Evaluation of Maintenance Procedures for Hard Shoulder Running, Phase 1

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16. Abstract

To address traffic congestion, the Ohio Department of Transportation (ODOT) plans to use the inside eastbound shoulder of I-670 on the east side of Columbus as an additional traffic lane during the afternoon commute as a trial of hard shoulder running active traffic management. In order to fully implement hard shoulder running a review and possible updates of the Department's operation procedures are necessary. The purpose of this research is to identify and recommend safe, efficient, and cost effective procedures and equipment which keep the shoulder clear of debris for use by traffic.

A detail literature search was conducted to identify equipment for cleaning shoulders and agencies with hard shoulder running. These agencies were contacted to learn their procedures and equipment used for cleaning shoulders. ODOT Franklin County garage and central office Traffic Management Center personnel were interview to learn current procedures for clearing shoulders. The ODOT Franklin County crew demonstrated current shoulder cleaning procedures on I-270 in northeast Columbus. Samples of the collected debris were obtained and the composition determined. Detailed information for identified shoulder cleaning equipment was compiled from which marginal shoulder cleaning cost per mile, operating speed, debris type collected, and safety of operation were determined and used for evaluating each cleaning procedure using a decision matrix.

Recommendations were made with regard to cleaning equipment and schedules; cooperation between ODOT, safety patrol, bus operator, and law enforcement; current procedures for clearing disabled vehicles and debris; and operation during inclement weather.

Based on a decision matrix analysis, the following equipment was recommended for further analysis under phase 2: street sweeper, Road Rake, and magnetic street sweeper. A phase 2 work plan was provided.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(°F-32)/9 or (°F-32)/1.8	Celsius temperature	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2 or psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celsius temperature	1.8°C + 32	Fahrenheit temperature	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2 or psi

* SI is the symbol for the International Symbol of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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Contents

List of Figures

List of Tables

1 Project Background

The management of traffic demand has become critical as congestion in urban areas during commute hours has increased. The direct and indirect cost of congestion in America was estimated to be $124 billion in 2013 and is expected to increase to $186 billion in 2030 [Guerrini, 2014]. One method agencies have begun to implement to alleviate congestion is hard shoulder running.

While shoulders are generally used for emergency stopping, under hard shoulder running, shoulders are used part time to carry traffic, thereby increasing capacity. When not needed as an additional lane to alleviate congestion, the shoulder is restored to its original purpose [Jenior et al., 2016]. Hard shoulder running provides a lower cost solution, compared to widening, to the need for additional capacity during commute hours or special events. Part time use can be divided into three categories [Jenior et al., 2016]:

1. Bus on Shoulder (BOS) to facilitate bus traffic during congestion
2. Static shoulder lanes, where use is limited to predetermined hours, and
3. Dynamic shoulder lanes, where use is based on predetermined congestion criteria

The concept of hard shoulder running was originally employed in the United States to facilitate bus traffic. In 1991, the city of Minneapolis permitted busses to use the hard shoulder when congestion reduced the main line speed to less than 35 mph (56 km/h). The busses could travel no more than 15 mph (24 km/h) faster than mainline traffic [Jenior et al., 2016]. As of 2016, BOS operations have been implemented in 13 additional states, including Ohio, where Columbus, Cleveland, and Cincinnati have implemented similar hard shoulder running procedures [Jenior et al., 2016]. In Ohio, busses have been permitted to use the shoulder when speeds drop below 35 mph (56 km/h) on I-70 in Columbus since 2006, on I-71 in Cincinnati since 2007, and on I-90 and SR-2 in Cleveland since 2008 [ODOT, 2018].

In 1992 Fairfax County in eastern Virginia became one of the first agencies to use the shoulder for general purpose traffic during commute hours. As of 2016 static part time shoulder use for general purpose traffic to relieve congestion has been implemented in eight states: Colorado, Georgia, Hawaii, Massachusetts, New Jersey, Virginia, Texas, and Washington. [Jenior et al., 2016]. Since 2016, dynamic use of shoulder has been implemented on I-35W in Minneapolis, Minnesota and I-66 in Virginia near Washington, D.C. [Jenior et al., 2016].

Transit Cooperative Research Program (TCRP) Synthesis 64 [Martin, 2006] identified the following traffic safety concerns for bus use of shoulders, most of which are applicable to mixed traffic use also:

- Conflicts at on- and off- ramps
- Sight distance adequacy
- Conflicts for motorists pulling onto shoulder
- Loss of safe evasive movement area
- Need for bus driver training
- Speed differential
- Impact on adjacent lane motorists
- Return merge distance adequacy
- Shoulder area debris hazards
- Reduced clearance for buses at bridge abutments
- Highway drainage

While all are important considerations, shoulder area debris and the evaluation of maintenance procedures for clearing the shoulder was the focus of this project. Effectively and efficiently clearing the shoulder of debris and hazards is critical to providing a safe lane for motorists when used for hard shoulder running. The time, personnel, and equipment utilized for this is also critical in maintaining hard shoulder running as a cost effective measure for managing traffic demands.

2 Research Context

To address congestion, the Ohio Department of Transportation (ODOT) funded a study to identify strategies to manage traffic demand. The strategies identified for consideration [Holstein, 2016] are listed in Table 1.

Table 1 Potential Active Travel Demand Management Strategies.

Potential Active Travel Demand Management Strategies	
Hard Shoulder Running	Truck Only Lanes
High Occupancy Vehicle (HOV) Lanes	Speed Harmonization
Bus Only Lanes	Dynamic Message Signs providing real-time traffic information
Priced Lanes	Dynamic Route Planning
TMC Improvements	Ramp Metering
Incident Response	Queue Warning
Integrated Corridor Management	Contra Flow Lanes

Several of the strategies identified in Table 1 are currently being explored or implemented by ODOT. One strategy of particular interest to ODOT is hard shoulder running. ODOT is currently implementing hard shoulder running to provide additional capacity for meeting traffic demands.

Routes in Ohio suitable for hard shoulder running by both busses and mixed traffic were identified in a 2016 report submitted by AECOM. The report concluded hard shoulder running had favorable benefit/cost ratios. I-670 EB, in Columbus, has been selected as the pilot project to demonstrate the use of hard shoulder running of mixed traffic, referred to as the SmartLane. An active system will be implemented, using overhead signs to open the shoulder to mixed traffic from 3:30 PM to 6:30 PM Monday through Friday to relieve congestion. [ODOT, 2018]

In order to fully implement hard shoulder running a review and possible updates of the Department's design and operation procedures are necessary. The overall goal of this project is to identify and recommend safe, efficient, and cost effective procedures and equipment which keep the shoulder clear of debris for use by traffic. To meet this goal, the specific objectives of this project are as follows:

1. Develop efficiency for "driving" the shoulder
2. Develop a draft standard operating procedure
3. Recommend equipment to increase efficiency
4. Recommend ways to utilize emergency response, law enforcement, and freeway safety patrol in this process

To achieve these objectives, the following tasks were undertaken:

1. Evaluate best practices for daily maintenance and hard shoulder running operations.

2. Characterize debris.
3. Conduct literature search.
4. Develop a matrix of equipment.
5. Perform cost-benefit analysis.
6. Prepare interim report.

3 Research Approach

3.1 Evaluate best practices for daily maintenance and hard shoulder running operations.

3.1.1 Conduct a review of current nationwide practices

Jenior et al. [2016] identified 25 agencies in 14 states currently permitting BOS operation and general purpose traffic use of shoulder. Due to the lack of literature on clearing shoulders prior to hard shoulder running, the research team reached out to agencies in 9 of the 14 states, including Ohio in person, by phone and/or email. In addition to the 14 states Jenior et al. [2016] identified, the state of California was also contacted to seek information for a specific type of equipment. Of the remaining five agencies, two agencies, Delaware and Maryland, utilize queue jump applications which were not applicable to this research; two agencies, Massachusetts and Georgia, discontinued traffic on shoulder use due to construction; and one agency, Hawaii, uses movable barriers to adjust the number of lanes prior to rush hour, which was not applicable to this research. A queue jump lane is typically a right turn lane at an intersection with a signal phased to provide the green light for the right turn lane before the through traffic lanes get a green light. Buses are permitted to use the right turn lane for travel straight through the intersection, "jumping" the queue traveling straight. One agency, Illinois, did not respond and one state, North Carolina, was unable to communicate as they were responding to damage from hurricane Florence.

Of the agencies responding, information was sought on the procedures and equipment currently in use for clearing shoulders for hard shoulder running, and areas which need improvement. A total of thirty two individuals were interviewed, as summarized in Table 2, from 9 of the 14 states identified by Jenior et al. [2016], plus personnel from the state of California who has had experience using one of the pieces of equipment being evaluated. A summary of the results of these interviews are presented in Appendix A.

Table 2 Summary of Agencies Contacted

State	Contact	Association	Comments
California	Wil White	AHMCT, UC Davis, Development Engineer	phone interview
	Hamid Saadatnejadi	CalTrans	phone interview
	Scott Wadsworth	CalTrans, District 7	phone interview
Delaware			queue jump application - N/A
Florida	Ramona Burke	FLDOT, ITS	phone interview
	Jorge Esparza	private contractor: DBI, Tampa	phone interview

State	Contact	Association	Comments
	Joel Perez	Miami/Dade bus operations	phone interview
Georgia			BOS discontinued due to wall construction
Hawaii			DOT using movable centerline barriers to adjust number of lanes in each direction during congestion, procedures not applicable to this project
Illinois	Guy Tridgell	IDOT	no response to email inquiry, unable to locate another contact
Kansas	Chris Lowe	Johnson County Multi Service City Manager	
	Randy Johnson	Kansas City Scout	
Maryland			queue jump application
Massachusetts			Traffic on shoulder eliminated after additional lane constructed
Minnesota	Carl Jensen	Transit Advantages Engineer	phone interview
New Jersey	Anthony D'Errico	NJDOT Regional Equipment	phone interview
North Carolina	Meredith McDiarmid	NCDOT, State ITS and Signals Engineer	sent BOS Implementation and Operations Plan by email
Ohio	James Cook	ODOT Central Office and District 6 Highway Management	8/22/18 meeting at 5th Avenue Outpost, Franklin County
	Shawn Anverse		
	Jason Lucas		
	Bob Wilson		
	Marques Evans		
	Jim Nelson		
	Keith Jones		
	John McAdams	ODOT TMC	9/14/18 meeting at ODOT TMC
	John McKnabb		
	Dominic DelCol		
	Adam Kieffer		
	Doug McElroy	ODOT District 4	phone interview
	Jason Smith	Columbus Police Department	phone interview
	Edward Mejia	Ohio State Highway Patrol	phone interview
	Joe Labella, Jr.	private contractor: Autobase	declined interview
Virginia	Michael Murphy	VDOT, Communications Coordinator	email response
	Kamal Suliman	VDOT, Regional Operations Director	email response
	Albert Rollins	VDOT, Northern Virginia	phone interview
	Sean Trapani	private contractor: DBI, Virginia	phone interview
Washington	Lisa Van Cise-Mathieson	WSDOT, Communications	email response

3.1.2 Evaluate current practices for daily maintenance and operations of hard shoulder running in Ohio

Interviews were conducted to understand current practices in dealing with debris and disabled vehicles in the travelled lane. Although hard shoulder running has not yet been implemented in Ohio, another type of part time shoulder use, BOS operations, has been implemented for close to ten years and maintenance for BOS may be applicable to hard shoulder running. Therefore, the research team also conducted interviews to gain an understanding of BOS operations and required maintenance in Columbus, Cleveland and Cincinnati.

The research team conducted an interview with personnel in ODOT's Traffic Management Center (TMC) to learn details on identifying and removing accidents. Since specific focus was placed on procedures in central Ohio, the team also interviewed the ODOT Franklin County garage managers to assess the maintenance procedures currently used on BOS routes in Columbus and determine limitations of the current ODOT work force in terms of personnel and equipment. The researchers contacted the Ohio State Highway Patrol and the Columbus Police to learn current procedures for dealing with debris and disabled vehicles in both the travelled lane and shoulder and to evaluate the effect hard shoulder running may have on their procedures. The research team also contacted AutoBase, who provides freeway safety patrol services for ODOT. AutoBase declined to be interviewed, citing contractual concerns and referring the team to the ODOT TMC. A summary of the results of these interviews are presented in Appendix A. A list of individuals interviewed in Ohio is included in Table 2.

In addition to the interviews conducted to gain insight into current practices for clearing and maintaining the shoulders in Ohio, the ODOT Franklin County garage crew offered a demonstration of their maintenance operations for shoulders. While not included in the original proposal the demonstration provided an excellent opportunity to observe ODOT's current procedure for maintaining the shoulders in central Ohio, as well as observing the equipment in-use, potential risks and benefits of the current procedure and observe the debris collected during the procedure. On September 6, 2018 the research team observed the Franklin County garage crew's procedure for sweeping the shoulder on a section I-270. Details related to this demonstration are presented under Appendix A.

3.2 Characterize debris

To determine the most effective and efficient method of removal there is a need to determine the composition of the debris accumulating on the shoulder. A survey of 240 roadway sections by Schulz and Stein [2009] for the Keep America Beautiful organization found litter to be primarily composed of tobacco products, paper, plastic, metal, glass, organic material, construction debris, vehicle debris, with the remaining items classified as "other". To gain a better understanding of debris on I-670 in Columbus, the collection of litter from a one mile section of the inside shoulder was proposed. However, during the course of this research, the inside shoulder of the proposed I-670 SmartLane was closed due to construction to upgrade the shoulder and signing for mixed traffic on shoulder use.

The crew from ODOT's 5th Avenue outpost provided the research team with a demonstration of their normal procedure for sweeping the shoulder from which a sample of the collected debris was characterized by the research team. A section of I-270 in Columbus was selected for the demonstration and debris collection which was similar, in terms of traffic composition and geometrics, to the section on I-670. The map in Figure 1 shows the location of the debris collection site relative to the proposed SmartLane. Debris was collected from the right

shoulder of the northbound Easton collector using an Elgin mechanical sweeper. Sweeping began at mile 32.27 and ended at mile 30.82, for a total length of 1.45 miles. The section had been swept previously, approximately one month prior to the demonstration on September 6, 2018.

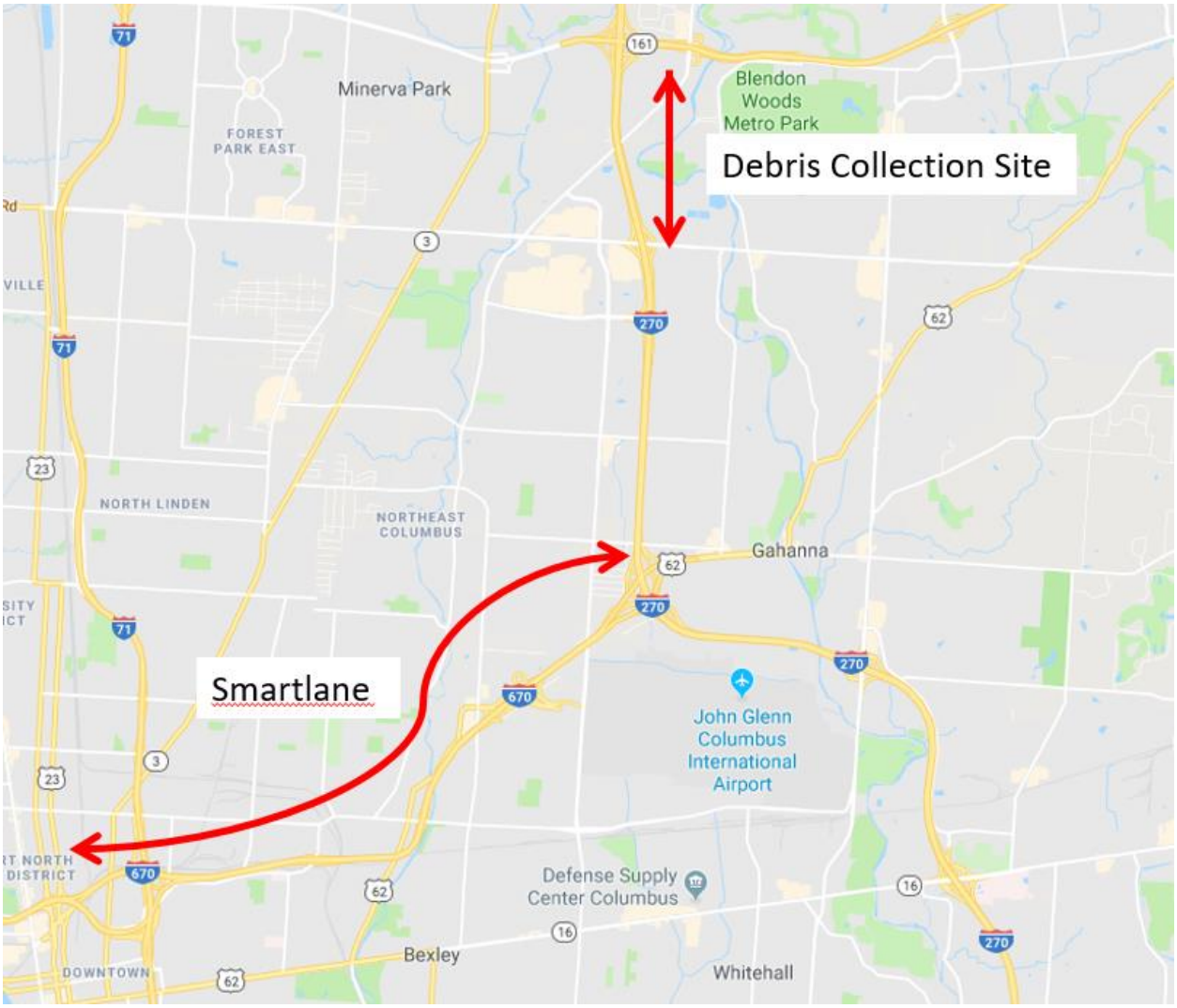

Figure 3.1 Location of Smart Lane and Debris Collection Site (maps.google.com)

The debris was emptied from the dump truck onto the pavement at the ODOT county garage (Figure 2). The measured volume was approximately 105 cubic feet. A sample of the debris was taken, as shown in Figure 3, for detailed evaluation.

Figure 3.2 Debris Collected from Demonstration on I-270

Figure 3.3 Sampling of Debris for Further Evaluation

3.3 Conduct literature search

A comprehensive literature search was conducted to identify best practices used nationally and internationally for clearing debris and hazards in a rapid, cost effective manner from the shoulder prior to traffic. The literature search is presented in Appendix B.

3.4 Develop a matrix of equipment

Information obtained from the literature search and interviews was used to develop a matrix of equipment to be considered for clearing debris from the shoulder prior to use. Equipment specifications, manufacturer contact information, equipment capabilities and estimated purchase price are provided.

3.5 Perform cost-benefit analysis.

The results of Task 1 through 4 were used to evaluate cost and benefit of each equipment option. The team considered labor and equipment cost, efficiency (i.e. operating speed), and other factors identified during Tasks 1 and 3. The team also considered ODOT's current procedure of cleaning shoulders on BOS routes.

4 Research Findings and Conclusions

4.1 Evaluate best practices for daily maintenance and hard shoulder running operations.

4.1.1 Conduct a review of current nationwide practices

Based on interviews conducted with agencies across the country which currently have part time shoulder operations, such as BOS or mixed traffic, a summary of the various practices and equipment used to maintain the shoulder is provided in this section. Specific interview questions and a summary of responses from each agency are provided in Appendix A.

Where BOS operations are allowed, agencies generally do not perform a sweep of the shoulder with cameras or personnel. Rather, it is left up to the bus drivers to determine when it is safe to operate on the shoulder under the designated criteria (typically a mainline speed threshold). For agencies allowing mixed traffic use of their shoulders, the agency's TMC (or equivalent) is utilized to manage the additional lane. One agency specifically reported the use of cameras to perform a sweep of the shoulder in advance of operating hours. Additionally, it was reported the agency's safety patrol performed daily checks looking for debris and disabled vehicles.

While part-time shoulder use presents unique challenges, keeping the shoulder clear of debris was found to be a routine practice regardless of whether part-time shoulder use is allowed or not. Agencies allowing part-time shoulder use did not indicate special operations for clearing the shoulder of debris for routes where BOS or mixed traffic operations on the shoulder were permitted. Furthermore, no agency reported formal written procedures for routine clearing of the shoulder, although informal practices exist in each state. Two states interviewed reported maintenance of the shoulder on the Interstate was performed by contract forces rather than in-house maintenance crews.

Practices for keeping the shoulder clear vary from agency to agency, however, some commonalities exist. Specifically, the use of a street sweeper was found to be a common practice among all agencies interviewed. The frequency of sweeping ranges widely. One agency reported sweeping annually, after the spring thaw, to clear their shoulders, citing traffic in areas of part time shoulder use helps keep the shoulder clear of small items. While another agency tries, although is not always able to achieve this frequency, to sweep their shoulders on a weekly basis. In another state, designated routes are swept less frequently, but hot spots, or areas prone to accumulation of debris (e.g. areas with barrier wall), are swept more frequently in the time between routine sweeping. Two agencies (other than ODOT) reported sweeping at a frequency of approximately one time per month.

At least one agency (other than ODOT) reported using personnel to manually pick-up large items as part of their planned sweeping operation, in which an individual walks the shoulder ahead of the sweeper, picking up larger items and disposing of them in a truck trailing behind the individual. In several states manual pick up of debris on the shoulder was conducted

in between sweeping operations. Some agencies utilize roving personnel which drive routes (typically in large metropolitan areas) looking for larger debris between sweeping operations. In one state roving personnel is deployed daily, in which case state maintenance crews are deployed to remove any items found. In other states roving personnel may perform manual pickup of debris one to three times a week.

Another commonality among reporting agencies was the use of their safety patrol for reporting and where possible, removing debris items. In most cases, safety patrol crews will remove or move, if they are able to, debris items (e.g. tire treads), found in the travelled lane to the side of the road and report larger items (e.g. mattresses) to the agency's TMC whether in the travelled lane or shoulder. One agency reported their safety patrol operates 24/7, 365 days of the year and continuously travels the designated area. The same agency reported several of their safety patrol vehicles are outfitted with snow plows which are used to move larger debris off of the travelled lane. Additionally, one safety patrol vehicle is equipped with equipment referred to as Julie's Automated Waste removal System (JAWS) to scoop up debris and a push bumper to push disabled vehicles out of the travelled lane.

In some states equipment, in addition to sweepers, were reported for clearing the shoulders. In one state, the Road Rake is used to clear the shoulder every other week, while personnel rove routes three times a week and remove any larger debris items spotted, while sweeping is performed approximately once a month. Another state indicated the Road Rake had been used for nearly 20 years for routine clearing of their shoulders. Other equipment was reported for spot removal, as opposed to routine clearance, of debris. One state utilizes equipment, JAWS, attached to a safety patrol vehicle that was designed and fabricated in-house, for removing debris. In ODOT's District 4 the Gator Getter^{TM} is attached to a dump truck and used for spot removal of debris items such as tire treads (also referred to as "gators").

As part of the literature review, several pieces of equipment were identified and agencies were specifically asked about their use. Equipment usage among states is further summarized in Table 3.

Table 3 Summary of Equipment Usage for Agencies Interviewed

Equipment	Agencies	Notes
Manual Collection	Florida, DBI	2 to 3 times a week
	MnDOT	FIRST (safety patrol) team will pick up large debris, patrol daily.
	NJDOT	Crew supervisor patrols daily. Will pick up smaller debris, send crew for larger debris.
	Virginia, DBI	Crew picks up debris 3 days a week
Automated bag removal	CalTrans	One prototype, CalTrans decided not to pursue because the arm operator is located on the back of the equipment.
Street sweeper	CalTrans District 7	Used a Global, one year old, tends to overheat when temperature is in the 90's. Diesel engine Elgin performed much better.
	Florida, DBI	Sweep once a month. Clean about 20 miles a day.
	MnDOT	Sweep annually after thaw. Use Elgin broom on a Sterling chassis.
	NJDOT	Sweep on a regular basis. Have used mechanical sweepers (Tymco and Schwarze) but will be switching to air sweepers January of 2019.
	ODOT District 4	Sweep 3 to 4 times per year. Use Tymco air sweepers. Dumps like a dump truck. Less moving parts than mechanical sweeper.
	ODOT District 6, Franklin County	Use Elgin, Schwarze, and Global. Elgin most effective, then Schwarze, then Global.
	Virginia, DBI	Sweep once a month
	WSDOT	Elgin mechanical sweeper. Sweep between 6 to 8.8 miles per day.
Road Rake	CalTrans District 7	Used every 1 to 1 1/2 month, 14 - 15 miles/day, would empty after 7 miles (1 month since last cleaning), not recommended to scoop anything weighing more than 75 lbs
	Virginia, DBI	Used every other week. Used since 2016. More durable than sweeper. Can do 100 miles in a 12 hour shift. Typically need to dump twice a day. Can break teeth ii lowered too much.
Gator Getter	ODOT District 4	Used since 2012. Used on freeway. Need to go at least 45 MPH (only use on mainline). Can collect several pieces of debris before emptying.
	ODOT District 7	Would kick up small debris
	Virginia, DBI	DBI owns one but does not use. "Shot" 2x4 across traffic during demo.
JAWS	Kansas City Scouts	Have one truck with the JAWS. Can scoop or push debris to shoulder. Built in-house. Has a push bumper. Specification and plans will be made available at no cost to public agencies.
Snow Plow	Kansas City Scouts	Have two trucks with small plows to push debris to shoulder
ARDVAC	CalTrans Districts 3 & 4	not commercial version, used mainly for cleaning drainage
Magnetic Road Sweeping	CalTrans District 7	Had magnetic bars on front of sweepers in the past
	Virginia, DBI	Daily patrol has magnet with removable strip on front bumper

4.1.2 Evaluate current practices for daily maintenance and operations of hard shoulder running in Ohio

The Department does not have a formal written procedure for clearing shoulders prior to BOS operation or the planned mixed traffic on shoulder operation. As was common with the other states interviewed during this research, Ohio has an unwritten process for identifying large debris, or disabled vehicles, on the shoulder and travelled lanes, and for removal of the debris.

There are several ways in which debris may be spotted. Debris may be reported to local law enforcement by the public, or identified by law enforcement themselves, or spotted by ODOT maintenance crews or freeway safety patrols. Debris may also be seen on camera by ODOT TMC. Bus operators on routes with BOS operation may also report large debris on the shoulder.

The ODOT county garage is primarily responsible for removal of debris. When on duty, the safety patrol will also actively remove debris from the travelled lane or move it to the shoulder if it can be moved. Law enforcement will report large debris to the ODOT county garage through the ODOT TMC. If the debris is on the travelled roadway and is an immediate hazard or can cause risk, law enforcement will move the debris to the shoulder, if it can be moved, or will block traffic from hitting the debris until cleared by ODOT, or a private firm under contract with the city.

There currently are no procedures for identifying and clearing debris from BOS and mixed traffic on shoulder routes. The ODOT Franklin County garage and outposts do have an unwritten procedure for cleaning shoulders on the Interstate and highways in Columbus.

Generally, shoulder sweeping is reactive, cleaning the worst of the worst first. It was reported in the Columbus area, the goal is to clean the shoulder approximately every 30 days. The procedure used for cleaning the shoulder in the Columbus area consists of a person picking up large debris ahead of the lead vehicle, typically a dump truck, followed by the street sweeper and then followed by a truck mounted crash attenuator and a truck with an arrow board. The person walking in front of the truck picks up large items the sweeper cannot pick up or which will plug the sweeper such as tires, big rocks, pallets, string, etc., and places the debris in the bed of the lead truck. This truck is also used to collect material from the sweeper, as needed. Based on interviews conducted within the state and with other agencies, it was found this process is commonly used across the country to clean the shoulders.

To collect material from the sweeper, the adjacent lane must be closed. To do so, traffic control moves into the right lane to divert traffic and the sweeper moves into the closed lane while the lead truck backs up beside the sweeper on the shoulder. The sweeper then dumps debris into the truck.

The speed of the operation is typically about 2 to 3 mph and is controlled by the person walking and picking up large debris. Completing four miles of sweeping in a day is considered a “good day”. Four miles will typically fill a truck with debris. Heavy silt presents problems, especially if it is wet, then dries as it makes it difficult to remove from the pavement surface with the sweeper. It was also reported string, wire, and cloth can get wrapped in the gutter broom and cause damage to the sweeper.

Disabled vehicles can present an immediate danger if in the travelled lane, therefore it is important to understand procedures used for addressing disabled vehicles on the roadway. Ohio Revised Code section 4513.61 grants law enforcement the sole authority to order into storage vehicles left on public property. When a law enforcement officer (LEO) encounters a disabled

vehicle the vehicle will be towed to storage if it is an immediate hazard or can cause risk, as would be the case if the vehicle is in a travelled lane. If the vehicle is not a hazard or risk, such as when the vehicle is on the shoulder, the owner has 48 hours to move the vehicle. The LEO will typically tag the vehicle with the date and time, and may notify dispatch. After 48 hours, an attempt to contact the owner will be made. If no response, the vehicle will be towed and stored. The owner then has one week to claim their vehicle. During the meeting with ODOT TMC, the research team was informed the Cleveland area safety patrol owns a tow truck and will tow a disabled vehicle to the shoulder or ramp to clear a lane.

4.2 Debris Characterization

A sample of the debris collected during the sweeping of I-270 was characterized by material type as shown in Figures 4 and 5. The sampled debris was divided into the following components, which are briefly described below:

- Sand and fines – likely soil blown onto the shoulder or falling from vehicles as well as fines from the breakdown of the asphalt surface.
    - Comprised approximately 82% of the total weight and 44% of the total volume of the sampled material.
- Asphalt chunks – a portion of the asphalt overlay which has spalled from the asphalt surface.
    - Comprised less than 1% of the sampled material by weight.
- Rubber – automobile parts/tire tread.
    - Comprised less than 5% of the sampled material by weight.
- Cardboard and paper – fast food sack, cup holder, cigarette pack.
    - Comprised less than 1% of the sampled material by weight.
- Cigarette butts
    - Comprised less than 1% of the sampled material by weight.
- Plastic – car parts and hubcaps, bottles, electrical equipment parts.
    - Comprised less than 3% of the sampled material by weight.
- Glass – broken bottles.
    - Comprised less than 1% of the sampled material by weight.
- Cloth – grout bag and clothing.
    - Comprised less than 1% of the sampled material by weight.
- Aluminum – automobile hubcap, pipe cap.
    - Comprised less than 1% of the sampled material by weight.
- Ferrous material – bolts, screws, automobile parts, raised pavement marker base.
    - Comprised less than 6% of the sampled material by weight.
- Construction debris/plywood.
    - Comprised less than 1% of the sampled material by weight.
- Material not picked up by the sweeper – aluminum pop cans, automobile parts, rocks
    - Comprised less than 1% of the sampled material by weight.

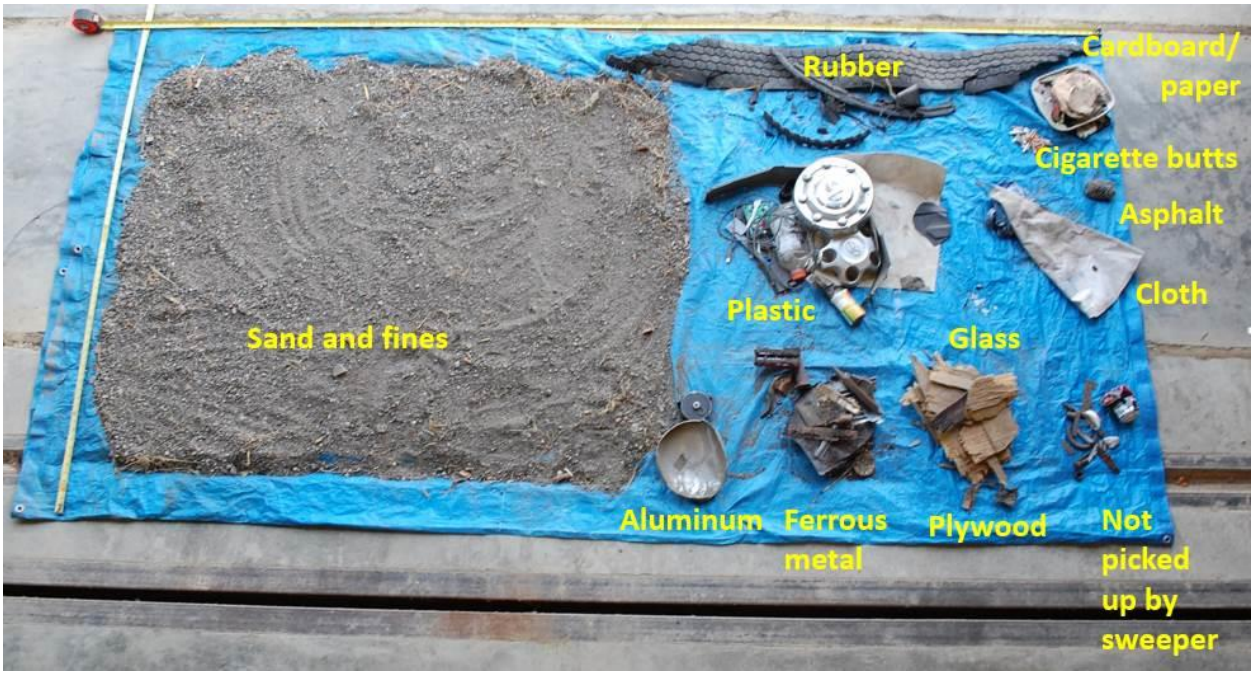

Figure 4.1 Sample of Debris Collected from I-270

Figure 4.2 Material left after passage of sweeper

The sample composition, by weight, is shown in Figure 6. The sampled material weighed a total of 128.2 pounds and had a total volume of approximately 3.3 cubic feet. Assuming the

sample represented the total debris collected, and knowing the total volume of material collected was 105 cubic feet, the total estimated weight of material collected on I-270 would be:

Total weight of debris collected = 128.2 lbs x 105 CF/3.3 CF = 4079 lbs, or slightly more than 2 tons.

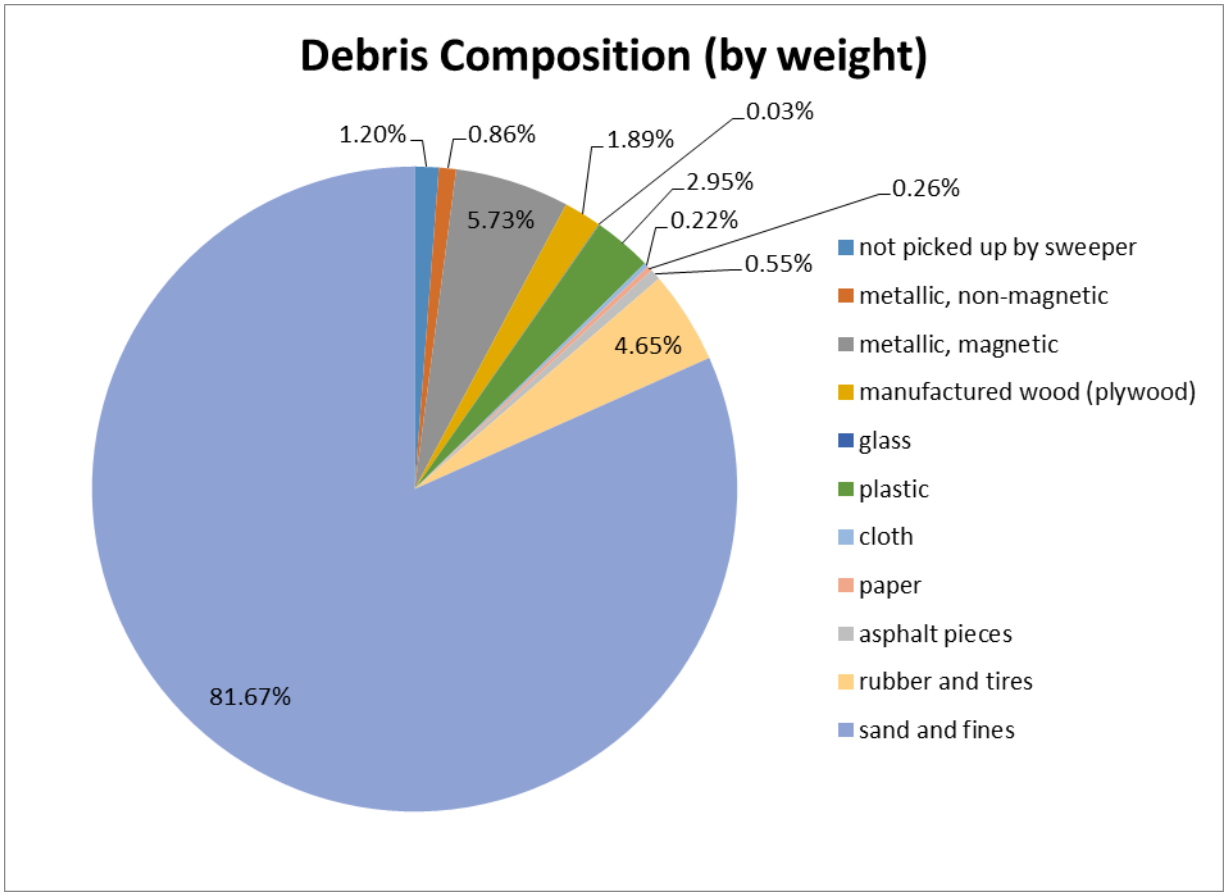

Figure 4.3 Composition of sampled debris

A MnDOT representative revealed during the interview that travelled shoulders are self-cleaning of small debris. Therefore, sand and fines should be blown off the surface by traffic and would only accumulate in areas with barrier. The same would likely be true for paper, glass, and other small debris. Although the collection of sand and other small debris may not be needed for safety, collection of this material may reduce the number of times the drainage system needs to be cleaned. Emptying the hopper of the sweeper requires the adjacent travelled lane be closed so the dump truck can pull next to the sweeper to empty the hopper. Anytime an active lane is closed temporarily presents a danger, and the length of time closed should be kept to a minimum.

Clearing the larger size debris is of most concern because it could prevent the use of the shoulder or create a hazardous situation for traffic using the shoulder. Therefore, the procedure to clear the shoulder should be capable of collecting larger pieces of metal, construction debris (plywood, masonry, etc.), plastic (electronics, buckets, etc.), and rubber (tires, etc.). Current procedures utilize a person walking along the shoulder manually picking up these large items. This presents an obvious danger that should be avoided if possible.

4.3 Literature search

No published procedures for clearing shoulders prior to bus or mixed traffic use were found during the literature search. Therefore, the literature search focused on equipment for clearing shoulders. The literature search identified the following types of equipment:

1. Debris Removal Attachment (DRA), to collect garbage bags left by cleanup crews
2. Automated Roadway Debris Vacuum (ARDVAC), a modified vacuum truck with a remote controlled arm
3. Street sweeper
4. Road Rake, beach cleaning equipment modified to collect debris from the highway
5. Gator Getter™, a truck mounted scoop to collect tire carcass and similar objects from the roadway at high speed
6. JAWS, a truck mounted scoop to collect tire carcass and similar objects from the roadway, or push the debris to the side of the road
7. Magnetic Road sweeper, an electro-magnet or permanent magnet which will collect ferrous material from the roadway.

More detail is provided for each type of equipment in Appendix B.

4.4 Equipment Matrix

One of the objectives of this study is to recommend equipment to increase efficiency of clearing shoulders, with the intent of further evaluating the recommended equipment in Phase 2. To meet this objective, various pieces of equipment and the methods with which they are used were identified and then evaluated based on several factors (discussed in more detail in the following section). In selecting equipment for the evaluation, priority was placed on equipment which improved efficiency over ODOT's current procedure and reduced exposure of personnel to traffic. One agency which has part time shoulder operations (both BOS and dynamic) indicated traffic helps to clean the shoulders of fines and found street sweeping was only necessary one to two times a year in areas without a barrier wall. However, in other states with both BOS and mixed traffic use on shoulders sweeping was conducted on a more frequent basis. Regardless, all three agencies indicated debris which could damage vehicles was of greatest concern in cleaning shoulders. Pertinent information gathered from interviews and the literature search is provided here for each equipment/method. Through interviews and literature search the following methods and equipment used to clear shoulders were identified for initial evaluation:

- Manual collection
- Manual collection with automated bag removal
- Street sweeper
- Road Rake
- Gator Getter™
- JAWS
- Snow Plow
- Vacuum - ARDVAC
- Magnetic Road Sweeping

This first method, manual collection, consists of personnel walking the shoulder and picking up debris. A vehicle would be needed to accompany personnel for disposal of items, for this evaluation it is assumed the vehicle would be a dump truck to accommodate large items such as a mattress. Other equipment exists to facilitate the removal of debris collected and bagged during manual collection. Such equipment often mounted to a truck automates the placing of the bagged debris into a truck bed. While manual collection enables the removal of various sizes of debris, personnel are exposed to traffic and the speed of the operation is slow.

Two types of sweepers can be used to remove debris from the shoulder: mechanical or vacuum sweeper. Currently ODOT Franklin County garage has three mechanical sweepers which are used to clean shoulders. However, a vacuum sweeper is used in ODOT's District 4. The type of sweepers used by other state agencies was mixed with some reporting the use of mechanical sweepers and others using vacuum sweepers. While mechanical sweepers are typically less costly than vacuum sweepers, additional maintenance costs are associated with mechanical sweepers. When the hopper is full, depending on the type and model of the sweeper, the adjacent travelled lane may need to be closed to allow for a dump truck to pull next to the sweeper to empty the hopper from the side. Discussions with sweeper manufacturers revealed mechanical sweepers are best for debris 6 inches or smaller, while vacuum sweepers can handle debris up to 14 inches. Additionally, the manufacturers indicated operating speed for both types, while dependent on the amount of material on the shoulder, is on average approximately 8 mph. Although, both mechanical and vacuum sweepers were included, no distinction was made in terms of the analysis. As noted previously, street sweepers are widely used to clear shoulders, however, they are limited in the size of debris that can be collected. For this reason, the use of the street sweeper may be combined with manual debris collection, when doing so, the operating speed would be controlled by the personnel walking the shoulder and picking up debris.

The Road Rake utilizes rotating brushes combined with tine rakes to remove debris from paved surfaces. The collected debris is transferred on a conveyor belt to a storage area in the pull-behind machine which can later be dumped into a bin or dump truck. The equipment is towed behind a vehicle and runs off either the hydraulic system of the truck or an internal engine. The Road Rake is part of scheduled shoulder cleaning in other agencies and was highly recommended. The Road Rake is capable of picking up debris up to 75 pounds in weight, however, it is not recommended for picking up small debris or flat items less than ¼" thick. As a result, the Road Rake greatly minimizes the need for personnel to be exposed but does not completely eliminate the need for manual collection of large (e.g. mattress or ladder) or flat items (e.g. license plate or plywood). Therefore, it may also be combined with other methods to remove all sizes of debris. While the equipment is capable of removing debris weighing up to 75 pounds, it should be kept in mind the vehicle towing the Road Rake must drive over the debris in order for the trailing Road Rake to remove it.

The Gator Getter™ is a drum shaped scoop designed to remove debris at highway speeds. It can be mounted to the front of a pickup truck or dump truck using a standard snow plow frame. The Gator Getter™ can be operated at a range of travel speeds, although speeds above 45 mph (72 km/h) are recommended for removal of tire debris. ODOT District 4 operates a Gator Getter™ and indicated debris can be kicked up during operation and the scoop needs to be emptied often, therefore it may be best used for spot cleaning. The Gator Getter™ was tried in another state, and in their experience small debris was also kicked up and they reported the equipment "shot" large debris into adjacent lanes.

JAWS, a retractable scoop attached to a push bumper on the front of a pickup truck, was designed and fabricated in-house by one agency, and therefore, is currently only used in that state. The driver can either lower the scoop to remove debris or push it to the shoulder or grass with the bumper. The push bumper can also be used to push disabled vehicles to the side of the road. Currently one of their safety patrol vehicles is equipped with JAWS and plans are in the works to expand the number of vehicles outfitted. Based on the low cost of materials and fabrication, and the ability to remove debris from the travelled lane or shoulder from a vehicle (as opposed to manual collection), JAWS was included in the evaluation of equipment.

The same agency has also outfitted two safety patrol vehicles with a snow plow. This enables them to push larger debris out of the travelled lane to the shoulder or grass. Although this method only moves debris out of the lane or shoulder and may require crews come back later and retrieve large debris, as necessary, it is a quick and efficient method of clearing large debris and the equipment, a snow plow, is relatively cheap. The snow plow, however, would not be effective for clearing shoulders with a barrier wall.

A modified vacuum truck with a remote controlled arm to control the vacuum hose from the vehicle called the ARDVAC was also included in the evaluation. The ARDVAC was designed at University of California Davis for CalTrans. Although not presently available commercially, a prototype was fabricated by a company located in Ohio. As with any vacuum system, there are limitations on size of debris the equipment is able to remove. This equipment was included for evaluation given the proximity of a manufacturer and the ability to remove debris remotely from the vehicle.

Lastly, a magnetic road sweeper, was included in the evaluation. There are two types of magnetic road sweepers: electro-magnetic or permanent. The electro-magnetic sweeper is typically more expensive than a permanent magnet. Magnetic road sweepers come in various forms, with some models available as a tow behind sweeper, and others which can be attached to a fork lift or mounted to a front bumper. Currently, ODOT has a magnetic road sweeper mounted to one of the three mechanical sweepers, however, the magnet does not have a release which makes it difficult to remove the ferrous material from the magnet once sweeping is completed. Much of the material that the street sweeper was not able to remove during the demonstration on I-270 was ferrous material. For this reason and because mounted permanent magnetic sweepers are relatively inexpensive the magnetic road sweeper was also included in the evaluation.

For each of the aforementioned methods and equipment information regarding, cost, size of debris collected, number of personnel needed, operating speed, and capacity of debris collected were gathered for various models of the identified equipment. Detailed information for each is provided in Appendix C.

Based on the information collected, the type of debris each equipment is capable of collecting was categorized into five categories: sand and fines, small (less than 6 inches), medium (e.g. tires), large (e.g. ladder), and magnetic material. The type of debris collected is provided below in Table 4. Debris size information was determined for each single piece of equipment as a stand-alone operation. However, based on findings from interviews with ODOT crew and other state agencies, cleaning operations may involve more than one type of equipment. Therefore, combinations of methods and equipment were also included. Where combinations of equipment/methods are provided, the type of debris collected considers the capability of all equipment included.

Table 4 Summary of Type of Debris Collected for each Equipment/Cleaning Procedure

Cleaning Procedure	Equipment	Type of debris collected				
		Sand and fines	**Small (<6")**	**Medium (tires, etc.)**	**Large (ladder, 2x4, etc.)**	**magnetic metal**
		Single Method				
Manual Collection	Dump Truck	No	Typically No	Yes	Yes	Some
	Stake bed truck with automated bag removal	No	Yes	Yes	No	Some
Street Sweeper	Street sweeper	Yes	Yes	No	No	Some
Road Rake	road rake with tow vehicle	No	No	Yes	No	Some
Gator Getter™	Gator Getter™ mounted on a dump truck	No	Typically No	Yes	No	Some
JAWS	Pickup truck equipped with JAWS	No	Typically No	Yes	Push to side	Some
Snow Plow	Snow plow mounted on a pickup	No	Typically No	Yes	Push to side	Some
Vacuum	ARDVAC	Yes	Yes	No	No	Some
Magnetic Road Sweeping	Pickup truck equipped with bumper mounted magnet	N/A	N/A	N/A	N/A	Yes
Cleaning Procedure	**Equipment**	**Combination of Methods**				
Manual Pickup and Street Sweeping	Dump truck and street sweeper	Yes	Yes	Yes	Yes	Some
Road Rake and Street Sweeping	Road Rake with tow vehicle, street sweeper	Yes	Yes	Yes	No	Some
Road Rake, Street Sweeping, and Magnetic Road Sweeper	Road Rake with tow vehicle, street sweeper, and magnetic sweeper	Yes	Yes	Yes	Yes	Yes
Road Rake, Street Sweeper, JAWS, and Magnetic Road Sweeper	Road Rake with tow vehicle, street sweeper, pickup truck equipped with JAWS, and magnetic sweeper	Yes	Yes	Yes	Yes	Yes

4.5 "Cost-benefit" analysis

Initially a cost-benefit analysis of the equipment identified and discussed in section 4.4 had been planned, however, during the course of this research, factors other than cost, such as safety of the work crew, clearing all debris from the shoulder, and the operating speed of the cleaning process, were identified. This type of decision does not lend itself to a simple cost-benefit analysis. The life of some equipment is not known, while some are prototypes with unknown production costs. It is difficult to capture the longevity or life of many of pieces of equipment, as that information is not available from the manufacturer while the use of others are not widespread preventing an accurate assessment of life. Furthermore, other costs are difficult to quanitify, i.e. the cost of the risk of having a person walking the side of a freeway. Therefore, a decision matrix was used to assess the equipment and identify equipment for further evaluation in Phase 2.

First, the team identifed four factors for analysis: cleaning cost per mile, operating speed, type of debris collected, and safety. The cleaning cost was determined for each of the cleaning procedures and is listed in Table 5. This process is described below. The type of debris collected, and operating speeds identified during the literature review and interviews are shown in Tables 4 and 5, respectively.

The equipment cost, expected life, hourly cost, personnel needed in addition to those operating the equipment, operating speed, and cleaning cost per mile was determined for each equipment/method and combination of equipment considered, as shown in Table 5. Costs for combination of methods and equipment are based on the sum of the cost for the individual equipment/methods included.

In calculating the equipment cost, the team assumed all equipment needed for the process, with the exception of the equipment used for maintenance of traffic, would be purchased to allow for a fair comparison. For example, the manual collection of debris included the purchase of a dump truck, even though ODOT has dump trucks at each garage. The cost of dump trucks and street sweepers, with the exception of Schwarze and Tymco, were obtained from the Ohio Department of Administrative Services (ODAS) web site. The cost of the Schwarze and Tymco sweepers were obtained from conversations with the manufacturers. Where more than one manufacturer or model of equipment were identified, as in the case of street sweepers, the equipment cost was determined by taking the approximate average cost of all models identified. Cost of pickup trucks, Road Rake, Gator Getter™, and magnetic road sweepers were obtained from the manufacturer's or distributor's website. Unfortunately, maintenance costs could not be obtained for the various equipment included in this study, so this was not considered in the evaluation of equipment and methods.

The average life of trucks and other equipment on the ODAS equipment salvage auction was 13 years, so this value was assumed for the expected life of motorized equipment. Non-motorized equipment was assumed to have a life of 20 years based on the life CalTrans obtained from their Road Rake.

Table 5 Summary of Associated Costs for each Equipment/Cleaning Procedure

Cleaning Procedure	Equipment	Equipment Cost	Expected life of equipment	Hourly Equipment Cost	Additional Labor	Labor Cost ($/hour)	Assumed Operating speed (MPH)	Cleaning Cost ($/mile)
		Single Method						
Manual Collection	Dump Truck	$87,000	13	$3.22	one highway worker walking	$20.00	2	$11.61
	Stake bed truck with automated bag removal	$57,000	13	$2.11	one highway worker walking	$20.00	2	$11.05
Street Sweeper	Street sweeper	$265,000	13	$9.80			10	$1.23
Road Rake	Road Rake with tow vehicle	$104,800	20	$2.52			18	$0.14
Gator Getter™	Gator Getter™ mounted on a dump truck	$109,000	20	$2.62			45	$0.06
JAWS	Pickup truck equipped with JAWS	$36,000	20	$0.87			45	$0.02
Snow Plow	Snow plow mounted on a pickup	$39,000	20	$0.94			45	$0.02
Vacuum	ARDVAC	$381,000	13	$14.09			2	$7.05
Magnetic Road Sweeping	Pickup truck equipped with bumper mounted magnet	$34,400	20	$0.83			5	$0.17
Cleaning Procedure	**Equipment**	**Combination of Methods**						
Manual Pickup and Street Sweeping	Dump truck and street sweeper	$352,000	13	$13.02	one highway worker walking	$20.00	2	$16.51
Road Rake and Street Sweeping	Road Rake with tow vehicle, street sweeper	$369,800		$12.32			10	$1.23
Road Rake, Street Sweeping, and Magnetic Road Sweeper	Road Rake with tow vehicle, street sweeper, and magnetic sweeper	$371,200		$12.35			10	$1.24
Road Rake, Street Sweeper, JAWS, and Magnetic Road Sweeper	Road Rake with tow vehicle, street sweeper, pickup truck equipped with JAWS, and magnetic sweeper	$407,200		$13.22			10	$1.32

The equipment cost and expected life were used to calculate hourly equipment cost, i.e. the cost of equipment divided by the number of hours of operation. The hours of operation were assumed to be 260-eight hour days per year over the life of the equipment. However, final cost will depend on actual time of usage of the equipment.

Personnel, in addition to equipment operators, were included for manual collection of debris, in which one person walks the shoulder. The labor cost for the additional personnel is included in the cleaning cost per mile. The cleaning cost, per mile, was calculated using the hourly equipment cost, cost of additional personnel, and the operating speed of the process.

Next, criteria were established for the four factors. Each cleaning procedure was rated based on these critiera. Criteria and ratings were as follows:

- Speed: Based on operating speed
    - Rating: 1 to 3, where,
        - 1 is good (≥45),
        - 3 is fair (8 MPH≤ speed < 45 MPH) and
        - 5 is poor (< 8 MPH)
- Cost: Based on cost per mile
    - Rating: 1 to 5, where,
        - 1 is good (<$1.00/mile),
        - 3 is fair ($1.00≤ cost <$10.00) and
        - 5 is poor (≥ $10.00)
- Debris: Based on capability of removing various sizes of debris
    - Rating: 1 to 5, where,
        - 1 is a procedure which collects all types of debris,
        - 2 collects 4 types of debris,
        - 3 collects 3 types of debris,
        - 4 collects 2 types of debris, and
        - 5 only collects one type of debris.
    - For procedures that collect some of a debris category, a half point was assigned.
    - Magnetic metal includes nails and screws as well as metal vehicle parts, etc.
- Safety: Based on personnel exposed and differential in traffic speed
    - Rating: 1 to 5, where,
        - 1 is good (equipment operates near highway speeds and no personnel on shoulder)
        - 3 is fair (equipment operates below highway speeds and no personnel on shoulder), and
        - 5 is poor (equipment operates below highway speed and there is personnel on the shoulder)

The ratings for each factor are shown in Table 6 for each of the cleaning procedures evaluated. ODOT's current procedure for clearing shoulders on BOS routes in central Ohio consists of manual pickup and street sweeping, the first combination of methods listed in Table 6. As shown in Table 5, the operating speed of this procedure is approximately 2 mph, based on the criteria listed above, it is rated poor, or "5" in that category. In terms of cleaning cost, this procedure rates as a 5 for poor, as it costs approximately $16.51 per mile (this includes the cost of a new street sweeper and dump truck), the most expensive of the equipment/methods investigated. As shown in Table 4, this procedure is capable of collecting 4 of the the 5

categories of debris, therefore it received a rating of "2". Lastly, ODOT's current procedure in central Ohio was rated as "5" because of both the slow operating speed and the need for personnel on the shoulder, exposing them to traffic for prolonged periods.
The team then worked with the Technical Advisory Committee (TAC) to assign weights to each factor. The weight reflects the amount of influence the factor should have on the decision. The TAC chose to assign 10% to cleaning cost and 30% each to operating speed, type of debris collected, and safety. A final score is then determined for each cleaning procedure by summing the product of the rating and weight for each factor. Based on the ratings which were selected, where a rating of 1 was best, lower total scores are desired. The final scores for each method or combination of methods are listed in Table 6 in bold.

Table 6 Decision Matrix for Evaluating Cleaning Procedures

	Rating				**Sum of weight*rating**	Rank
	Operating Speed (MPH)	**Cleaning Cost**	**Type of Debris Collected**	**Safety**		
	weight =30%	weight =10%	weight =30%	weight =30%		
Cleaning Procedure	**Single Method**					
Manual collection	5.0	5.0	3.5	5.0	**4.6**	10
Manual collection with automated bag removal	5.0	5.0	3.5	5.0	**4.6**	10
Street sweeper	3.0	3.0	3.5	3.0	**3.2**	5
Road Rake	3.0	1.0	4.5	3.0	**3.3**	6
Gator Getter™	1.0	1.0	4.5	3.0	**2.7**	3
JAWS	1.0	1.0	4.5	1.0	**2.1**	1
Snow Plow	1.0	1.0	4.5	3.0	**2.7**	3
Vacuum - ARDVAC	5.0	3.0	3.5	3.0	**3.8**	7
Magnetic Road Sweeping	5.0	1.0	5.0	3.0	**4.0**	8
Cleaning Procedures	**Combination of methods**					
Manual Pickup and Street Sweeping	5.0	5.0	2.0	5.0	**4.1**	9
Road Rake and Street Sweeping	3.0	3.0	3.0	3.0	**3.0**	4
Road Rake, Street Sweeping, and Magnetic Road Sweeper	3.0	3.0	2.0	3.0	**2.7**	3
Road Rake, Street Sweeper, JAWS, and Magnetic Road Sweeper	3.0	3.0	1.0	3.0	**2.4**	2

The lowest, and therefore, most favorable score, was a value of 2.1 for JAWS operating as a stand-alone cleaning procedure. As shown in Table 6, JAWS received a rating of "1" for three of the four factors. While JAWS operates at one of the fastest operating speeds, and has a low cleaning cost per mile, and is considered safe because of its operating speed and it does not rely on personnel on the shoulder, it is not capable of retrieveing a wide range of debris types. On the other hand, the highest score or least favorable, was associated with manual collection

with or without the automated bag removal system, both with a score of 4.6. Manual collection with or without automated bag removal received ratings of "5" in all categories except type of debris collected in which it received a rating of "3.5."

Although JAWS as a stand-alone operation ranked number one with the most favorable score in the decision matrix, similar to the Gator Getter™, it may be best for spot cleaning due to its limited bin capacity. The snow plow also received a low total score, however it requires debris be pushed to the side. In areas with barrier wall, such as the I-670 SmartLane, there is limited space to push the debris to and therefore, the snow plow would not be recommended. However, it may be an effective method of clearing the shoulder on other routes.

Stand-alone operations are cheaper than combination of methods due to the need for less equipment. However, cleaning cost was assigned the lowest weight, while the remaining three factors, operating speed, type of debris collected and safety each had weights of 30%. Based on this it can be interpreted ODOT is willing to pay more for a cleaning procedure which is faster, removes a wide range of debris and is safer. Combining equipment and methods enables a wider range of debris to be collected. This is evident by the lower ratings for "type of debris collected" shown in Table 6. While type of debris collected is improved, the operating speed and safety for cleaning procedures with a combination of equipment/methods are controlled by the slowest and least safe equipment/method included in the procedure.

ODOT's current procedure is a combination of manual pickup and street sweeping and it received a total score of 4.1 which ranks it as number 9. This is an improvement over manual pickup as a stand-alone procedure (total score of 4.6) because of the increase in debris that can be collected, however, the manual pickup is the slowest (an assumed operating speed of just 2 mph) and the least safe part of the operation. ODOT's current procedure has the lowest equipment cost among the combination of methods at $352,000, but the highest cleaning cost among all procedures with a value of $16.51 per mile.

The cleaning procedure which includes the Road Rake, street sweeper, JAWS, and magnetic road sweeper received the lowest score among the combination of methods investigated with a score of 2.4, which is the second lowest score among all procedures considered. The most favorable procedure, JAWS, may operate best for spot cleaning as opposed to scheduled cleaning, therefore, the combination of the Road Rake, street sweeper, JAWS and magnetic road sweeper would be preferred. The results of the analysis were presented to the TAC on November 26, 2018. The TAC decided to forego any further analysis of the JAWS due to concerns about the anticipated time and cost needed to construct this equipment in-house.

Given the TAC's decision, the cleaning procedures with the next best rank should be considered. The next most favorable score was 2.7 and three procedures received this score: the Gator Getter™, snow plow, and the combination of Road Rake, street sweeper, and magnetic road sweeper. As noted previously the Gator Getter™ and the snow plow may be best for spot cleaning, therefore the combination of Road Rake, street sweeper, and magnetic road sweeper would be preferred. This combination of methods has an equipment cost of $371,200 which is approximately $19,200 greater than ODOT's current procedure. This translates to an increase of 5.5% in equipment costs, however, the cleaning cost at just $1.24 per mile represents a fraction (7.5%) of the cleaning cost for ODOT's current procedure. Relative to ODOT's current procedure, this additional equipment cost allows for more miles to be covered in the same amount of time, increases the type of debris that can be collected, and eliminates the need for personnel to be exposed to traffic for a prolonged period of time.

5 Recommendations

Based on the interviews conducted and literature review, recommendations are provided in the following subsections regarding equipment and operating procedures for clearing shoulders for part-time shoulder use.

5.1 Equipment

Based on the decision matrix analysis using weights selected by the TAC, most procedures evaluated have a lower total score than the current procedure of manual pick up followed immediately by street sweeping. Therefore, in terms of speed, cost, type of debris collected, and safety, all cleaning procedures evaluated, with the exception of manual pick up as a stand-alone procedure are better than the current procedure. In order of decreasing effectiveness, the following methods will remove most debris in a quick, safe manner compared to the current procedure:

1. Combination of Road Rake, street sweeper, JAWS, and magnetic road sweeper
2. Combination of Road Rake, street sweeper, and magnetic road sweeper
3. Combination of Road Rake and street sweeper

Other procedures received a more favorable ranking than the current procedure however, these would not be as effective as the current method in removing debris but are quicker and safer. These procedures include:

1. JAWS
2. Snow plow
3. Gator Getter™
4. Street sweeper
5. Road rake
6. Vacuum
7. Magnetic road sweeping

This list does show the flaw in the decision matrix as constructed since the street sweeping would not be possible without removing larger debris which would plug the machine. In addition, the remaining equipment, with the exception of the street sweeper and vacuum, can only remove a limited number of debris types. Therefore the research team recommends Phase 2 focus on equipment combinations to remove a range of debris. It is important to note the equipment in the combination does not have to be operating on the same schedule. Based on the results of the decision matrix and feedback from the TAC, it is recommend the combination of Road Rake, street sweeper, and magnetic road sweeper be further evaluated in Phase 2. It is recommended field trials of the equipment be conducted to verify the results of the analysis conducted herein and to determine the best operating schedule and procedure to maximize the benefits of the equipment.

5.2 Operating procedure

The current procedure for clearing shoulders in Franklin County is to conduct manual pick up of larger debris (that cannot be collected be the sweeper) in conjunction with street sweeping approximately once a month. Additionally freeway safety patrol operating in the area will either pick up or move to the shoulder any debris found in the travelled lane. Based on interviews with

agencies across the country and a review of current procedures in Ohio, the following recommendations are made:

- The SmartLane on I-670 is a pilot program, therefore, any standard procedure should be considered preliminary and revisited after 6 months of operation. Furthermore, the operating procedures should be revised prior to deployment of SmartLane technology in other areas of the state.
- Currently the freeway safety patrol operates in Central Ohio during the hours of 6:00 AM to 9:00 PM Monday through Friday. Consideration should be given to include them as part of shoulder clearing for morning and afternoon commute. This would require an extension of the morning hours to an earlier start time.
- A full camera sweep of the SmartLane should be conducted by ODOT TMC prior to hours of operation. Any debris should be reported to ODOT maintenance crew from the appropriate county garage. Disabled vehicles should be reported to appropriate law enforcement.
- In central Ohio good coordination was found to exist between ODOT TMC, law enforcement, ODOT county garage, and freeway safety patrol. Consideration should be given for establishing procedures for Central Ohio Transit Authority (COTA) bus drivers to report debris on BOS routes and mixed traffic routes through their dispatcher.
- Currently, disabled vehicles or debris found on the shoulder are not classified as an immediate risk or hazard by law enforcement. Consideration should be given to applying procedures for removal of disabled vehicles and debris found in the travelled lane to shoulders designated as a SmartLane.
- The Road Rake should be considered for removal of large debris. Based on interviews with agencies using the Road Rake as part of routine clearance of shoulders, it is recommended ODOT consider using the Road Rake every week and adjust the frequency as needed based on accumulation of medium sized debris (e.g. tires or tire treads). Additionally, it is recommended the Road Rake be used prior to sweeping, either the day of or one day prior, to remove medium sized debris which the sweeper is not capable of removing or may clog the sweeper.
- It is recommended ODOT continue to use the street sweeper to remove finer debris. Based on interviews and current procedures, it is recommended ODOT sweep as necessary to remove fine material to minimize maintenance on drainage. Initially ODOT may consider a frequency of one time per month and adjust this frequency based on the accumulation of fines observed by maintenance crews.
- In areas where debris and fine material tend to accumulate, such as areas with barrier wall and bridges with parapet walls, more frequent cleaning of the shoulder may be necessary using equipment necessary for the debris size.
- Magnetic road sweepers which are relatively cheap can be mounted to any bumper and are effective in removing nails, screws, etc. as well as most of the items that were not picked up by the sweeper during the demonstration on I-270. It is recommended ODOT consider mounting magnets to the sweeper, and/or the Road Rake. Magnets with removable covers are recommended to allow for easy removal of material from the magnet.
- It was found many other states do not clear the shoulder in inclement weather, therefore, consideration should be given to suspending operations during rain or snow for safety.

- Recommended standard operating procedures were developed (Appendix C) for further evaluation in Phase 2.

6 Phase 2 research plan

With the soon to be deployed SmartLane on I-670, there is a need to establish equipment and operating procedures for cleaning the shoulder prior to the opening of the SmartLane to traffic. Work completed in Phase 1 identified current procedures and equipment utilized in Ohio and other states for clearing shoulders. Focus was placed on agencies with part time shoulder operations. Outcomes of Phase 1 research include recommended equipment and a draft standard operating procedures for cleaning the shoulder to maintain the SmartLane corridor.

Currently, ODOT cleans shoulders with BOS operations on approximately a monthly basis in which crew walk the shoulder picking up larger debris items the trailing street sweeper is unable to remove. While proper maintenance of traffic is provided, personnel walking the shoulder are exposed to traffic, creating a safety concern. Furthermore, speed of the operation is controlled by personnel walking the shoulder. Therefore, there was interest in equipment which could improve the cleaning operation in terms of safety and speed.

Additionally, it is recognized there are fundamental differences in traffic between BOS and the proposed SmartLane operations, and therefore current procedures and equipment used for BOS operations may not be adequate for SmartLane operations. Based on the interviews conducted in Phase 1, a draft standard operating procedure was developed incorporating the recommended equipment. However, there is a need to evaluate the recommended equipment and procedures from Phase 1 to establish a standard operating procedure for keeping the SmartLane clean.

It is recommended further research be conducted with the primary goal to verify the ability of the selected equipment to remove various debris encountered on a typical interstate shoulder and to verify, and refine the draft standard operating procedure developed in Phase 1. Research in Phase 2 will be threefold: 1) conduct a demonstration of recommended equipment to select equipment for purchase and evaluation; 2) evaluate the equipment selected for purchase in context of the draft standard operating procedure; and 3) refine the standard operating procedure based on the evaluation of the equipment's ability to clear an in-service shoulder on an interstate in Columbus. The following equipment is proposed for further evaluation of Phase 2 of this study:

- Sweeper
- Road Rake
- Magnetic Road Sweeper

To meet this goal, the following tasks are proposed:

Task 1: TAC meeting.
The research team will meet with the TAC to come to a consensus on criteria for evaluating the selected equipment.

Task 2: Schedule demonstration of equipment
The research team will contact equipment manufacturers and/or distributors to establish dates and costs (if any) for demonstration.

The research team has had discussions with manufacturers of the equipment recommended for field evaluation regarding the possibility of demonstrations. Two street sweeper manufacturers, Schwarze and Tymco, have indicated local distributors may be able to provide demonstrations. Ohio magnetics was contacted regarding a mountable magnet with cover and the research team was informed a 60-inch magnet that can be attached to a forklift could be available for a demonstration. The manufacturer of the Road Rake does not have a unit available for demonstration, however, they will construct a unit to be rented for at least 2 weeks. The cost associated with the rental would include one day of training on the use and maintenance of the equipment, the shipment of the unit to and from the manufacturer, and rental fee for a total approximate cost of $5900. If the Road Rake were to be purchased this cost would be discounted from the total price. The delivery time from time of rental agreement would be 120 days to allow for manufacture and shipment of the unit. If this time and cost is prohibitive an alternative to the demonstration of the Road Rake may be a site visit to Indiana DOT as they have recently purchased several units.

Task 3: Conduct demonstrations

Demonstrations will be conducted to verify the limitations of the equipment and to evaluate the ability of the selected equipment to remove various sizes and types of debris. A sample of debris collected from the roadway by ODOT and sorted by the researchers will be used in the demonstration to evaluate the equipment. As an example, the following is a minimum of what will be evaluated:

- The ability of the sweepers and the Road Rake to pick up flat debris. Plywood of various thickness and size will be provided for the evaluation.
- The ability of the Road Rake to pick up heavy material. Bulky material, e.g. tires, mufflers, brake drums, etc. will be used.
- The ability of the vacuum sweeper and the mechanical sweeper to pick up fine material.

In cooperation with ODOT, the research team will determine the composition of the debris prior to the demonstration. The research team will also evaluate the composition of the debris collected and not collected by each piece of equipment. Assistance will needed from ODOT to collect debris to be used for the demonstration. This would include storage of debris collected from a scheduled cleaning.

In cooperation with ODOT, the research team will identify suitable locations to conduct demonstrations of the selected equipment. Sites should allow for travel of speeds up to 10 mph and have little or no traffic. Possible locations include the parking lot at OU-Lancaster, service roads on DEL-23 at the Ohio/SHRP test road, State or county Fairgrounds, or other roads where existing sections have been closed such as old US-33 in Nelsonville or old US-50 in Vinton County (part of SOLVER).

Task 4: Summarize findings from demonstrations

The research team will summarize the amount and type of debris collected by each piece of equipment and evaluate the equipment based on the criteria established in Task 1. Final recommendations will be made on purchasing equipment.

Task 5: Evaluate and refine standard operating procedure

Once equipment has been purchased the research team will work with the crew from ODOT's 5th Avenue Outpost garage to evaluate the draft standard operating procedure. This task will consist of ODOT's crew carrying out the standard operating procedure for a minimum of one full month. After one month the research team will evaluate the standard operating procedure and refine as necessary.

If the SmartLane corridor of I-670 eastbound is available, the evaluation will take place there. If it is not, consideration will be given to the westbound direction of I-670 along the same stretch designated for the SmartLane corridor. If neither is available, a route will be selected with consensus from the TAC. Ideally a route will be selected that has a stretch of approximately 5-10 miles of shoulder available for cleaning with barrier wall or median wall along much of the stretch to simulate the characteristics of the SmartLane corridor.

Prior to the first week of evaluating the draft standard operating procedure, the shoulder should be cleaned following current procedures. Debris collected with the Road Rake will be characterized after each week. Characterization of debris collected with the street sweeper will be conducted after the first use of the sweeper. The research team will follow the operation on at least one occasion to make observations. The crew will be asked to document total miles covered, number of times the hopper of each, the Road Rake and Street Sweeper, is emptied and any issues encountered for each outing.

After the first month an after action review will be conducted. This will include interviews with crew and supervisors from ODOT's 5th Avenue Outpost garage to hear concerns regarding the procedure, areas that worked, and what did not work as expected. Based on the interviews and the research team's evaluations the research team will refine the standard operating procedure to address items identified in the after action review.

Task 6: Finalize standard operating procedure

Once the research team has refined the standard operating procedures, the crew will then be asked to make the recommended changes and follow the procedure for another full month. As was done in Task 5, the research team will evaluate the changes made to the standard operating procedure by making observations, characterizing collected debris and conducting interviews with personnel from ODOT's 5th Avenue Outpost. The research team will then make final recommendations on the standard operating procedure.

Task 7: Summarize results

The research team will summarize results of Tasks 5 and 6.

Task 8: Final Report

The research team will document the work accomplished in Phase 1 and Tasks 1 through 7 of Phase 2 and provide recommendations for a final standard operating procedure.

Duration: 18 months, including a four month review period of the draft final report.

A proposed project schedule is provided below.

Evaluation of Maintenance Procedures for Hard Shoulder Running - Phase 2

Instructions: **1**. Enter project Title (Cell B1) - **2**. Enter estimated project start date (Cell C3) **3**. Enter each task and their deliverable (Cells B7-B26) - 4. You may delete or change task rows you don't need.- **5**. Shade in the cells along the timeline for each task's duration - 6. Mark the month for each task's deliverable to be turned in to ODOT. AN EXAMPLE SCHEDULE IS SHOWN ON ANOTHER WORKSHEET BELOW

Project Schedule

Start Date	Feb 1, 2019

# Month (i.e.-1 represents first full month completed)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	Notes
Month:	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	
Task 1: TAC Meeting																																										
Task 1 Deliverable:																																										
Task 2: Schedule Demonstration of Equipment																																										
Task 2 Deliverable:																																										
Task 3: Conduct Demonstration																																										
Task 3 Deliverable:																																										
Task 4: Summarize Findings from Demonstrations																																										
Task 4 Deliverable:																																										
Task 5: Evaluate and Refine Standard Operating Proecedure																																										
Task 5 Deliverable:																																										
Task 6: Finalize Standard Operating Procedure																																										
Task 6 Deliverable:																																										
Task 7: Summarize Results																																										
Task 7 Deliverable: Describe deliverable																																										
Task 8: Final Report																																										
Task 8 Deliverable: Final Report																D			F																								

Figure 6.1 Proposed Phase 2 Project Schedule

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8 Appendix A: Interviews

8.1 Meeting with ODOT District 6 Franklin County

The research team initially met with representatives from ODOT central office and District 6 Highway Management, supervisors from the ODOT Franklin County garage and outposts, and the mechanic from the Fayette County garage. The agenda for the meeting, with pertinent information gathered at the meeting shown in italics, is shown below:

- Discuss current procedures for hard shoulder maintenance for bus on shoulder (I-70) in Columbus
    - Cleaning/sweeping:
        - *ODOT patrols an area of the freeway at least weekly. For all freeway shoulders, sweeping is reactive, do worst of the worst. About 5% of the year is devoted to sweeping.*
        - *Use moving operation maintenance of traffic (MOT) setup. Typically six people but can be by with five. Lead vehicle is a truck. One person walks in front of truck picking up large items such as tires, big rocks, pallets, etc. that will plug the sweeper. This debris is placed in the bed of the lead truck. This truck is also used to collect material from the sweeper as needed. The sweeper is the second vehicle followed by a truck mounted crash cushion and a truck with an arrow board.*
        - *To collect material from the sweeper, traffic control will move into the right lane to divert traffic. The sweeper will move into the closed lane and the lead truck will back up beside the sweeper. The sweeper then dumps debris into the truck.*
        - *Typical operation moves about 2 to 3 MPH. Speed of operation controlled by person walking and picking up large debris. Four miles of sweeping is*

a "good day". Four miles will typically fill a truck with debris. Heavy silt presents problems, especially if it is wet, then dries.

- Role of various agencies:
  - COTA – *will report large items on bus on shoulder routes*
  - CPD/Columbus Fire Department (CFD) – *will report large items. May move problematic debris to a safer area if necessary.*
  - Franklin County Sheriff – *will report large items to ODOT traffic management center (TMC)*
  - Ohio State Highway Patrol – *will report large items to ODOT TMC*
  - State Farm safety patrol
    - *Starts at 6:00 AM, may not be useful for clearing SmartLane on I-670. Will move items to shoulder on all routes they patrol.*
  - Traffic Management Center
    - *Can see "everything" on cameras. Will notify garage if they see or get a report of debris. Will make the decision of when to open or close SmartLane.*

- Discuss planned procedures for hard shoulder maintenance for mixed traffic on shoulder (I-670)
  - Cleaning/sweeping
    - *Would like to find a more efficient way to maintain SmartLane.*
  - State Farm safety patrol
    - *Have five trucks that patrol the Columbus area.*
- View equipment at ODOT Franklin County garage
  - *The county has three sweepers: Elgin, Schwarze, and Global. The Elgin and Global were on site. The Elgin was operational, the Global was down for repair. All have similar capacity. Anything bigger than a fist could cause problems. Biggest obstacle if keeping sweepers up and running. More mechanical components and less electrical components are best for sweepers.*
  - Equipment: *Elgin*
    - Labor needs: *One operator. Another person can ride in cab for training. Has controls on both sides.*
    - Operating speed: *speed is controlled by how fast the laborer is able to pick up large debris ahead of sweeper*
    - Capacity: *five cubic yards*
    - Maintenance cost: *Has been the most cost effective. Parts are easy to obtain.*
    - Pros and Cons*: Conveyor belt has slats which moves material into hopper. Wide broom in the back of the machine. "Dustless" system does not work well.*
  - Equipment: *Schwarze*
    - Labor needs: *One operator. Another person can ride in cab for training. Has controls on both sides.*
    - Operating speed

        - Capacity: *four to five cubic yards*
        - Maintenance cost: *More cost effective than the Global but not as cost effective as the Elgin.*
        - Pros and Cons: *Has pinch point where debris can get stuck. Electrical issues when wet. Has magnet on the front of the machine. Permanent magnet, difficult to remove debris from magnet.*
    - Equipment: *Global*
        - Labor needs: *One operator. Another person can ride in cab for training but has to set on a jump seat*
        - Operating speed:
        - Capacity: *four to five cubic yards*
        - Maintenance cost: *About 50% more than the Elgin. About a one to two week wait for parts.*
        - Pros and Cons: *Has pinch point where debris can get stuck. Electrical issues when wet. Have to get very close to dump truck to unload, easy to cause damage to sweeper or truck. Meant for light city trash, not highway use Wide broom mounted in the middle of the sweeper.*
    - Equipment: *Gator Getter™*
        - Labor needs
        - Operating speed
        - Capacity
        - Maintenance cost
        - Pros and Cons: *District 7 has one, not happy with performance. Will pick up large debris but small debris is thrown "everywhere".*
- Litter sampling: need alternative location, I-670 is under construction: *County will coordinate with research team to locate a section on I-270 similar to I-670*
- Other issues identified:
    - *Staffing is an issue*
    - *Streamline the process*
    - *Keeping shoulder clean also helps maintain drainage*
    - *Need equipment designed for Interstate type work*

8.2 Meeting with ODOT Traffic Management Center

The research team met with the Administrator, both TMC supervisors, and the transportation systems management and operations coordinator from the ODOT statewide traffic management center on September 14, 2018. The agenda for the meeting, with pertinent information gathered at the meeting shown in italics, is shown below:

Current Procedures:

- What are the current TMC procedures for monitoring bus on shoulder routes for debris and disabled vehicles (Columbus I-70, Cleveland I-90/SR-2, Cincinnati I-71)?
- *If debris or disabled vehicle is spotted on camera or reported, TMC will contact appropriate garage or law enforcement agency*

- Are they systematically scanned or just as the eye catches it?
  There is no sweep of the area or systematic procedure. Main focus is anything blocking the travel lanes.

- How many cameras currently monitor each corridor?
  10-20 cameras per corridor. Currently they do not have 100% coverage of areas with BOS

- What is the frequency or reach of cameras (1 mile, 2 miles, etc.) on each corridor?
  No more than 1 mile of reach, also depends on terrain, vegetation, etc.

- What is the resolution of the cameras? And what are you able to see with them (fenders, tires, etc.)?
  With current cameras, can see tire size object, but not hub cap size. Moving towards high definition cameras in Columbus. Cincinnati has already converted to high definition cameras. As cameras fail, they are being replaced with hi-def cameras

- Coordination with/role of county garage
  Franklin County (Columbus) typically sweeps every weekend (3rd shift) or as needed, Cincinnati and Cleveland do the same.

  - What are they responsible for handling (debris only)?
    ODOT garages responsible for "everything" the freeway safety patrol cannot handle (large items).

  - How are they dispatched and how do you know which garage to dispatch?
    Each district has a call out list. Not all districts go thru TMC, some may go straight to the garage.

  - What is the response time (the length of time from spotting something to someone being dispatched and then to someone on site removing debris/disabled vehicles)?
    During normal hours (7AM – 3 or 4PM), less than an hour. After hours, response may take 2 to 3 hours or longer for calls from TMC. Every debris call does not come from TMC.

- Coordination with/role of bus operators
  - Are the corridors checked before buses are allowed to run on shoulder (i.e. are they given an "all clear" before they start)?
    No, COTA does not receive an "all clear" from ODOT prior to use.

  - Do they contact TMC directly if they spot something?
    No, bus operators do not communicate with the TMC.

  - What do they do if there is debris or a disabled vehicle in the shoulder, do they move over to outside lane and then move back into shoulder?

Typically get back on the mainline and go around

- Coordination with/role of PD/FD
  TMC has direct contact thru dispatcher

    - What are they responsible for handling (disabled vehicles only) and in what areas?

    - How are they dispatched and how do you know which station to dispatch?

    - TMC does not dispatch law enforcement or FD, but they may inform PD (or sheriff

    - What is the response time?

- Coordination with/role of Sheriff
  Communicates with TMC

    - What are they responsible for handling (disabled vehicles only) and in what areas?

    - How are they dispatched?

    - What is the response time?

- Coordination with/role of OSHP
  Communicates with TMC

    - What are they responsible for handling (disabled vehicles only) and in what areas?

    - How are they dispatched?

    - What is the response time?

- Coordination with/role of safety patrol
  Safety patrol trucks are equipped with front and rear facing cameras. In Cleveland the safety patrol owns 1 tow truck and is able to move disable vehicles out of travel lanes, but cannot tow the vehicle anywhere (except to shoulder or ramp to clear lane) without permission of owner or law enforcement. Columbus area safety patrol will have a tow truck July 1, 2019.

    - What hours do they operate and how many crews?
      6:00 AM to 9:00 PM Monday thru Friday; outside of those hours ODOT (garages) handles. 5 patrols plus one spare truck.

- Coordination with/role of others
  Companies on call to tow tractor/trailer
  Can't tow vehicle without permission of law enforcement officer in Columbus.
  Cleveland has a towing pen (quick clear)
  TMC cannot authorize towing

Procedures for inclement weather
TMC can access front and rear facing cameras on freeway safety patrol. Also pavement sensors which give speed, sends an alert to TMC when traffic is stopped

- How does TMC and bus on shoulder operations change during times of heavy rain or snow (e.g. high water or snow on shoulder)?
  Buses won't use shoulder during heavy rain or snow

If money were no option, what would you change about the current procedures to improve efficiency of keeping routes clear and to improve motorist safety?
Install more HD cameras the better
Use data from cell phones to track speed, which they are already doing

Proposed procedures for I-670 cameras (sensors? drones? other?)
There will be a dedicated person at the TMC to monitor corridor

- How many cameras?
  Thirty three new cameras and nine side fired radar units will be installed

    - Camera type and interval spacing of cameras?
      Plans were provided to the research team

- Will there be an increase in safety patrol?
  Safety patrol will be more dedicated.

- Additional concerns:
  Public will use the lanes when not open – law enforcement will need to monitor usage in off-hours.

8.3 Interview with Law Enforcement Agencies and Safety Patrol service, Franklin County

A dispatch supervisor from the Columbus police department (CPD) and an officer from the Ohio State Highway Patrol (OSHP), which have jurisdiction over the section of I-670 containing the SmartLane, were interviewed for this research. The Franklin County Sheriff department has jurisdiction over a small portion of SmartLane but were not interviewed because the interview with CPD and OSHP provided sufficient information. The research team also contacted AutoBase, who provide freeway safety patrol services for ODOT. AutoBase declined to be interviewed, citing contractual concerns and referring the team to the ODOT Traffic Management Center. The agenda for the interviews, with pertinent information gathered during the interview shown in italics, is shown below:

What is the current procedure when large debris is seen or reported

- In the travelled lane?
  CPD: debris in the travelled lane is a 2nd level priority which means the department won't clear an officer off another incident to respond but may call in an officer from a different area to respond. Responding officer will move debris if they can. If they can't, will control traffic and call either ODOT TMC or bring in private firm to move

  OSHP: If in the roadway and can be moved, they will move it to the berm/shoulder. If it is too large they will call ODOT and wait with the debris until ODOT arrives.

- On the shoulder used for bus on shoulder (BOS) travel?
  CPD: Haven't had to address this situation, would not treat as a high priority.

  OSHP: Handled the same as any other road (i.e. they would call ODOT if it is large, otherwise they wouldn't do anything since it is already on the shoulder and out of the travelled lane). Most BOS are in the city and they do not patrol in the city

- On the shoulder not used for BOS?
  OSHP: If on berm or shoulder same will apply but they usually will not stay with the debris (i.e. they would call ODOT if it is large, otherwise they wouldn't do anything since it is already on the shoulder and out of the travelled lane).

- What changes in this procedure do you foresee on I-670 when active traffic control is implemented?
  OSHP: They anticipate ODOT would have a protocol for cleaning shoulder. If ODOT would require they stay with large debris like they already do when it is in the travelled lane (mainline) then they would do that.

What is the current procedure when a disabled vehicle is seen or reported?

- In the travelled lane?
  CPD: Stop behind vehicle with lights on. Call tow truck. Remain on site until vehicle is removed.

  OSHP: If vehicle is an immediate hazard or can cause risk, will tow. Only LEO can order a car towed per ORC 4513.61.

- On the shoulder used for bus on shoulder travel?
  CPD: Officer's option. Will tag car with notice. May or may not notify dispatch.

  OSHP: On any shoulder, per statute, owner has 48 hours to remove if not a hazard or can cause risk. Normal procedure is to stop behind with lights on and approach car. Inventory contents. Notify dispatch. After 48 hours, if still there, dispatch will try to

contact owner. If no response, vehicle will be towed. Owner has one week to claim vehicle.

- On the shoulder not used for BOS?
  CPD: Same as BOS routes

- What changes in this procedure do you foresee on I-670 when active traffic control is implemented?
  CPD: Haven't considered yet. Will likely treat shoulder as moving lane when open to traffic.

  OSHP: OSHP does not patrol municipal areas under another LEO jurisdiction unless requested. Don't foresee change in policy but would be willing to change procedure if ODOT needed (i.e. stay with a piece of debris until picked up)

- How often, on average, is a section of Interstate travelled by LEO/safety patrol?
  Rate of patrol is based on statistics. Areas with a high rate of property damage/injury accident are patrolled more often. Emphasis on Interstate but may be drawn off by other factors such as a fatality on other route. Handle everything the same. Don't routinely patrol city routes.

- Will this change when active traffic control is implemented?

- Based on your experience, what type of debris is most likely to damage or disable a vehicle? How often do you see this type of debris?
  CPD: Don't receive this type of information. Do see a lot of ladders and mattresses.

  OSHP: Semi tires cause most damage, especially on cars with low clearance. Also, items like ladders, can cause damage.

8.4 Interview of Agencies in Other States

The team then reached out to agencies in 9 of the 14 states identified by Jenior et al. [2016] currently permitting BOS operation and general purpose traffic use of shoulder. As mentioned in Section 3.2 of this report the team did not attempt to contact five states agencies: Delaware and Maryland, were queue jump applications which were not applicable to this research; Massachusetts and Georgia discontinued traffic on shoulder due to construction, and Hawaii uses movable barriers to adjust the number of lanes prior to rush hour, which is also not applicable to this research. One agency, Illinois DOT, did not respond to the teams email and one state, North Carolina DOT, was responding to emergencies created by hurricane Florence and appropriate personnel were not available to be interviewed. Virginia and Florida outsource shoulder cleaning on the Interstate. For these two states, the contractor, DBI in both cases, was contacted and interviewed. The agenda for the interviews, with pertinent information gathered during the interview shown in italics, is shown below. Note, all questions were not asked at every interview.

This is because some interviews, such as the ones with the contractors, were focused on specific topics, such as equipment. In other cases, the interview was shorten due to time constraints:

Background

- Miles of shoulder with
    - Bus on shoulder
      MoDOT Scouts: 12 miles I -35, used when speeds drop below 35, rarely used. Rely on maintenance to remove debris, not a top priority.

      MnDOT: 290 miles used by bus when mainline speed < 35 MPH

      VDOT: 1.3 miles

      WSDOT: 2 miles

    - Mixed traffic used
      MnDOT: 2.5 miles, I-35 W, "price dynamic shoulder": inside toll road (MNPASS), free for transit and HOV, single occupancy must pay. Started several years ago
      VDOT: 18 miles

      WSDOT: 5 miles

Monitoring sections

- Frequency of patrol
  FLDOT: In Tampa area, the "Road Rangers" have 21 trucks which patrol 15 zones.

  MnDOT: Eleven "FIRST" team trucks cycle through metro area. First team are MnDOT employees. Will make a couple of passes each peak period.

  MoDOT Scouts: Five zones on Missouri side. Procedure applies to all freeways. During peak hours, hot spots are heavily patrolled. Section of Interstate will normally be covered once per hour. Patrols operate 24/7, 365 days a year. Feel it's worth the money, they tend to see lot of things before it's noticed on cameras

  NJDOT: Standard procedures apply to all highways. Crew supervisor will travel route in pickup truck. If smaller size debris (tire peel) is encountered, it will be picked up and put in the truck. If larger debris is encountered, i.e. mattress, a crew will be dispatched to pick up.

  VDOT: have 24/7 Safety Service Patrol on two Interstate routes

  Virginia DBI: One person roving every day in a pickup.

WSDOT: Daily check by TMC via camera in advance of operation. Cameras along the length of the shoulder segment.

- Cameras/sensors
  FLDOT: Most effective tool, will do sweeps.

  MnDOT: Sensors in pavement monitor speed

Current procedures for hard shoulder maintenance for bus on shoulder

- Cleaning/sweeping
  Caltrans District 7: All shoulders - Sweep once a week, use Road Rake (litter getter) every 1 to 1 ½ month

  Florida DBI: Operator, with truck, will patrol section 2 to 3 times per week, manually pick up debris. Will sweep once a month.

  FLDOT: Clearing debris from roadway and shoulder is outsourced on the Interstate system.

  MnDOT: Sweep annually after spring melt. Travelled shoulders are self-cleaning of small debris. Large stuff picked up by FIRST team or maintenance crew.
  - Typical "setup" # of vehicles,
    MnDOT: Street Sweeper (Elgin & Pelican), water truck, dump truck, 1 ton truck to pick up large debris, crash truck, arrow board.

  - People

  - Maintenance of Traffic (MOT)
    MnDOT: Moving operation

    VDOT: Interstate related work is outsourced. Cleaning setup is a Road Rake followed by a street sweeper.

    WSDOT: Truck in front picks up large debris, street sweeper, two truck mounted attenuators.

Role in reporting/clearing debris:

- Bus operators
  FLDOT: In Tampa area, BOS is proposed. Current plan will have bus operators report debris.

  Florida Miami/Dade bus operations: bus drivers will report to bus control center, who will then contact the DOT.

  MnDOT: Bus operator will report debris/large items to their regional center who then report to MnDOT regional center. MnDOT regional center can dispatch maintenance or

FIRST team. Large items are left until congestion is over, buses will pull back into traffic to go around.

VDOT: Not many report

WSDOT: Drivers will call dispatch if debris or disabled vehicle is blocking shoulder

- Police department/fire department
  FLDOT: LEO will direct call contractor

  MnDOT: Seldom report debris

  VDOT: Will possibly report debris

- Sheriff
  MnDOT: Seldom report debris

- State police/highway patrol
  MnDOT: Seldom report debris, will report to regional MnDOT TMC

  Virginia DBI: have a working relationship with state police

- Safety patrol
  MnDOT: First team will pick up larger debris

  VDOT: Assist disabled vehicles and provide temporary closure for incidents to support FD and PD

  WSDOT: Assist with physical sweeps of shoulder lanes

- Traffic Management Center
  FLDOT: Will direct call contractor

  MnDOT: Approximately 600 high definition cameras in metro areas

  VDOT: Open and close shoulder to traffic on set schedule. Not specifically looking for debris. If debris is reported, will zoom in to locate.

General information on clearing shoulder

- Procedures for inclement weather
  MnDOT: No change during rain event. For snow event, depends on how bad, they will clear as much as possible with snow plows

  VDOT: loss of storage for snow is huge expense, takes more time and effort.

WSDOT: Shoulder lanes are lowest priority to clear snow.

FLDOT: rely on Road Rangers more

VDOT: Not allowed on shoulder during inclement weather.

- % time devoted to clearing shoulder
  MnDOT: One week per year

- How is environmentally regulated material (i.e. tires) disposed?
  MnDOT: Not an issue, tires are placed in separate bin at garage

Equipment

- Have you used any of the following?
  - Manual pickup
    Hand crew will pick up any large debris, patrol 3 days a week

  - Debris Removal Attachment
    California AHMCT: One prototype. Fairly functional. Built by an Ohio company by reconfiguring a garbage can collector. One reason CalTrans did not pursue was the arm operator was located on the back of the vehicle, which is not a good setup when using a moving operation MOT.

  - Street sweeper
    Florida DBI: Can sweep about 20 miles per day. Use contract sweeper. String will wrap on gutter brushes, need to clear before continuing.

    FLDOT: primary method

    MnDOT: Elgin broom on sterling chassis

    NJDOT: Sweep on a regular basis. In the past, used mechanical sweepers, going to the air sweepers in January. (Tymco and Schwarze)

    Virginia DBI: Typically sweep once a month. Used to pick up nails.

    WSDOT: Elgin mechanical sweepers. Average between 6 to 8.8 miles per day

    ODOT District 4: Use vacuum sweeper, sucks up more debris, doesn't leave a pile of debris at the end of a run. Less moving parts compared to mechanical sweeper.

  - Gator Getter™
    NJDOT: have not used

Virginia DBI: During demo, threw a 2x4 across traffic. DBI has one but doesn't use. Kicks up debris.

ODOT District 4: Purchased 2012. Used on freeway, need to be travelling at least 45 MPH. Does successfully pick up tires. Need to empty often, best for spot cleaning.

- JAWS

  MoDOT Scouts: Have one JAWS unit, built in house, now has 112,000 miles on it. Material cost is $3000. Have been able to push or scoop anything they have encountered. Equipped with a camera. Plan to put specs and plans on line, at no cost, by mid-November, 2018. MoDOT wants to build at least 25 more. Also has a push bumper, can push disabled vehicles to the side of the road. Like snow plows, push debris onto shoulder or into the grass. If debris has to be manually removed from a travelled lane, will wait until there are two trucks (had a fatality when an operator tried to remove debris alone – led to two truck policy) unless debris is in right lane next to white line. One truck sits in front of debris, 2nd is a backup.

  NJDOT: have not used

- Road Rake

  CalTrans District 7: Had older model, purchased around 1996, called litter getter. One of the most useful piece of equipment they have used. Would use one day before sweeping, would pick up about 95% of the debris. Clears 14 to 15 miles per day. Can clear 7 miles before emptying bin. Picking up heavy debris, more than 75 pounds, could damage tines. Self-contained, used a diesel engine.

  California AHMCT: Probably used in southern region, District 7, because there is little vegetation. One issue with Road Rake is the vehicle must drive over the debris being picked up.

  Florida DBI: don't use because it doesn't clear the drains well.

  NJDOT: Have not used

  VDOT: Precedes the street sweeper. Can clean about 10 miles/day. Picks up 6" or bigger material.

  Virginia DBI: Used since 2016 based on cost analysis. Primary equipment for shoulder cleaning. Less self-destructive compared to street sweeper. Use every other week. Operation travels at 5 to 10 MPH. Can do 100 lane miles in a 12 hour shift. Need to keep bearings lubricated. Can break tines if bar is lowered too much, very difficult to repair.

- Automated Roadway Debris Vacuum
  California AHMCT: Commercial version is not being produced. VacAll and MadVac tried to produce commercial versions. Not able to pick up some debris, such as a 5 gallon bucket. When used in CalTrans trials, was mostly used to clean drainage. CalTrans decided not to pursue. One reason was it required a person operate it from the back of the vehicle and Caltrans is against putting anyone on the truck for a moving operation.

  MnDOT: Vacuum not used for clearing shoulder, usually down for maintenance

  NJDOT: Have not used

- Magnetic Road Sweeper
  NJDOT: Have not used

  Virginia DBI: Roving patrol has a Northern Star magnet on front bumper with removable strip. Cost $800

- Snow plow
  MoDOT Scouts: Two trucks with small snow plows. Push debris onto paved or grass shoulder. If debris has to be manually removed from a travelled lane, will wait until there are two trucks (had a fatality when an operator tried to remove debris alone – led to two truck policy) unless debris is in right lane next to white line. One truck sits in front of debris, 2nd is a backup.

Notes

MnDOT: Satisfied with current procedures, work well

Florida Miami/Dade bus operation: BOS has worked well, no accidents. Most recent section have used the inside shoulder which eliminates the entrance/exit issue.

VDOT: people use shoulder during off peak hours, have to treat as open lane 100% of the time.

VDOT: Interstate related work is contracted. A third party rates the contractor using performance based criteria. Shoulders cleaned with the Road Rake/sweeper combination have the highest ratings.

Virginia DBI: VDOT requires debris be removed within 3 days. As a result, DBI does a lot of self-inspection. DBI developing a debris pickup device.

8.5 Demonstration of Shoulder Sweeping on I-270

A laborer, followed by a dump truck, Figure 7, preceded the sweeper, would pick up flat items, metal objects too heavy for the sweeper to pick up, wire, bottles if full of liquid, and large items such as stones, wood, and tire carcasses which too heavy for the sweeper to pick up or would clog the sweeper. String, which may get wound onto the gutter brushes, would also be picked up. This material was placed in the dump truck.

Figure 8.1 Clearing shoulder of large debris prior to sweeping

The Elgin sweeper, shown in Figure 8, immediately followed. On the day of the debris collection, the hydraulics apply the down pressure on the gutter brush was not functioning correctly, leaving debris behind the sweeper, Figure 9, which would have normally been collected. A crash truck and arrow board followed the sweeper.

Figure 8.2 Shoulder sweeping

Figure 8.3 Debris left by inadequate down pressure on gutter brush

The sweeper emptied its hopper into dump truck once, after approximately 30 minutes of sweeping. The Elgin hopper is on the right hand side. The crash truck would pull into adjacent lane to stop traffic in that lane. The sweeper then pulls into the adjacent ahead of the crash truck. The dump truck preceding the sweeper backs up on shoulder next to sweeper. The sweeper then empties it's hopper into the truck (Figure 10). The process takes 5 to 10 minutes.

Figure 8.4 Emptying sweeper hopper

Sweeping of the 1.45 mile section was completed in 1 hour 5 minutes. The speed of the sweeping operation is controlled by the speed of the laborer in front, picking up the flat and/or large items.

9 Appendix B: Literature Review

During the time the shoulder is not being used for traffic, various debris (trash discarded by motorists, parts or cargo that fall from cars and trucks, tire threads, etc.) accumulates on the shoulder. Furthermore, vehicles which have experienced car trouble or have been involved in minor traffic crashes will park on the shoulder until repaired or towed. These obstacles must be identified and removed prior to opening the shoulder to traffic.

Jenior et al. [2016] identified best practices from case studies across the nation for implementing part-time shoulder use. Inspecting the shoulder in its entirety prior to opening to traffic was identified as one of the best practices. Suggested methods included use of CCTV cameras, where full coverage is available, to identify debris or disabled vehicles, or manually driving the length of the shoulder to be used for hard shoulder running. It was also suggested incident response vehicles be readily available to clear disabled vehicles. Jenior et al. [2016], Martin [2006], and Levecq et al. [2011], as well as other literature reviewed related to part time shoulder use, provide guidance and methods for detecting debris and stalled vehicles but provide no guidance or procedures for the actual removal.

The composition of the debris must be known to determine the most effective and efficient method of removal. A survey of 240 roadway segments by the Keep America Beautiful organization found 91% of the litter is less than 4 in (10 cm) long [Schultz and Stein, 2009]. As shown in Figure 9.1, they also found the plurality of the litter, 37.7%, consisted of tobacco products. Based on their survey, they estimated there are 6,729 pieces of litter per directional mile of roadway [Schultz and Stein, 2009]. Most of the small debris, such as cigarette butts, is of

little concern with regard to hard shoulder running. However, construction debris, vehicle debris, and pieces of metal and/or glass can damage tires and vehicles, and these need to be removed prior to opening the shoulder to traffic; these categories add up to 14.4% of total debris collected by Schultz and Stein [2009].

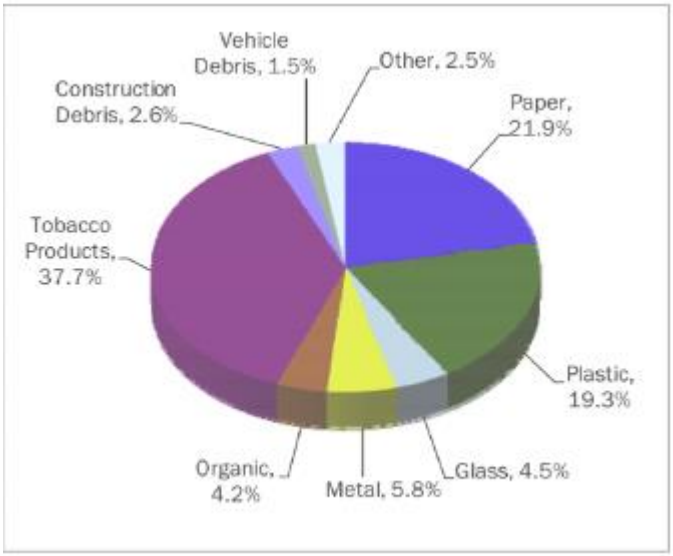

Figure 9.1. Aggregate Composition of Litter, All U.S. Roadways. [Schultz and Stein, 2009]

A preliminary search identified several technologies available for removal of debris. These range from manual removal to driven collection devices that employ drum scoops, mechanical brooms, vacuum technology or heavy duty magnets.

One of the more common methods is manual litter pick up. While it would not be feasible for ODOT crews to remove debris every day, as seen in Figure 9.2a, the use of inmate or contract labor may be feasible. Additionally, equipment such as that shown in Figure 9.2b has been developed to automate the collection of garbage bags and objects up to 100 lb (45 kg) [AHMCT, 2011] and could be used to assist and expedite a manual litter pick-up.

a) b)

Figure 9.2 a) Manual Litter Pick-up [https://www.flickr.com/photos/ohiodot/albums] b) Debris Removal Attachment [AHMCT, 2011].

The Gator Getter™ is a drum shaped scoop designed to remove debris at highway speeds. Shown in Figure 9.3, the Gator Getter™, can be mounted to the front of a pickup truck or snow plow including "VALK or other similar push frames" [http://www.gatorind.com]. In a 2014 study, Strong and Vasques conducted field reviews of the Gator Getter™ at a range of travel speeds, concluding it was best suited for use on interstates and is effective in removing tire debris at speeds above 45 mph (72 km/h). However, they recommended it should not be used to remove objects such as rocks, concrete, metal or mixed debris fields. They also recommended the Gator Getter™ not be used over railroad tracks or bridge decks.

Figure 9.3 Gator Getter™. [Strong and Vasques, 2014]

Julie's Automated Waste removal System, JAWS, also uses a scoop to remove or push debris from the pavement. Shown in Figure 14, JAWS replaces the front bumper of a pickup. The scoop, equipped with a camera, is lowered to scoop or push debris from the roadway. The bumper can be used to push disabled vehicle to the side of the road [DeGood, 2018].

Figure 9.4 JAWS [DeGood, 2018]

Street sweepers are common in urban areas. Mechanical sweepers typically consist of a self-contained unit with a main broom and side broom which sweep debris from the road into a

hopper via a conveyor belt. Vacuum sweepers typically consist of side brooms which sweep debris into a vacuum nozzle which sucks the debris into a hopper. Regenerative air sweepers are vacuum sweepers which use side brooms and a blast of air to move debris to the vacuum nozzle. Models designed for sweeping heavy material from congested urban areas, such as the model in Figure 15, can travel at higher speeds and have large capacity hoppers.

Figure 9.5 Mechanical Street Sweeper [elginsweeper.com]

The Road Rake, shown in Figure 16, utilizes rotating brushes combined with tine rakes to remove debris from paved surfaces. The collected debris is transferred on a conveyor belt to a storage area in the pull-behind machine which can later be dumped into a bin. Caltrans has utilized an earlier version called the Litter Picker, which does not have the rotating brushes [hbarber.com], in tandem with a street sweeper to remove debris from their highways [Public Works, 2000]. Caltrans operated the Litter Picker at a speed of 15 mph (24 km/h) picking up an estimated 95% of the debris [Public Works, 2000].

Figure 9.6 The Road Rake [hbarber.com]

Equipment based on vacuum technology has also been used for removal of debris from the roadway. The Automated Roadway Debris Vacuum (ARDVAC), shown in Figure 17, is a self-contained vacuum system with an extendable arm controlled from the cab of the vehicle. It was developed at the University of California at Davis [AHMCT, 2007].

Figure 9.7 Automated Roadway Debris Vacuum [AHMCT, 2007].

Magnetic highway sweepers, such as the one shown in Figure 18, can be used to remove iron based debris from the shoulder. Given the specialized nature of this equipment, it would have to be used with other techniques to remove all debris from the shoulder.

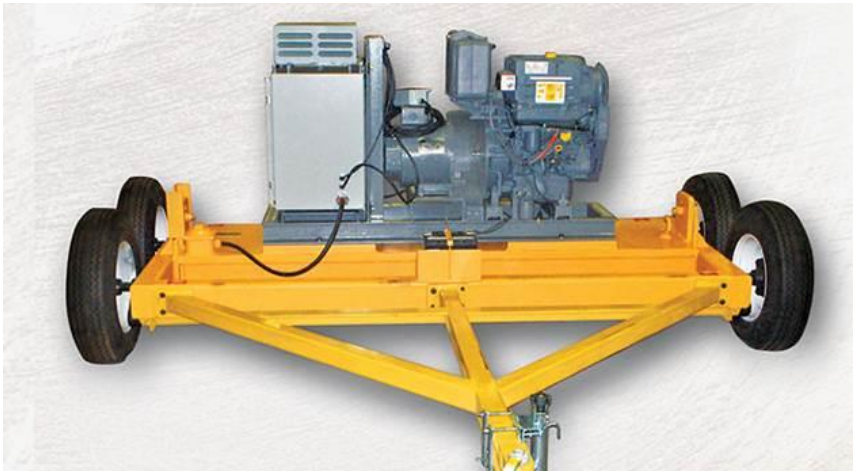

Figure 9.8 Self-Contained Magnetic Road Sweeper [ohiomagnetics.com]

10 Appendix C: Evaluation of Equipment

Procedures and equipment to clean a highway shoulder were identified during the literature search and the interviews. The research team collected pertinent information: manufacturer, model, contact information, cost, limitations, personnel need, and operating speed for each procedure/equipment. This information is summarized in Table 6.

During the course of this research, factors other than cost, such as safety of the work crew, clearing all debris from the shoulder, and the operating speed of the cleaning process, were identified. This type of decision does not lend itself to a simple benefit/cost analysis. Therefore the research team chose a decision matrix approach. The decision matrix method is a rational method of prioritizing multiple choices. A decision matrix consists of "…establishing a set of criteria options which are scored and summed to gain a total score which can then be ranked." [https://en.wikipedia.org/wiki/Decision-matrix_method]. Both single method/equipment and combination of methods and equipment were considered.

Table 7 Information for Selected Equipment Types

Procedure	Manufacturer	Model	Manufacturer/ Distributer Location	Manufacturer/ Distributer Phone Number	Web site	Initial cost	Limitation on size of debris collected	Personnel needed	Operating speed	Capacity
Manual collection	N/A	N/A	N/A	N/A	N/A		Highway worker limited to lifting no more than 50 to 100 lbs	1	1 to 2 MPH	N/A
		Debris Removal Attachment for automated bag removal	Not commercially available	Wil White (Primary contact) 530-752-1455	http://ahmct.ucdavis.edu/projects/debris-removal-attachment/		built for larger items	1, 2	stationary	N/A
Street sweeper	Elgin	Eagle (mechanical sweeper)	Jack Doheny Companies 1860 Summit Commerce Park Twinsburg, OH 44087 Ohio Distributor	847-741-5370	http://elginsweeper.com/www.dohenycompanies.com	Badger $128,473 Broom Bear $145,431 Eagle $170,498	typically nothing larger than 6 inches in diameter	1	5-10 mph	4.5 yd^3
	Schwarze	Twister (air sweeper)	Southeastern Equipment Co 10874 East Pike Road P.O. Box 536 Cambridge, OH 43725	800-879-7933	http://schwarze.com/Bunklesbay@southeasternequip.com	A7, A8, or A9 Twister $250,000 to $275,000	typically nothing larger than 14 inches in diameter	1	5-10 mph	8 to 9.6 yd^3
	Vacall	AllSweep (mechanical sweeper)	406 Mill Ave. SW New Philadelphia, OH 44663	800-382-8302	http://vacall.com/products/allsweep-street-sweeper.php	AllSweep $230,000	typically nothing larger than 6 inches in diameter	1, 2	0-11 mph	10, 13, 16 yd^3

Procedure	Manufacturer	Model	Manufacturer/ Distributer Location	Manufacturer/ Distributer Phone Number	Web site	Initial cost	Limitation on size of debris collected	Personnel needed	Operating speed	Capacity
	Johnston North America	ES 351 (mechanical sweeper)	M Tech 7401 First Place Oakwood, OH 44146 Ohio Distributor	704-658-1333	http://johnstonnorthamerica.com/	ES351 $257,000	typically nothing larger than 6 inches in diameter	1	2 - 15 MPH	4.5 yd^3
	Tymco	Model 500X, Model 600 (air sweeper)	Contract Sweepers and Equipment 2137 Parkwood Ave. Columbus, OH 43219	614-221-7441	https://www.sweepers.com/	$220,000 to $265,000	typically nothing larger than 14 inches in diameter	1	1 – 8 MPH	4.5 to 6 yd^3
	Global	M4 (mechanical sweeper)	M Tech 7401 First Place Oakwood, OH 44146 Ohio Distributor	909-713-1600	https://globalsweeper.com/ mtechcompany.com	M4 $235,112	typically nothing larger than 6 inches in diameter	1	5-11 mph	5.6 yd^3
Scoop/push debris	Barber	Road Rake: 200, 200T(powered by tow vehicle)	15 Raytkwich Road Naugatuck, CT 06770	203-729-9000 800-355-8318	http://www.hbarber.com/LitterCollection/RoadRake/default.html	$71,800-$81,800	has issues picking up small debris	1	1-18 mph	4 yd^3
	Gator Industries, LLC	Gator Getter	806 Island Ford Road McGaheysville, VA 22840	540-289-5051	http://www.gatorind.com/	$22,000	best used for medium sized debris/ tires	1	minimum 45 MPH	N/A
	N/A	JAWS assembled in house by MoDOT	Missouri DOT	Randy Johnson, TMC Manager, 816-607-2000	https://www.kshb.com/news/local-news/new-technology-jaws-keeping-roadways-clean-crews-safe	$3000 for material + labor	best used for medium sized debris/ tires	1	any	N/A

Procedure	Manufacturer	Model	Manufacturer/ Distributer Location	Manufacturer/ Distributer Phone Number	Web site	Initial cost	Limitation on size of debris collected	Personnel needed	Operating speed	Capacity
	Meyer (Columbus distributor is Buckeye Body and Equipment)	Drive Pro Snow Plow	939 E. Starr Avenue, Columbus, Ohio	614-299-1136	https://www.buckeyebody.com	$6,000	best used for medium sized debris/ tires	1	any	N/A
Vacuum	ARDVAC		Not commercially available	Wil White (Primary contact) 530-752-1455	http://ahmct.ucdavis.edu/projects/automated-roadway-debris-vacuum/	$381,000	dependent on hose size	1	2 mph	
	Old Dominion Brush (ODB)	SCL800SM-3X, truck mounted automated self contained debris collector	5118 Glen Alden Drive Richmond VA 23231	800-446-9823	http://www.odbco.com/equipment/debris-collection-equipment/scl800sm-3x.html		nothing larger than 16"	1		14, 20, 25, 30 yd^3
Magnet	Ohio Magnetics (Stearns)	ERS-96	5400 Dunham Road Maple Heights, OH 44137	1-800-486-6446	http://ohiomagnetics.com/our-products/magnetic-road-sweepers	$85,000	Can't be larger than the magnet itself	1	5 mph	8 feet wide
		YSI	5400 Dunham Road Maple Heights, OH 44137	1-800-486-6446	http://ohiomagnetics.com/our-products/magnetic-road-sweepers	$495-$1,400	Can't be larger than the magnet itself	1	5 mph	4-8 feet widths
	Storch	MSE	11827 Globe Road Livonia, MI 48150	734-591-2200	https://www.storchmagnetics.com/electromagnetic-sweepers/	$17,500-$20,500	Can't be larger than the magnet itself	1	5 mph	5-8 feet widths
		SuperMag	11827 Globe Road Livonia, MI 48150	734-591-2200	https://www.storchmagnetics.com/supermag-lp/	$5,500-$10,500	Can't be larger than the magnet itself	1	≤ 15 mph	4-10 feet widths

11 Appendix D: Standard Operating Procedures for Debris and Disabled Vehicle on Shoulder Removal: I-670 SmartLane

BACKGROUND

The management of traffic demand has become critical as congestion in urban areas during commute hours has increased. One method agencies have begun to implement to alleviate congestion is hard shoulder running. Under hard shoulder running, shoulders are used part time to carry traffic, thereby increasing capacity. When not needed as an additional lane to alleviate congestion, the shoulder is restored to its original purpose [Jenior et al., 2016]. Hard shoulder running provides a lower cost solution, compared to widening, to the need for additional capacity during commute hours or special events. Part time use can be divided into three categories [Jenior et al., 2016]:

1. Bus on Shoulder (BOS) to facilitate bus traffic during congestion
2. Static shoulder lanes, where use is limited to predetermined hours, and
3. Dynamic shoulder lanes, where use is based on predetermined congestion criteria

In Ohio, busses have been permitted to use the shoulder when speeds drop below 35 mph (56 km/h) on I-70 in Columbus since 2006, on I-71 in Cincinnati since 2007, and on I-90 and SR-2 in Cleveland since 2008 [ODOT, 2018]. I-670 EB, in Columbus, has been selected as the pilot project to demonstrate the use of hard shoulder running of mixed traffic. An active system, referred to as SmartLane, will be implemented, using overhead signs to open the shoulder to mixed traffic from 3:30 PM to 6:30 PM Monday through Friday to relieve congestion [ODOT, 2018]. Additional Interstate sections will likely be adopted to active systems if the I-670 SmartLane is successful.

Effectively and efficiently clearing the shoulder of debris and hazards is critical to providing a safe lane for motorists when used for hard shoulder running. The following draft standard operating procedures are proposed for the SmartLane on I-670 pilot program. This standard operating procedure should be considered preliminary and should be revisited after 6 months of operation. Furthermore, the operating procedures should be revised prior to deployment of SmartLane technology in other areas of the state.

MONITORING PROCEDURES

- ODOT
    - Franklin County, Fifth Avenue Outpost

        - Conduct daily patrols of the shoulder along the SmartLane corridor prior to operating hours.
            - Manually remove debris which may damage vehicles (e.g. tire carcasses) found on the SmartLane shoulder.
            - Send crew for debris on the SmartLane shoulder too large for one person to manually remove.
            - Report disabled vehicles to appropriate law enforcement agency.
        - If debris is reported to ODOT during hours of operation
            - ODOT garage/outpost forces should remove debris when deemed safe to do so, or at the end of the scheduled operating hours (after 6:30PM).
    - TMC
        - Prior to hours of operation
            - Conduct full camera sweep of corridor
            - Report debris which may damage vehicles to appropriate ODOT garage/outpost
            - Report disabled vehicles to appropriate law enforcement agency
        - During hours of operation
            - Monitor travelled lanes by camera
            - Report debris which may damage vehicles to appropriate ODOT garage/outpost and discontinue use of shoulder for remainder of scheduled operating hours or until hazard is removed. ODOT garage/outpost forces should remove debris when deemed safe to do so, or at the end of the scheduled operating hours (after 6:30PM).
            - Report disabled vehicles to appropriate law enforcement agency.
    - Freeway Safety Patrol
        - Conduct daily patrols along the SmartLane corridor prior to operating hours
            - If deemed safe to do so, manually remove debris which may damage vehicles (e.g. tire carcasses) found on the shoulder. If not safe to do so, report debris to TMC or ODOT 5th Avenue outpost.
            - Report debris too large for one person to manually remove to ODOT TMC or ODOT 5th Avenue outpost.
            - Report disabled vehicles to ODOT TMC or appropriate law enforcement agency.
- LEO

    - Currently, disabled vehicles or debris found on the shoulder are not classified as an immediate risk or hazard by law enforcement.
        - Procedures for removal of disabled vehicles and debris found in the travelled lane should be applied to shoulders designated as a SmartLane during SmartLane operating hours.
- COTA
    - Report to dispatcher any debris or vehicles on shoulders designated for bus on shoulder use or as a SmartLane during SmartLane operating hours which are an immediate risk or hazard.
    - Dispatcher relay information to ODOT or appropriate law enforcement agency.

CLEANING PROCEDURES

It is recommended ODOT conduct scheduled cleaning of the SmartLane at the beginning of each week using the Road Rake. Additionally, it is recommended the street sweeper be utilized to clear the shoulder of finer debris on a monthly basis. The use of the street sweeper should coincide with the use of the Road Rake to minimize the need for personnel to exit the vehicle to remove larger debris which the sweeper is unable to remove. The street sweeper should be used either immediately following the Road Rake or up to one day after the Road Rake has been used to clean the shoulder of larger debris. Non-scheduled cleaning may be necessary where debris tends to accumulate at a faster rate such as in areas with barrier walls. Scheduled cleaning operations should consist of the following:

Weekly cleaning:

- One truck with two people
- Road Rake
- Appropriate vehicles/signage to meet ODOT's requirements for maintenance of traffic for a moving operation

Monthly cleaning:

- One truck with two people
- Road Rake
- Street Sweeper
- Appropriate vehicles/signage to meet ODOT's requirements for maintenance of traffic for a moving operation

Additional details regarding recommended equipment and procedures are provided below:

- ODOT 5th Avenue Outpost truck (two people)
    - In addition to a daily patrol, a crew should be designated to assist with scheduled cleaning operations. This crew should proceed the Road Rake or street sweeper and have the following responsibilities:
        - Pick up debris too large for road rake and sweeper, e.g. mattresses, car bumpers, etc., and flat debris (1/2" in thickness or less) which is greater than 14" in dimension.
        - It is recommended the crew remain in the truck until debris described above is identified.
        - This truck can also be used to dump the contents of the Road Rake hopper or Sweeper as needed.
- Road rake (beginning of each week, i.e. Monday morning)
    - The Road Rake should be considered for removal of medium sized debris.
    - The Road Rake should be operated on a weekly basis to remove medium sized debris prior to the use of the SmartLane corridor each week.
    - On a monthly basis, the use of the Road Rake should correspond with sweeping, such that the Road Rake is operated prior to sweeping, either the day of or one day prior, to remove debris which the sweeper is not capable of removing or may clog the sweeper.
- Street sweeper
    - Use a street sweeper to remove smaller debris (< 14").
        - Initially ODOT may consider a frequency of one time per month and adjust this frequency based on the accumulation of fines observed by maintenance crews. Regardless of the frequency selected, sweeping should be conducted immediately after or up to one day after the use of the Road Rake.
- Magnetic road sweeper
    - It is recommended ODOT consider mounting magnets to the ODOT truck or street sweeper.
    - Magnets with removable covers are recommended to allow for easy removal of material from the magnet.
- Hot spots
    - In areas where debris and fine material tend to accumulate, such as areas with barrier wall and bridges with parapet walls, more frequent cleaning of the shoulder may be necessary. These areas may become evident during daily patrols and weekly cleaning operations.
    - ODOT should select equipment (e.g. Road Rake, street sweeper, or truck with mounted magnet) necessary for the debris size observed.
- Inclement weather
    - It was found many other states do not clear the shoulder in inclement weather, therefore, in the interest of safety, consideration should be given to suspending clearing operations during rain or snow events.

GREEN ARROW: SmartLane is OPEN

RED X : SmartLane is CLOSED

Source: ODOT SmartLane Fact Sheet (http://www.dot.state.oh.us/districts/D06/projects/SmartLane/Documents/SmartLane%20Fact%20Sheet.pdf)