s Wing Gate ARS

A research study was conducted to evaluate the efficiency of the Wing Gate by the city of Baltimore, in partnership with the Waterfront Partnership of Baltimore Inc. For this study, Wing Gates were installed on a street through Baltimore's historic Fells Point neighborhood which is a commercial district full of small stores and restaurants. The installation proceeded on schedule without any complications. According to Adam Lindquist, project manager for the Healthy Harbor Initiative, the city has since experienced storms with rain up to 4 inches, and the Wing Gate worked as planned without problems. He says there are no incidents of flooding occurring since the installation. In an extreme 500 to 1000-year storm event, the area received 3.91 inches of rain in one hour. The Wing Gate prevented flooding as they were designed to do and then returned to the job of capturing trash (Roberta Baxter 2015)

United Storm Water also manufactures a Connector Pipe Screen (CPS). The CPS as shown in Figure 33, is placed against the outlet pipe in a catch basin to prevent the debris from entering the outlet pipe. The CPS is made of stainless steel with 5 mm perforations which blocks all kinds of trash and gross solids greater than 5 mm.

Figure 33. United Storm Water's connector pipe screen

Advantages:

1. Reduces flooding
2. 1" to 2" gaps are provided above the screen as an overflow bypass.
3. The wing gate can only be removed by using a special theft proof stainless steel button head cap screw removal tool, protecting the screen from theft.

Disadvantages:

1. Higher cost.

SOP Technologies

SOP technologies has a patented Curb Inlet Filter shown in Figure 34. The filter uses a unique upward flow design that allows water flow without allowing the debris to enter the catch basin. The filters are made of stainless steel and can be customized based on the sizes of curb inlet openings. To protect the screens from theft SOP Technologies manufactures screens with a mix of Aluminum and high-density polyethylene which has 40% less Aluminum when compared to traditional screens. These screens also reduce the overall cost of the product.

A research study was conducted to evaluate the performance of the filters in the city of Key West, Florida. After a 3-month study period, officials were satisfied with the filters. Another research study was conducted in the City of Aventura, Florida. In this study, the filters were installed and tested at 35 inlets. The study identified several benefits on installing the filters including cost savings due to decreased frequency of required catch basin cleanings since street sweeping is enough to collect the litter blocked by the filters. Based on this study, officials approved the installation of an additional 177 filters of various sizes at various inlets (SOP Technologies 2019)

Figure 34. SOP Technologies' curb inlet filter

Advantages:

1. Patented Upward flow allows water flow while blocking trash.

Protection Bars

Protection bars are devices used to prevent large debris from entering catch basins. These can be installed at both median barrier inlets and curb inlets. Protection bars can be used along with screens to protect the screens from theft and vandalism. The other main purpose of protection bars is to prevent large debris to get in contact with the screens to prevent further blockage of inlets with large debris. The research team contacted a manufacturer called "Long Beach Iron Works". They have two types of protection bars, horizontal protection bars and vertical protection bars respectively. They are both made of steel. The horizontal bar (LB409F) has a ¾" diameter and is installed using end anchors. Whereas, the vertical bar (LB409G) has a 1" diameter and can be directly installed in concrete.

Figure 35. Horizontal protection bar

Advantages:

1. Protection bars can be used at any location.
2. Ease of installation.

Disadvantages:

1. Only acts as a partial capture device and almost all kinds of debris enter the catch basin.

3- Develop matrices of practices used for debris/litter removal and minimizing litter/debris from entering the storm drainage system and develop cost/benefit analysis for proposed solutions

Three matrices of practices were developed to summarize findings related to the following 3 research areas:

- Devices for preventing litter from entering the roadway storm drainage system
- Equipment for collecting debris off the pavement
- Equipment for collecting large debris on the Pavement

Devices for preventing litter from entering the roadway storm drainage system

Matrix of practices

As shown in the Matrix of practices (Figure 36), there are several devices that can be used to minimize litter and debris entering the roadway storm drainage system. These can be categorized in two main categories (1) inlet protection and (2) outlet pipe protection. Each of these two types of devices can be used in a standalone configuration or they can both be installed together. Installing them together has a significant environmental benefit as it will significantly reduce the amount of litter traveling via the stormwater conduits and eventually reaching and harming receiving water bodies. However, installing both devices together will increase the amount of maintenance needed and associated resources and costs. In a combined installation, although the inlet screen reduces the amount of debris entering the catch basin, whatever debris does enter is prevented by the connector pipe screen from travelling via the stormwater conduit and thus retained in the catch basin requiring more maintenance. On the other hand, just installing an inlet screen reduces the catch basin's maintenance required provided that an effective sweeping program is used to regularly collect the debris blocked by the inlet screen.

There are different inlet protection devices (screens) and each has its advantages, disadvantages and optimal installation as previously discussed and as summarized in Figure 36. It is recommended that in future research, the various types are tested to confirm their applicability at different locations in Ohio.

Cost Benefit Analysis – Screen for a median barrier inlet

Cost of the Screen

As documented in the matrix of practices, the cost of a stainless steel screen for a median barrier inlet varies between $800 to $1000. To be conservative we assumed $1000 in the analysis. Also the time of installation varies between 5 to 20 minutes. Again to be conservative we assumed an installation time of 20 minutes.

Depending on the location of the drain, the installation process may or may not need a maintenance of traffic (MOT) procedure involving lane closures to ensure the safety of the workers. Again to be conservative, it is assumed in the analysis that MOT is required. The MOT procedure requires the use of flaggers, arrow boards and a crash attenuator.

Based on the assumptions above, the resources required for screen installation and their hourly costs are provided in Table 3. As shown in Table 3, the installation cost is estimated to be $94.91.

Table 3. Screen installation cost

Screen Installation with MOT				
		Quantity	Unit Price ($/hour)	Hourly cost ($/hour)
Labor				
	Flaggers	2	34	68
	Highway tech	3	34	102
Equipment				
	Dump truck to pull crash attenuator	1	71.03	71.03
	Pickup truck / cone trailer	2	16.87	33.74
	Arrow boards	2	2.38	4.76
	Crash attenuator	1	5.5	5.5
			Total Hourly Cost ($/hour)	**$ 285.03**
			Installation time (hour)	**0.333**
			Installation Cost ($/hour)	**$ 94.91**

Since the screens don't need additional maintenance other than the regular sweeping performed by ODOT, it is assumed that the maintenance cost is $0 in this analysis. The total cost of the screen installed on a median barrier inlet as shown in Table 4 is estimated to be $1094.91

Devices for Preventing Litter from Entering the Roadway Storm Drainage System													
	Type	Description	Manufacturers	Model		Applicability (where it is installed)	Type of pollutants captured	Ease of Installation	Equipment Cost	Ease of Maintenance	Material used to manufacture	Advantages	Disadvantages
Inlet Protection	Fixed Inlet Screen	Fixed inlet screens are used to prevent the litter from entering the catch basin.	SOP Technologies	Curb Inlet Filter		Drain inlets (median barrier and curb)	larger than 1/2"	5- 10 minutes	$750 for 4"x10' inlet #3, $550 for 4'9"x6" CB#3	Street sweeping is enough to collect the litter blocked by screens	Aluminum and High Density Polyethylene	Patented upward flow allows maximum water flow rate through the screen	Potential for flooding if a regular sweeping program is not performed
	Automatic Retractable Inlet Screen	Automatic retarctable screens are the updated versions of fixed inlet screens. These screens open automatically during storm events to prevent flooding.	Hydra TMDL Systems	Hydra ARS Storm drain gate		Drain inlets (median barrier and curb)	larger than 1/2"	5 to 10 minutes	$600 for 4"x10' inlet #3, $440 for 4'9"x6" CB#3	Street sweeping is enough to collect the litter blocked by screens	Plastic	The screen design is expected to open to curb flow in order to reduce the potential for flooding during wet weather. Lower cost	Due to the absence of locking mechanism, trash enters into catch basin when a street sweeper is used
			United Storm Water Inc.	Wing Gate ARS		Drain inlets (median barrier and curb)	larger than 1/2"	20 minutes	$1000 for 4"x10' inlet #3, $600 for 4'9"x6" CB#3	Street sweeping is enough to collect the litter blocked by screens	Stainless Steel	Can be calibrated to open for different water levels.	Moving parts (i.e. springs may not withstand harsh Ohio environment
	Protection Bars	Protection bars can be used to prevent large debris from entering storm water systems.	Long Beach Iron Works	LB409F and LB409G		Drain inlets (median barrier and curb)	Large debris	10 minutes	$300 for 4"x10' inlet #3, $150 for 4'9"x6" CB#3		Stainless Steel	Can be used at any location	Only prevents large debris from entering the catch basin
Outlet pipe protection	Connector Pipe Screen	Placed against outlet pipe in catch basin to prevent the debris from entering the outlet pipe.	United Storm Water Inc.	Connector Pipe Screen		Inside catch basin over the outlet pipe.	All types of debris larger than 5 mm will be trapped.	25 minutes	$500	A Vac Truck should be used to clean the catch basin.	Stainless Steel	Can be used at catch basins with no sumps	More frequent maintenance
	Snout	Snout is a catch basin hood which is placed against the outlet pipe in a catchbasin to prevent the debris from entering the outlet pipe.	Best Management Products Inc.	Snout		Inside catch basin over the outlet pipe.	Debris, Total Suspended Solids and Hydrocarbons	Within an hour	$ 437.7 for 18" pipe	A Vac Truck should be used to clean the catch basin.	Marine fiberglass	Maintenance of pipes decreases.	Can only be used at catch basin with sumps.

Figure 36. Matrix of practices - Devices for preventing litter from entering the roadway storm drainage system

Table 4. Screen installation cost

Median Barrier Inlet Screen Total Cost		
Material	$	1,000.00
Installation	$	94.91
Maintenance	$	-
Total Cost ($)	$	1,094.91

Benefit of the Screen

The economic benefit of the inlet screen results from the reduction in required catch basin maintenance. Feedback from device manufacturers have indicated that a minimum 50% reduction in catch basin maintenance should be expected when the screens are installed.

To determine the savings associated with the screen, the cost of cleaning a catch basin should be estimated. The catch basin cleaning process may or may not need a MOT. To be consistent with the assumption made above, it is assumed that MOT is required. The resources required for cleaning the catch basin and their hourly costs are provided in Table 5. The time required for cleaning a catch basin varies significantly depending on the amount, type and the degree of compaction of the debris. Cleaning time can be as small as 30 minutes and as large as 6 hours. In this analysis, a cleaning time of 2 hours is assumed. Based on these assumptions and as shown in Table 5, the catch basin cleaning cost is estimated to be $905.3.

Table 5. Catch basin cleaning cost

Catch Basin Cleaning using a Sewer Truck with MOT				
		Quantity	Unit Price ($/hour)	Hourly cost ($/hour)
Labor				
	Flaggers	2	34	68
	Highway tech	4	34	136
Equipment				
	Sewer Truck	1	133.62	133.62
	Dump truck to pull crash attenuator	1	71.03	71.03
	Crash attenuator	1	5.5	5.5
	Pickup truck / cone trailer	2	16.87	33.74
	Arrow boards	2	2.38	4.76
			Total Hourly Cost ($/hour)	**452.65**
			Catch Basin cleaning time (hour)	**2**
			Catch Basin Cleaning Cost ($/hour)	**$ 905.30**

Payback

The payback period of screen installation depends on the original required cleaning frequency. The required cleaning frequency varies from one catch basin to another and depends primarily on the amount/type of trash, location of catch basin and surface area of watershed drained by the catch basin. Table 6 shows expected payback for catch basins that are typically cleaned every 6 month, 1 year and 2 years before the screen is installed and assuming that the installation of the screen will double the time between required cleaning. As shown in Table 6, installing screens on inlets of “problem” catch basins that require more frequent cleaning has shorter payback periods.

Table 6. Payback periods for installing screen

Original Cleaning Frequency (years)	Estimated Cleaning Frequency with Screen Installed (years)	Annual Savings ($) from reduced cleaning	Pay back period (Years)
0.5	1	$ 905.30	1.2
1	2	$ 452.65	2.4
2	4	$ 226.33	4.8

Equipment for collecting debris off the pavement

Matrix of practices

As shown in Figure 37, the matrix of practices provides information on manufacturers, model numbers, applicability, size and length of hose, hopper capacity, cost, impact on traffic, advantages and disadvantages of the various researched equipment. The information was collected based on phone interviews, literature reviews and site visit as was previously discussed.

Based on the matrix of practices, the site visits and the phone interviews, the research team is recommending the Trilo S8 for further testing. The tractor-pulled S8 has a large hopper capacity (10.5 cy) which reduces the time of driving back and forth from and to an unloading location. Additionally, with the S8, it is possible to easily exchange the work shaft to mow and collect debris in one pass. When only collecting litter an "event cleaning" brush shaft can be used for quick and easy collection. Furthermore, the S8 comes with an optional wander hose that can be controlled from the cabin to collect trash from hard to reach places.

Cost Benefit Analysis of Trilo S8

Hourly cost of proposed equipment

As documented in the matrix of alternative, the purchase price of the proposed equipment (Trilo S8) is $93,500. To be able to perform a cost analysis for the proposed Trilo S8, it is important to first estimate the **hourly ownership cost**. Ownership costs are those costs which accrue whether or not the equipment is used. The hourly ownership cost is largely dependent on the purchase price ($93,500).

The **hourly ownership cost** can be calculated by dividing the purchase price by (an expected use rate per year multiplied by the useful life of the equipment). It should be noted that both the expected use rate per year and the equipment's useful life will have a significant impact on the outcome of the cost analysis and therefore should be carefully determined. The research team after getting input from equipment manufacturers has decided to use conservative values of 300 hours for the expected use rate per year and 10 years for the useful life of the equipment. Thus the **hourly ownership cost** is:

$$\$93,500/(300*10)= \$31.17/hr$$

Maintenance and repair costs for the S8 was assumed to be $1,500/year. Based on this, the **total hourly cost** of the Trilo S8 is:

$$\$31.17/hr + \$1,500/300 = \$36.17/hr$$

Debris Collection Equipment - Off Pavement																
	Type	Description	Manufacturer	Model	Picture	Hose Diameter	Hose Length	Hose Features	Hopper Capacity	Hopper Features	Engine Power	Applicability	Cost	Impact on Traffic	Advantages	Disadvantages
Traditional Method	Manual Collection	People collect litter into plastic bags on foot	N/A			N/A					N/A	Debris can be collected from all locations where a person can reach	$26/bag	Minimal	No initial investment	Time consuming, expensive and highly dangerous procedure
Researched Methods	All Terrain Compact Vacuum Units	These vehicles can be used on both on and off pavement.	Neptune Wash Solutions	Trash Vac		12"	10'	Controlled from cabin	4 CY	It can be hydraulically raised and tilted to dump load	64 hp	Litter can be collected off the pavement.	$104,000	Minimal	4.5" vertical range. High engine power helps to control on slopes	Need to be tested for suitability for rugged environment
			Madvac	LR50		8"	15'	Controlled from cabin	0.6 CY	Single heavy duty disposable/ Re-usable bag	24.8 hp	Litter can be collected using either suction head or vacuum hose.	$75,000	Minimal	Fully robotic arm and 48" suction head	Small Hopper Capacity. Fragile
	All Terrain Mid Size Vacuum Units	These vehicles can be used on both on and off pavement.	Trilo	S8		9.84" and 13.8"	26.25'	Joystick controlled and can be used on both left and right sides	10.5 CY	Hydraulic back door with conveyer	70-110 hp (required power takeoff from the tractor attached)	Can be used to collect litter off the pavement using both suction hood and vacuum hose.	$93,500	Minimal	Compact in size when compared to other equipment in its class. Availability of wander hose	Requirement of external power source such as tractor.
	Large Vehicles	Can only be used on pavement, but can collect litter adjacent to roadway by an automatic vacuum hose	Pik Rite	Debris Collector Vehicles		18"	10'	Three axis hose boom with joystick control	19 CY	Internal Hydraulic Compactor		Used to collect litter adjacent to the road (Shoulders, berms, medians)	$200K +	Moderate: vehicle operate on pavement at a lower speed than traffic	Availability of safety sensors. Option of roll off units.	Reach is limited. High Cost

Figure 37. Matrix of practices - Debris collection – off pavement

Once the **hourly cost** of the proposed Trilo S8 is calculated, a cost analysis comparing it to the traditional process for collecting debris manually can be performed by knowing the required crew composition, hourly rate of the equipment used, and crew wages needed for each method.

Cost of manually picking trash

For the manual cleaning method, the resources required and their hourly costs are provided in Table 7. The production rate (# of bags picked per day for a 4 members crew) was obtained from the phone interviews. As shown in Table 7, the cost per bag is calculated to be $26.31/bag which is in line with data provided by ODOT district 2.

Table 7. Cost of manually picking trash

Manual Collection of Litter (4 persons crew)				
		Quantity	Unit Price ($/hour)	Hourly cost ($/hour)
Labor				
	Highway tech	4	34	136
Equipment				
	1 ton Dump truck	1	35	35
			Total Hourly Cost ($/hour)	**$ 171.00**
			# of bags (25 gallons) picked per hour	**6.5**
			CY picked per hour	**0.80**
			Cost per bag	**$ 26.31**

Required production rate of proposed equipment to break even

The research has indicated that the production rate of the Trilo S8 will vary depends on the density of the trash. The production rate will increase significantly when the density of the trash is high as shown in Figure 38.

Figure 38. Dense trash

For this reason, instead of calculating the cost of removing trash based on an assumed production rate which can vary depending on the situation, the research team decided to calculate the required production rate of the proposed equipment to break even. In cases when the proposed equipment can be more productive than this break even rate, the equipment will generate savings to ODOT.

To calculate the breakeven rate, the resources required for using the proposed equipment and their hourly costs were obtained as shown in Table 8.

Table 8. Cost analysis of proposed equipment

Proposed Equipment (Trilo S8) Cost Analysis				
		Quantity	Unit Price ($/hour)	Hourly cost ($/hour)
Labor				
	Highway tech	2	34	68
Equipment				
	1 ton Dump truck	1	35	35
	Tractor	1	35	35
	Flat bed trailer	1	8.45	8.45
	S8	1	36.17	36.17
			Total Hourly Cost ($/hour)	**$ 182.62**
			Productivity required to break even (CY/Hour)	**0.86**

The hourly cost of using the Trilo S8 was calculated to be $182.62/hour which is about 7% higher than the hourly cost of manually picking the trash using a 4-person crew. Therefore, the breakeven production rate is also 7% higher than the manual production rate and is calculated to be **0.86 cy/hour**.

Considering the amount of trash that the research team observed in several areas in District 2 and considering that the hopper capacity of the Trilo S8 is 10.5 CY, the research team believes that the breakeven production rate can be easily achieved. However, this can only be confirmed by conducting field tests.

Equipment for collecting large debris on the Pavement

Matrix of practices

Since street sweepers are not able to able to collect and remove large debris from the road way, there is a need to separately collect such large debris before the sweeper is used on a particular segment of the road. The current method of removing large debris from the roadway is by manual labor as shown in Figure 39. This current method has a large impact on traffic and is potentially dangerous.

Figure 39. Manual removal of large debris from the roadway

As shown in Figure 40, the matrix of practices provides information on alternate researched methods for collecting large debris ahead of sweeper activities and their advantages and disadvantages. The information was collected based on phone interviews, literature reviews and site visits as was previously discussed. Based on the matrix of practices, the site visits and the phone interviews, the research team is recommending that ODOT further test the debris collection attachment developed by MoDOT.

Large Debris Collection - On Pavement														
	Type	Description		Manufacturer	Model	Hopper Capacity	Hopper Features	Applicability	Safety	Cost	Performance	Impact on Traffic	Advantages	Disadvantages
Traditional Method	Manual Collection	Working crew collects large debris manually in front of sweepers and place it in dump truck		N/A	N/A	N/A	N/A	All the debris that can be picked by an ordinary person can be collected.	High Risk	Labor intesive	Good since all debris can be collected	High since safety vehicles should be used behind the crew collecting litter	No initial investment	Time consuming, expensive and highly dangerous procedure
Researched Methods	Debris Collector Attachment	Used to safely move the large debris present on the road to the shoulder where it can be safely collected		Modot	JAWS	N/A	N/A	Can be used to bring large debris to the shoulder ensuring safety of crew	Safer as person sits in the cabin.	$2900 (Material Cost)	Good according to MoDOT	Moderate since Highway technician doesn't leave cabin	Saves money by reducing the number of workers and increase safety.	None reported by MoDOT
	Raking Machines	These machines are used to collect the large debris which cannot be collected by a sweeper		Barber	Road Rake	4 CY	Can be hydraulically raised and dumped	Before using a sweeper on the road, Road Rake is used to collect the large debris.	Safer as person sits in the cabin.	$81,800	Leaving behind large debris such as tire treads.	Moderate since Highway technician doesn't leave cabin	Saves money by reducing the number of workers and increase safety.	Not effective in removing large debirs

Figure 40. Matrix of practices - Large debris collection equipment – on pavement

4- Document and provide alternatives for dealing with additional secondary issues resulting from roadway litter

Manually removing debris from the roadway both on and off the pavement is associated with many safety/health hazards. Manually removing large debris from on-the pavement before sweeping operations exposes workers to road traffic travelling at high speed and can cause fatalities as was reported by the Missouri Department of Transportation. Manually collecting litter debris off the pavement had negative health impacts on ODOT technicians. In many cases the technicians have to travel on rugged steep slopes for long distances to collect the trash and in other cases, they are rear ended by public drivers. Additionally, workers are on foot at the road edge and vulnerable to hazards associated with cars whizzing by to speed up to 60/70 miles per hour. The workers are also subject to physical injuries such as those associated with lifting and tripping.

Data provided by ODOT have indicated that such a rugged and harsh work environment has caused several injuries/incidents including tendon rupture, syncope (temporary loss of consciousness caused by a fall in blood pressure), open wounds, scrapes and/or bruises resulting from being hit with flying rocks, injuries to lower back and/or internal derangement of the knee due to falling and rolling down a steep hill. Such accidents result in lost work days, put stresses on ODOT employees and their families, reduce employees' moral and increase ODOT liability.

The research proposed several methods to be field tested that if implemented will increase productivity and worker safety by removing workers from the roadside. These methods include:

- Installation of devices that prevent litter from entering the catch basins. Such devices will reduce the frequency of required catch basin cleaning.
- Use of vacuum machines to collect trash and litter off the road. This will not only remove workers from the treacherous conditions associated with collecting litter but will make them available to complete other necessary operations needed in their garages.
- Use of the automated drop-down skid plate (JAWS) that scoops up large debris on the pavement and move it to the shoulder out of traffic, where it can be handled more safely.

Implementing these proposed strategies will result in additional secondary benefits to ODOT including lower costs and reduced pollution of Ohio water bodies. As environmental regulations continue to become more and more stringent, implementing the strategies above will increase ODOT's capacity to meet such regulations.

5- Provide a report detailing the findings from all the above steps. Recommend solutions for infield testing and analysis

The research team recommends that ODOT conducts future research to do the following:

1. Test the performance of devices installed to prevent litter from entering the catch basins.
2. Test the use of debris collection equipment and/or improving the current manual process.

Each of the above recommendations are discussed in more detail in the following sections.

Test the performance of devices installed to prevent litter from entering the catch basins.

The research proposed several devices to be installed and further tested. Such devices will reduce the frequency of required catch basin cleaning. As previously discussed, there are different types of devices and each has its advantages, disadvantages and optimal application. It is recommended that the various types are field tested to assess their performance and effectiveness in preventing trash from entering the storm drain system at different locations in Ohio. The performance of the devices should be tested at different conditions such as different terrains where the devices will be used, presence of different types of debris and different quantities of debris.

The impact of the following factors on the performance and durability of the installed devices should be identified:

- Weather conditions (dry vs wet) since floatable materials are more likely to be mobilized and transported to the CB during rain events
- Debris/litter type and its potential to clog the opening of the installed devices
- Amount of Debris
- Terrain (flat vs rolling terrain): Steep slopes can interfere with successful operation of some automatic retractable screens resulting in a screen that would remain in a fixed position most of the time.
- Size of watershed area drained by the catch basin where the screen is installed
- Installation location: previous studies have shown that in some locations, screens are more prone to theft and/or to tampering by individuals determined to pushing trash inside the catch basin.
- Potential to cause flooding
- Impact on street sweeping activities: Previous studies have shown that the placement of the catch basin curb opening screen cover (flush with the curb or recessed) may affect the sweeper's ability to collect trash and debris that accumulated directly in front of the screen. Some automatic retractable screen covers have a locking mechanism that prevent the screen from being pushed in by the operation of the sweeper and will only retract during the presence of storm water flow.

To determine the impact of the above factors on the performance of the screens, field observations should be performed during dry weather, after major storms and during sweeping operations. The scope and duration of the research should be long enough to allow for a range of field observations during various rain events to comprehensively verify the performance of the installed devices.

It is anticipated that the installation of such devices will generate cost savings to ODOT by reducing the required frequency of catch basin cleaning and will reduce pollution of Ohio water bodies. As environmental regulations continue to become more and more stringent, installing those devices will increase ODOT's capacity to meet such regulations.

Test the use of debris collection equipment and/or improving the current manual process

The research proposed the tractor-pulled Trilo S8 for further testing to determine its cost effectiveness.. Several productivity studies should be conducted to determine the production rate of the Trilo S8 under

different project conditions. The impact of the following factors on the production rate should be identified:

- Weather conditions (dry vs wet).
- Debris/litter type
- Amount of Debris
- Terrain (flat vs rolling terrain)
- Size of area to be cleaned

The research team also recommends improving the current manual process of collecting litter off the pavement. The current manual process had negative health impacts on ODOT workers. In many cases the technicians have to travel on rugged steep slopes for long distances to collect the trash. The workers are also subjected to physical injuries such as those associated with lifting and tripping.

Based on discussion with the technical liaison team, the current strenuous manual process can be potentially improved by letting ODOT workers use John Deere Gator utility vehicles when collecting litter rather than collecting litter on foot. It is anticipated that with this method, ODOT can remove litter from longer stretches of the road in a shorter time. There are different types of small all-terrain vehicles (ATVs) with different power capacities that are suitable for different terrains and these have to be further researched to determine the most applicable model.

The West Central Region (WCR) of Alabama DOT (ALDOT) adopted this process improvement in 2018 and was able to double the productivity of its roadside trash collection activities. Figure 41 illustrates the use of ATVs in trash collection operations by ALDOT.

Figure 41. Use of all-terrain vehicles in roadside debris collection by ALDOT

Below is the information received through a phone interview with WCR.

- WCR employs a 5-person full-time crew for trash collection. Each person has an ATV for a total of 5 vehicles
- During the 12 months in which WCR implemented the process improvement (10/2018 to 10/2019), the 5-man crew collected 113 tons of trash
- Before the use of the ATVs, the same crew collected 60 tons of trash/year. In other words, the productivity almost doubled.
- The crew uses litter pickers to collect the trash and place it in a trash can attached to the ATV

- The process improvement was first piloted only in Tuscaloosa since it experiences a large amount of trash compared to other areas in Alabama
- After the success of the process improvement, other ALDOT districts are planning to implement it.
- Alabama DOT has spent $6.8 Million for litter pickup in 2018.
- The state government has realized how big the problem is and has increased the fine for littering. Because of new state legislation, littering is now considered a class B misdemeanor with a minimum fine for first offense of $500 and a minimum fine for 2nd offense of $1,000.

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