Optimizing Storm Sewer Cleaning Operations with Alternative Equipment.

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Abstract

State and local transportation agencies are responsible for maintaining roadways under their jurisdiction. One of the maintenance tasks that is most important is that of storm sewers. Storm sewers are responsible for quickly removing water from the roadway surface. When these structures become blocked by debris, they may allow standing water to accumulate on the roadway. The presence of standing water on the roadway presents a safety concern for the traveling public that results in time lost due to congestion and present dangerous driving conditions.

The current practice used to clean storm sewers often times has a low production rate, limiting how many structures may be cleaned in a single shift. Alternative equipment that has emerged in the U.S. market has potential benefits such as; an increase in the storm sewer cleaning production rate, a decrease in time spent cleaning storm sewers and lower annual costs associated with cleaning storm sewers. The recycler truck is a piece of equipment that separates solid particles from the water collected during the cleaning process in order to reuse it for additional cleaning. Reusing the water collected allows the equipment to avoid lengthy trips to refill the water tank and increases the overall production rate. This increased production rate may result in lower labor costs, an important factor for government agencies that may have low funding.

Introduction

One of the most important tasks for state and local transportation agencies is the maintenance of storm sewer systems. Storm sewers are critical infrastructure for the traveling public as they may quickly become full of storm water which may overflow and reside on the roadway if blocked by debris. Therefore, removing blockages and allowing storm water to efficiently flow is essential in preventing the occurrence of standing water on the road surface. The presence of standing water on the roadway results in both time lost due to congestion, and potentially dangerous scenarios that the traveling public must navigate.

The use of alternative equipment to maintain storm sewers has potential benefits such as; an increase in the storm sewer cleaning production rate, a decrease in time spent cleaning storm sewers and lower operational costs associated with cleaning storm sewers. By increasing the storm sewer cleaning production rate, it is expected that cleaner storm sewer systems will decrease the number of times roads will flood, resulting in more efficient travel time and a safer network for the public to travel on. Additionally, the increased production rate may result in lower labor costs, an important factor for government agencies that may have low funding. The objective of this paper is to determine if alternative equipment is a viable option that may increase storm sewer cleaning production.

Project Setting and Equipment Evaluated

This study worked in cooperation with the Ohio Department of Transportation (ODOT) in District 6. District 6 is composed of eight counties in central Ohio; Marion, Morrow, Union, Delaware, Madison, Franklin, Fayette and Union. District 6 is responsible for 4,921 lane miles including I-70, I-71 and I-270 through the city of Columbus (1). The counties studied are present in blue in Figure 1.

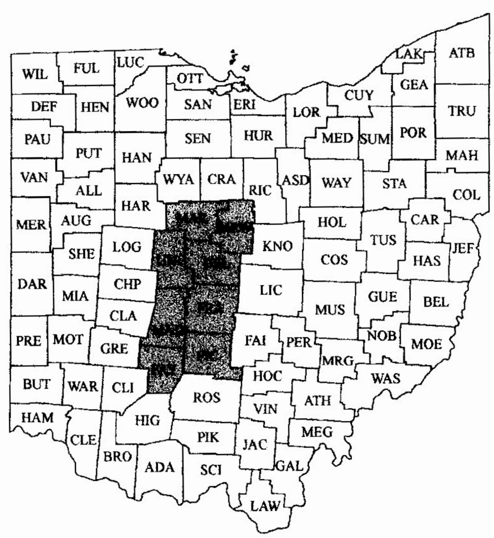

Figure 1: Project Setting for Study.

The current equipment that is used to clean and maintain storm sewers is the vacuum jet truck (VJT) which is also often referred to as a combination truck. The VJT is an industry standard when it comes to cleaning storm sewers. Currently, District 6 currently employs the use of two VJTs, although not concurrently. The VJT is one of the most common pieces of equipment that Department of Transportation's (DOTs) use to clean storm sewers. It is extremely versatile in that it may both vacuum out water and debris, as well as jet through sediment, roots and any other debris that may be clogging the drain. Figure 2 shows the current VJT's in operation.

(a) (b)

Figure 2: Current VJT equipment. (a) Vac-Con preparing for roadside operations. (b) Vactor 2100 decanting at City of Columbus Grit Pad Facility.

While the VJT is a versatile machine, its inability to reuse water limits its efficiency due to numerous trips to refill water. In addition, in many locations, environmental regulations prohibit decanting any water or material collected by the VJT back into the storm sewer system (2) (3) (4). For ODOT and many other agencies, approved decanting facilities may be limited and expensive. This increases the round-trip times to refill water and decant which reduce the production rate of the VJT.

Recently, a new equipment option has emerged in the U.S. market, which address the limitation of the current VJT. The recycler truck is a piece of equipment that has been used in Europe for several years but is currently increasing in popularity among DOT agencies in the U.S. market as well. The recycler truck is similar in functionality to a VJT but, with a water recycling system added. The use of a recycler enables the water to be reused for jetting, thereby extending the number of storm sewers that may be cleaned in a single shift.

Internally, a mixture of liquids and solids enter the unit and pass through an initial physical screen and the large debris settle to the bottom of the debris tank. Next, the particles begin to travel in a circular path. The resultant centrifugal force causes the heavier particles to move downward, and the water, which may also contain particles with density lighter than or close to the density of water, exits the top of the system. The difference between the two types of recycler truck technologies is the cyclone systems use a series of multiple cyclones to separate the particles whereas centrifuge systems use a single centrifuge that is sometimes aided with the use of an additional filter. The last step of the recycling system for both centrifuge and cyclone removal techniques is to send the water through a final filter whose purpose is to protect the jetting pump from any debris that may have gotten through the previous treatment steps. Once the water has completed every step of the recycling system it is ready to be pumped to the jetting nozzle to clean the storm sewer or to be recirculated into the debris tank where it re-enters the recycling system. Figure 3 shows the flow of treatment steps in a cyclone type recycler truck.

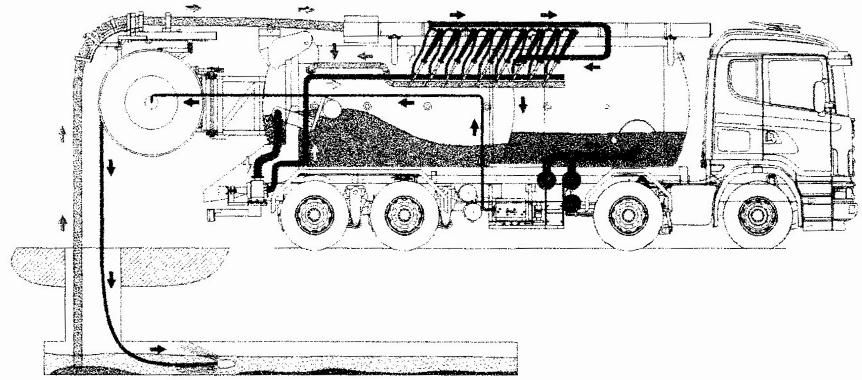

Figure 3: Recycling System (5).

A common shortfall of the recycling system is the effect of grease and fine silts. These two substances are tough on the recycling system across all recycler trucks as they tend to clog the system and requires constant backwashing through the system to be dislodged. Recycler truck vendors recommend turning off the recycling system when cleaning a storm sewer that is known to contain grease or fine silts (6) (7) (8) (9). To better understand and evaluate how the recycler trucks operate, the research team completed demonstrations of the GapVax Recycler, BUCHER 315 RECycler, Camel 1200 Recycler and Vactor 2100 Plus Recycler. Figure 4 shows two of the recycler trucks that were evaluated.

(a) (b)

Figure 4: Recycler Truck Equipment. (a) Camel 1200 Recycler Truck. (b) BUCHER RECycler 315.

As seen in Figure 4, the recycler truck typically has the same footprint as the VJT (shown in Figure 2). Some models, such as the Camel 1200 Recycler and Vactor 2100 Plus Recycler have the same "base" as the non-recycler model with the addition of the recycling system. Other models, such as the GapVax Recycler and BUCHER RECycler 315 were designed from the ground up as recycler trucks. In both scenarios, the equipment is very similar.

Production Rate Analysis

The first step in comparing the recycler trucks to the VJT is determining the difference in production rates between the two technologies. The research team first determined the number of storm sewers that each could clean in a shift. The number of storm sewers each piece of equipment could clean in a single shift is then used to determine the production rates of the equipment. By incorporating the frequency of cleaning cycles per shift, minutes of cleaning, and how long it takes to clean a single storm sewer. The team determined the production rates using Equation 1, presented below:

$$PR = (n_j)(n_s) \qquad \text{Equation 1}$$

where
PR = Production rate (storm sewers cleaned per shift),
n_j = Number of jet cycles per shift, and
n_s = Number of storm sewers cleaned per jet cycle.

Table 1 shows the number of the storm sewers that each piece of equipment is able to clean in a shift.

Table 1: Storm Sewers Cleaned per Shift

Equipment	Average	Standard Deviation
VJT	7.8	4.0
Recycler Truck	12.1	6.1

Note: The storm sewer cleaning rate was provided by ODOT as 2 for every 10-minutes of jetting.

The research team then found the production rate increase of the equipment options by comparing the production rate of the recycler truck divided by the production rate of the VJT using Equation 2, presented below:

$$PR_i = \frac{PR_r}{PR_v} \qquad \text{Equation 2}$$

where
PR_i = Production rate increase,
PR_r = Production rate of recycler (min), and
PR_v = Production rate of VJT (min).

Table 2 shows the production rate increase of the recycler truck when compared to the VJT.

Table 2: Production Rate Increase

Description	Average	Standard Deviation
Production Rate Increase	1.55	0.3

Note: The increase in production rate is based on a normal distribution curve.

Figure 5 shows the normal distribution curve of the production rate increase.

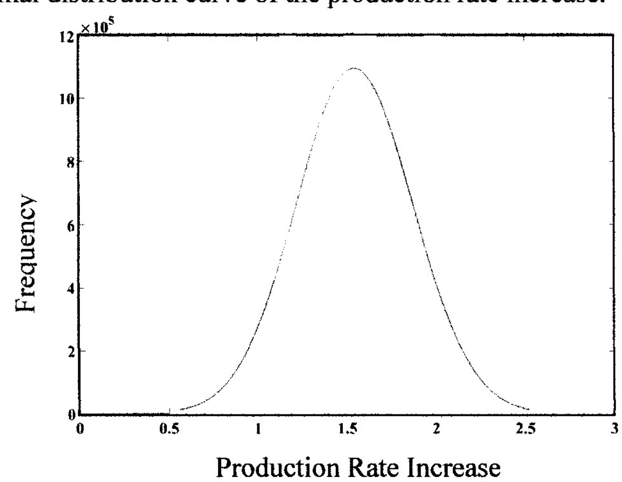

Figure 5: Production Rate Increase Normal Distribution Curve

The results show the recycler truck has a production rate increase of 1.55 times the current VJT system. This number is supported by the completed customer surveys that estimated a production increase, on average, of between 40-60%. Based on a current work schedule of April through October, there are approximately 145 working days in a cleaning season. Table 3 shows the difference in number of days worked for each piece of equipment in order to clean the same number of storm sewers.

Table 3: Work Day Production Comparison

Description	Average	Standard Deviation
VJT Days Worked (days)	145	15
Recycler Truck Days Worked (days)	94	10

Note: The reduction in hours worked results in higher operational costs per equipment hour worked.

As per Table 3, the recycler truck may clean the same number of storm sewers as the VJT in 51 fewer days. This time savings may either allow ODOT to clean additional storm sewers per year, or work 51 fewer days and apply that labor time elsewhere within the district. In addition, values used are based on surveys and discussions with the ODOT technical liaisons. The research team recommends verifying these numbers with field data.

Annualized Cost Analysis

When comparing the recycler truck to the VJT, three cost categories are analyzed; capital cost, operational cost and maintenance cost. Each of these categories is computed to determine the annual cost over the lifespan of the product. Figure 6 shows the costs and associated variables.

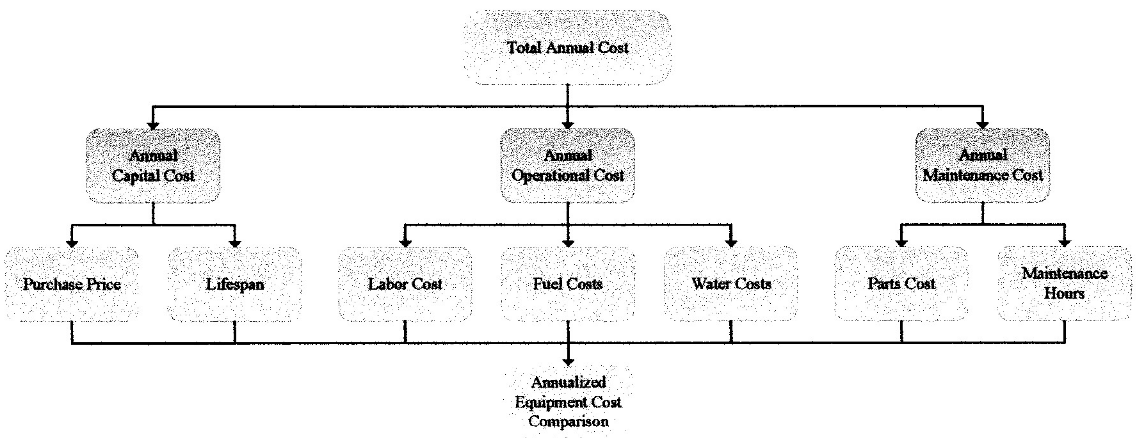

Figure 6: Annual Cost Matrix

The research team used a conservative approach in analyzing the costs associated with the recycler truck and VJT. The team notes that with the use of a positive displacement (PD) pump and snorkel attachment to the vacuum hose, the recycler truck is able to start vacuuming at the bottom of a storm sewer that is full of standing water. This process lets the system avoid using debris tank space for recovered storm water, allowing for fewer decant trips per shift. This method is applicable for cleaning large storm sewer assets such as hydrodynamic separators that District 6 is responsible for maintaining (10). In contrast, the VJT without a PD pump must vacuum from the top of the water column and empty the structure before cleaning the bottom, adding substantial time to the process.

Capital Cost

The research team determined the capital costs of the recycler truck and VJT by conducting phone interviews of people who had purchased each piece of equipment. In addition, the team received quotes from vendors and distributors. Table 4 provides a summary of the capital costs associated with each piece of equipment.

Table 4: Recycler Truck Capital Costs

Price Range	Average	Standard Deviation	Cost Difference
VJT	$360,000	$89,500	$0
Camel 1200	$464,000	$25,000	$104,000
VacAll AJV	$475,000	$25,000	$115,000
Vactor 2100 Plus	$595,000	$25,000	$235,000
BUCHER 315	$595,000	$25,000	$235,000
GapVax	$750,000	$25,000	$390,000

Note: (1) Price for mid-range recycler truck is the median of the low and high range price points.

The costs quoted are used to determine an annualized capital cost. The team understands that there may be a salvage value for equipment if it is sold at an ideal time; however, for this cost analysis, the salvage value is not considered in the annualized cost. The annualized capital cost is determined using Equations 3 and 4, presented below:

$$AC_c = (C_c)(AF) \qquad \text{Equation 3}$$

where
AC_c = Annualized capital cost ($/yr),
C_c = Capital cost ($), and
AF = Annualized factor (yr^{-1}).

$$AF = \frac{i}{(1+i)^n - 1} + i \qquad \text{Equation 4}$$

where
i = Discount factor (4% +/- 2%), and
n = Life expectancy (yr).

In Equation 4, the annualized factor is known as the discount rate. The life expectancy of the recycler truck and the VJT, based on national and ODOT district surveys and discussions with District 6, is set at 10 years with a deviation of plus/minus 2 years. The results of the capital costs of the recycler truck and the VJT are seen in Table 5.

Table 5: Annualized Capital Costs Based on Ten Year Lifespan

Equipment	Average per Year	Standard Deviation per Year
VJT	$46,186	$15,616
Camel 1200	$59,543	$13,346
VacAll AJV	$60,941	$17,786
Vactor 2100 Plus	$76,351	$16,952
BUCHER 315	$76,351	$16,952
GapVax	$96,243	$21,165

Note: The VJT has an annual capital cost savings of approximately $10,000 to $50,000.

As seen in Table 5, the VJT has a significant cost savings in terms of annual capital costs. The annualized capital costs is the largest advantage that the VJT has over the recycler truck. The following section will describe the maintenance costs associated with each option.

Maintenance Cost

The recycler truck is the same system as the VJT except for the recycling option added on, so the general equipment maintenance, i.e. chassis, engine, debris/water tanks, are expected to incur the same maintenance costs. The recycler trucks do have some added maintenance costs associated with them. As mentioned earlier, the premise behind the recycler truck is that it reuses water that has been cleaned to an extent; however, some fine debris does remain in the water as it passes through the jetting pump and out the jet nozzle. Customers have said that nozzle wear has led to an increase in replacement from every six months to every two to three months.

In addition, pump wear is expected to increase, but due to the recycler technology being so new, it is hard to estimate the increase in costs associated with pump maintenance at this time. The recycler truck also uses a series of screens, cyclones, centrifuges and filters to clean the water, these elements require frequent maintenance as well.

The annual maintenance costs are determined using Equation 5, presented below:

$$AC_m = (C_p) + (n_h)(C_l) \qquad \text{Equation 5}$$

where
AC_m = Annualized maintenance cost ($/yr),
C_p = Cost of parts ($/yr),
n_h = Number of maintenance hours (hr), and
C_l = Cost of labor ($/hr).

Table 6 breaks down the annual maintenance costs for both pieces of equipment.

Table 6: Annual Maintenance Costs

Equipment	**Average per Year**	**Standard Deviation per Year**
VJT	$6,360	$1,017
Recycler Truck	$12,040	$2,032

Note: Annual maintenance costs were determined using a normal distribution curve.

Since there is little data available on the system, the research team is conservative, using a maintenance cost that is double the VJT. As expected, based on capital and maintenance costs, the recycler truck is more expensive on an annual basis; however, the strength of the recycler truck is its savings in operational costs, as seen in the next section.

Operational Cost

The recycler truck makes significant savings in operational costs, primarily due to the increased productivity allowing for more storm sewers to be cleaned in an eight-hour shift. The increased productivity allows the recycler truck to do the same amount of work as the VJT in 51 fewer days. With a labor rate provided by ODOT at $34/hr and a crew size of 5 workers, 51 days means that a large savings in labor costs may be realized. The research team used Equation 6 to then calculate the total annual operational costs with Equation 6, as presented below:

$$AC_o = (AC_l) + (AC_w) + (AC_f) \qquad \text{Equation 6}$$

where
AC_o = Annualized operational cost ($/yr),
AC_l = Annualized labor cost ($/yr),
AC_w = Annualized water cost ($/yr), and
AC_f = Annualized fuel cost ($/yr).

Table 7 shows a breakdown of the annual operational costs for both options.

Table 7: Annual Operational Costs

Equipment	Average per Year	Standard Deviation per Year
VJT	$228,180	$61,181
Recycler Truck	$144,330	$26,848

Note: The annual labor costs account for 52-68% of the total annual costs depending on capital cost of equipment. This is calculated by dividing the total annual costs by the estimated labor costs.

As seen in Table 7, the annual operational costs of the recycler truck-are nearly $85,000 less than the VJT, which includes the fuel, water and labor costs of each technology. This cost savings makes up for the higher annual capital and maintenance costs as seen in the following section. The team notes that while the recycler truck would see fuel savings from fewer water and decant trips, it would still be using fuel to clean additional storm sewers. This analysis considered the recycler truck fuel savings to be negligible.

Summary of Annual Costs

Based on the annual capital, maintenance and operational costs, the research team can determine a final system annual cost for each type of equipment and cost range as seen in Table 8.

Table 8: Detailed Annual Cost Summary

Equipment	Description	Average per Year	Standard Deviation per Year
VJT	Total Annual Cost	$280,680	$54,782
	Total Lifespan Cost	$2,790,000	$769,820
Camel 1200	Total Annual Cost	$215,910	$27,956
	Total Lifespan Cost	$2,137,000	$422,320
VacAll AJV	Total Annual Cost	$217,260	$31,359
	Total Lifespan Cost	$2,150,200	$432,460
Vactor 2100 Plus	Total Annual Cost	$232,720	$29,471
	Total Lifespan Cost	$2,299,800	$428,330
BUCHER 315	Total Annual Cost	$232,720	$29,471
	Total Lifespan Cost	$2,299,800	$428,330
GapVax	Total Annual Cost	$252,610	$32,427
	Total Lifespan Cost	$2,490,600	$439,150

Note: Cost calculations were derived using data from 2017.

Based on the total annual costs, the recycler truck is more cost efficient in every scenario, including the most expensive recycler trucks that are approximately $30,000 less than the VJT. The majority of these savings come from the savings in labor achieved from working fewer days with the recycler. This economic analysis provides a conservative view of the expected cost savings of a recycler truck compared to a VJT. The research team recommends that all variables associated with the cost analysis should be verified with additional field data.

Results and Discussions

The research team compared the traditional VJT to the recycler truck technology to determine if the new technology was a viable option to implement in ODOT. Table 9 shows the comparison between the VJT and recycler truck technology.

Table 9: Equipment Viability

Category	Item	Vacuum Jet Truck	Recycler Truck
Production	Jetting Capacity[1]	Low	High
	Debris Capacity[2]	Low-High	Medium-High
	Production Rate	Low	High
Operations	Labor Costs	High	Low
	Water Costs	High	Low
	Fuel Costs	High	Low
Total Capital Cost		Low-Medium	Medium-High
Total Maintenance Cost		Medium	High
Total Operational Cost		High	Low
Annual Cost		High	Low-Medium
Lifespan Cost		High	Low-Medium

Note: (1) Jetting capacity refers to the amount of jetting the equipment is able to complete before needing to refill the water tank. (2) Debris capacity refers to the amount of debris/wastewater that is able to be vacuumed before needing to make a decant trip.

The research team concludes that every recycler truck studied is a viable option to improve ODOT's storm sewer cleaning operations. The increased capital cost is offset by the operational savings associated with the decrease in labor costs for the recycler truck technology. The team notes that additional research is necessary, particularly in term of maintenance costs as the technology ages. Operator training is also an area of potential future focus as the increased equipment complexity may require more training hours and a temporary reduction in the production rate. In addition, future analysis of real world field data would present a clearer picture of the actual, realized production improvements and cost reductions.

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Author Contribution Statement

Tyler Mikita collected field data, built production and cost models, analyzed results and was the lead author on the paper. William Schneider developed data collection methodology and assisted in developing production and cost models. Teresa Cutright assisted in reviewing applicable environmental regulations and field data collection. Mallory Crow assisted with developing production and cost models as well as edits to this paper.

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