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This issue presents a shortened version of a paper that Roger and Terry Martin (Seattle Public Utilities) presented at STORMCON 2006 in Denver this past July. If you want the complete paper, email Roger. **But first we need to remind you to resubscribe for 2007 if you have not already done so. The subscription form is presented at the back of this issue.** *Also note that Gary is giving his short course in Seattle Jan 30 and 31. The early bird savings deadline is January 12th, Friday of this coming week.*

STREET CLEANER UP PICKUP PERFORMANCE TESTING

Introduction: The City of Seattle is considering an expansion of its existing street cleaning program to reduce pollutant loadings. Pacific Water Resources, Inc. (PWR) was contracted by the City of Seattle Public Utilities to design and implement a pick-up performance test for up to ten different models of street cleaners. The results of these tests along with other testing and observations by the City of Seattle's Department of Transportation helped determine the manufacturer and model of a new street cleaner fort the City.

The City invited four street cleaner manufacturers to demonstrate the performance of several new cleaner models and to participate in the various tests. The manufacturers (Elgin, Schwarze, Tennant and Tymco) brought a total of seven new machines. In addition, the City asked PWR to test two of its existing machines, the Elgin Broom Bear and the Mobile Patriot. This paper briefly documents the test procedures and results of the pick-up performance tests.

Test Procedure: Since the testing was expected to occur over several days it was important that PWR design a repeatable test procedure. A "street dirt" simulant was created and a small portion was used for each test. The test procedure was quite simple. A known quantity of the street dirt simulant was spread evenly on a designated pre-measured test track using a fertilizer spreader. A street cleaner then performed a single pass at a designated forward speed of two to three miles per hour. However, the actual speed was determined by knowing the distance traveled and the time. Following the cleaning, an industrial vacuum cleaner was used to hand vacuum the simulant that remained on the test track. The accumulated sample was placed in a labeled bag and taken to the City's soils lab where it was weighed, dried, weighed again and sieved into eight pre-selected particle size groups. A single sample of the simulant was sieved so the particle size distribution of the initial material was also known.

Idealized Conditions: The testing procedure requires dry pavement. However, the tests were scheduled to occur in the fall season, which can be wet in Seattle. Therefore, the tests were conducted inside an old airplane hanger at a former US Naval base in northeast Seattle. These interior location guaranteed dry pavement conditions.

Pavement conditions significantly affect pick-up performance (Sartor and Boyd, 1972). The concrete pavement in the hanger was in excellent condition as there were very few cracks or other imperfections. Also, the pavement had been sealed with a smooth rubber based coating .

Obstructions such as street curbs or roadway barriers have a significant effect on the accumulation of "street dirt" and the ability of street cleaners to effectively pick up the accumulated material. A study in

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San Jose, California found that on residential asphalt streets approximately 58 to 73% of the street dirt was within two feet of the curb (Pitt, 1979). Street dirt monitoring at bus stops in six cities s found that 90% of the solids were located within one foot of the curb (Sartor and Boyd, 1972).

Street cleaners are more effective in picking up solids located a few feet from a curb than those accumulated right along the curb. Our tests were considered ideal because no curb or other obstruction was simulated. Also, the accumulation throughout the 8-foot wide and 40-foot long test track was fairly uniform with slightly more material (e.g. on a unit area basis) located within 2 feet of the line that represented the curb. All of the machine operators chose to use their right side gutter brooms during the tests but applying water was not allowed.

The forward speed of a street cleaner affects its ability to pick up material. All else equal, pick-up effectiveness increases as the forward speed decreases (Sartor and Boyd, 1972). The machine operators were instructed to clean at two to three miles per hour (mph). Operating at these speeds, it would only take 9 to 14 seconds to clean the 40-foot long test track. However, most of the sweepers cleaned at much slower speeds since the vendors wanted to do the best possible job. Actual cleaning times varied from 10 to 22 seconds or 2.7 to 1.2 mph average forward speed. Keep in mind that recommended normal operating speeds are generally 5 to 6 mph but actual practice could be even higher.

It is important to recognize that for the various reasons noted previously, test conditions were ideal. The resulting pick-up efficiencies will likely be much higher than those expected under the real world conditions. However, the tests still provided a comparative analysis of the nine cleaners.

Street Dirt Simulant: One of the most important aspects of a street cleaner pick-up performance test is the amount and particle size distribution of the street dirt that is used. The amount and particle size distribution (PSD) of accumulated street dirt has been investigated for over 30 years. The first and largest street dirt dataset collected in the Seattle metropolitan area (Bellevue) occurred in the early 1980's as part of the Nationwide Urban Runoff Program (USEPA, 1983). Street dirt was monitored in five small urban watersheds and approximately 600 samples were obtained over a two-year period.

Our objective was to create a street dirt simulant that was as close as possible to the average PSDs found in the Bellevue data. Due to an unfortunate miscommunication, the amount of coarse sand available for the mixture recipe was limited so the resulting PSD was much finer than that observed earlier in Bellevue. Approximately 105 lbs of the street dirt simulant was produced using a portable concrete mixer that the City brought on the first test day. This was more than enough material for several days of testing that actually occurred. The PSD of the street dirt simulant is presented in Table 1.

Table 1 – Particle Size (PS) Distribution of Street Dirt Simulant

Sieve No.	Size, Microns	% Incremental	% Retained	% Passing
10	>2000	0.1	0.1	99.9
20	850-2000	3.5	3.6	96.4
30	600-850	7.3	10.9	89.1
60	250-600	27.8	38.7	61.3
140	106-250	39.5	78.2	21.8
200	75-106	2.4	80.6	19.4
270	53-75	0.7	81.3	18.7
Pan	<53	18.7	100	0.0

The Bellevue street dirt data also showed that the average dry season accumulations ranged from 160 to 920 lbs per curb mile (i.e. 45 to 259 grams per curb meter), depending on several factors like land use and traffic (Pitt, 1985). One of the common mistakes made during most street cleaning pick-up tests or demonstrations is of an excessive amount of material used, which does not represent day-to-day realistic loading conditions (Sutherland, 1997). The original intent of the PWR designed cleaning tests was to spread out 4 lbs (i.e. 1816 grams) of the simulant along the 40-foot (12.1-meter) long by 8-foot (2.4-meter) wide test track. This would represent an accumulated loading of 528 lbs per curb mile (i.e. 150 grams per curb meter), which is well within the range of the average accumulations observed in Bellevue. However, a malfunction of the fertilizer spreader on the first day of testing created a situation where the actual initial accumulations for the four tests conducted on that day were not exactly known. Photos taken before each of the tests were used to estimate the initial accumulations on the first day to be approximately one half of those used on the second and third day where 4 lbs (i.e. 1816 grams) was known to have been used.

Pick-Up Efficiencies: The pick-up performance data are presented in Table 2. The results show that the observed pick-up efficiencies are very high and that very little difference separates eight of the nine cleaners. However, high removals were expected since the test conditions were ideal as discussed earlier. It is a mistake to assume that these pick-up percentages would occur in the real world that contains: (1) rough textured pavements, (2) pavements in poor condition, (3) curbs and other obstructions like parked cars, (4) street dirt accumulations concentrated along the curbs, and (5) much greater forward operating speeds.

Table 2 – Pick-Up Performance Test Results

Manufacturer	Model	Type	New or Used	Remaining Mass (gms)	Initial Mass (gms)	Pick-up Mass (gms)	Pick-up %	Forward Speed (mph)
Elgin	Broom Bear	Mechanical	Used	124.2	908[1]	783.8	86.3	2.7
	Geo Vac	Vacuum	New	8.7	1816[2]	1807.3	99.5	1.6
	Crosswind	Regenerative	New	8.1	1816	1807.9	99.6	1.5
Mobile	Patriot	Mechanical	Used	96.8	1816	1719.2	94.7	2.7
Schwarze	M6000	Mechanical	New	36.7	908[1]	871.3	96.0	1.4
	A8000	Regenerative	New	8.1	908[1]	899.9	99.1	1.4
Tennant	Centurion	Mechanical	New	15.1	908[1]	892.9	98.3	1.2
Tymco	435	Regenerative	New	58.7	1816	1757.3	96.8	2.1
	600	Regenerative	New	71.9	1816	1744.1	96.0	1.8

1. Estimated after the tests.
2. Entire accumulation was placed in a 2-foot wide area along the simulated curb line.

With one exception (Tennant Centurion), the mechanical cleaners had the lowest pick-up efficiencies. The two machines with the lowest pick-up percentages were used mechanical sweepers currently owned by the City. However, both of these machines were operated at the fastest forward speed, which was approximately 2.7 miles per hour. All of the new machines were operated at slower speeds (2.1 to 1.2 miles per hour, see Table 2). As mentioned above, slower cleaning speeds will generally increase the pick-up performance. The two new mechanical cleaners (Schwarze M6000 and the Tennant Centurion) were operated the slowest of all, which could somewhat explain the higher than expected removals. The average forward speed of the vendor-operated cleaners was approximately 1.5 miles per hour. Tymco operated their machines at the highest speed for the non-mechanical cleaners tested and Elgin operated at the slowest speed for this category. This may help explain why Tymco had a slightly lower pick-up percentage when compared to Elgin, which had the highest pick-up of all the machines tested. However, the Elgin machines appeared to generate the greatest amount of dust, which will be discussed below.

Remaining Amounts: It would be nice if we could conclude that the machine that left the least amount of material should be declared the winner. Unfortunately, it is not that simple, since the actual initial loadings for the first day's test (i.e. Schwarze, Tennant and the used Elgin Broom Bear) were not known exactly. Since we do know that the remaining amount of material will increase with increasing initial amounts and that the first day tests used less material than subsequent days, we can conclude that the remaining amounts for the first day should be increased when comparing them to those found on subsequent days. If we assume the first day remaining amounts should be doubled then the pecking order for the new cleaners from best to less than best would be: Elgin Crosswind, Schwarze A8000, Elgin GeoVac, Tennant Centurion, Tymco 435, Tymco 600 and Schwarze M6000.

But once again, this would not be fair to Tymco, since their machines were operated at a higher speed than the new Elgins and the Schwarze A8000. This higher operating speed reduced their pick-up efficiencies. And the Elgin machines created more dust, which appears to have increased its pick-up efficiency since the wind blown material is not accounted for if it doesn't fall back on to the test track. Also, errors in the estimate of the actual first day loads could either benefit or hinder the perceived performance of the Schwarze and Tennant machines.

All of the cleaners generated a certain amount of dust. The loss of material due to dust generation was not measured in this test. However, photos and notes were taken before, during, and after each test. A review of this information indicated the Elgin machines generated more dust than the others. This was especially true for the GeoVac. Contributing to the dust problem were: (1) a very fine PS distribution of the simulant (see Table 1); (2) smooth and sealed pavement surface; (3) no water (used for dust control) was applied during the test; and (4) certain design features of some machines appeared to increase dust generation. In regards to the latter item, the air exhaust located at the back of the machine for both the Elgin GeoVac and the Elgin Crosswind (to a lesser extent) is directed directly down at the pavement. This appeared to increase the amount of fugitive dust that these machines create. Also, the reduced sweeper path width of the GeoVac, which is a pure vacuum machine, required that all of the 4 lbs of simulant be placed in an area 2 feet wide, which concentrated the material exposed to this fan exhaust and added to the dust generation.

Particle size distributions were obtained for several of the remaining masses. Not all of the mass remaining after each test run was analyzed for its PSD due limited quantities in some cases. The results of this analysis are presented in Table 3.

The results in Table 3 indicate that all of the cleaners evaluated except the City's Elgin Broom Bear left a mass that would be considered finer than the initial accumulation. In fact, the used Elgin Broom Bear had the lowest pick-up performance and essentially did not change the overall PS distribution of the original simulant. A shift towards the fines is expected from cleaning and has, to the author's knowledge, always been observed. The only explanation for the Broom Bear's performance may because the brooms were worn . The greatest shift to finer material occurred for the City's Mobile Patriot and the Tymco 435. The Tymco 435 result is expected but the Mobile Patriot results can't be explained. However, the remaining mass for the used Patriot was the second highest and the overall pick-up efficiency was the second lowest. The 150-micron size (61%, last column in Table 3) found for the mechanical Schwarze M6000 is more like what would have been expected for the mechanical Patriot. Also, the 123-micron size found for the Tymco 600 was actually much coarser than the distribution that would have been expected.

Table 3 – Results of PS Distribution Analysis of the Remaining Amounts

Manufacturer	Model	Type	New Or Used	Remaining Mass (gms)	Sieve Size 61% Passing (microns)
Elgin	Broom Bear	Mechanical	Used	124.2	250
	Geo Vac	Vacuum	New	8.7	excluded
	Crosswind	Regenerative	New	8.1	excluded
Mobile	Patriot	Mechanical	Used	96.8	<53
Schwarze	M6000	Mechanical	New	36.7	150
	A8000	Regenerative	New	8.1	excluded
Tennant	Centurion	Mechanical	New	15.1	excluded
Tymco	435	Regenerative	New	58.7	<53
	600	Regenerative	New	71.9	123

Summary: Pick-up performance tests on nine different cleaners were conducted on three separate days. Four different street cleaner manufacturers brought a total of seven new machines to be tested. Of these new machines, four were classified as regenerative air, two were mechanical, and one was a pure vacuum. Two used mechanical sweepers owned and operated by the City of Seattle were also tested.

The overall pick-up efficiencies were quite high and ranged from 86.3 to 99.6%. The difference between the highest pick-up percentage and that for the next to the lowest was only 4.8%. The two used machines (i.e. Elgin Broom Bear and Mobile Patriot) had the two lowest pick-ups at 86.3 and 94.7%, respectively. The difference in pick-up percentage between the best new machine and the worst new machine was only 3.6%. The pick-up efficiencies were very high because the test conditions were essentially ideal since they: (1) occurred indoors, (2) no curb was simulated, (3) the pavement was in excellent condition and was sealed and coated, which made it very smooth, and (4) the initial simulant was generally spread out evenly over the test track width instead of being concentrated along the curb.[1]

The street dirt loadings used for the tests were reasonable and well within the range observed but the particle size distribution was much finer than those observed some 20 years ago in Bellevue, Washington. All of the cleaners generated dust when they operated, which created fugitive dust losses. Since fugitive dust was not measured, the net result is that pick-up efficiencies were higher than they actually were had the losses been measured and taken into account. Clearly the new Elgin cleaners generated the most dust. None of the cleaners were allowed to use water for dust suppression during the tests because dry pavement conditions were needed to obtain the after sample.

An analysis of the remaining masses concluded that the differences between the best and less than the best for all of the new cleaners could be explained by differences in initial loadings, forward cleaning speed, and fugitive dust losses. Due to a spreader malfunction, the initial loadings used for the first day of testing were not exactly known like they were for subsequent days. The forward speeds of the new cleaners varied greatly from 1.2 miles per hour to 2.1 miles per hour, which affected pick-up performance with slower cleaners picking up more material.

[1] This was not the case for the Elgin GeoVac whose sweeping path was only 30 inches.

An analysis of the particle size distribution of the remaining masses for five of the nine tests yielded results that were not always explainable. The low remaining mass weights found in four of the tests essentially excluded them from this analysis due to reliability concerns.

Recommendations: Based on the results of the pick-up tests, it was not prudent to recommend that any of the seven new cleaners should be eliminated from further consideration. Any of these cleaners may be able to prove that they have the capabilities of picking up a reasonably high percentage of the dirt that can be found throughout the streets of Seattle. With that said, it is difficult to believe that a mechanical sweeper like the Schwarze M6000 or the Tennant Centurion will be able to achieve the performance that any of the regenerative air machines are likely to achieve. But that opinion is based on previous testing of older mechanical machines so one should always maintain an open mind regarding these newer mechanical sweepers until their actual capabilities are proven one way or the other.

PWR recommended that the City retest each of these seven machines under a set of real-world conditions. The tests should be conducted outside using a curb. The former Naval Air Base at Sand Point could be used as the site since many curbed streets are available.

Post-Script: Following this pick-up performance testing, which was conducted in the fall of 2004, the City of Seattle wanted to implement a street sweeping program for residential areas by redirecting financial resources from its existing stormwater utility. However, an opinion by the City's counselor on the use of stormwater funds for the transportation run sweeping program concluded that it would be prudent for the City to first establish through further study that sweeping, in fact, did improve stormwater quality.

As a result, the City budgeted financial resources for a future street sweeping pilot study. The development of the monitoring program for this street sweeping pilot study began in the fall of 2005. Data collection activities began in June 2006 and is expected to be completed by May 2007. A multiple paired basin approach is being used where one basin of each pair is unswept and remains as the control. The other basin in each pair is then swept based on a set schedule that will include parking controls to ensure that the cleaner can sweep along the curb. Three different sets of paired basins are being monitored. For more information on the Seattle Street Sweep Project go to (http://www.seattle.gov/util/Services/Drainage_&_Sewer/Keep_Water_Safe_&_Clean/Street_Sweep_Project/index.asp). For an interview of Keith Ward, Seattle's project manager, by Ranger Kidwell, editor of www.worldsweeper.com, go to (http://www.worldsweeper.com/Street/Studies/Seattle2006/SeattleInitialInfo.html).

In anticipation of the street sweeping pilot, the City of Seattle purchased a new Schwarze A8000 sweeper in 2005. It is unclear how much of a role the results of this pick-up performance testing played in the sweeper selection. It's quite possible that the "high dump" feature only available with this machine was the determining factor in its selection.

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