ICPIF Paver Analysis Report:

Pittsburgh, Philadelphia/New Jersey, & Northern Virginia

Report Prepared By: Eric Sinagra, CEO, pathVu,
eric.sinagra@pathvu.com
August 30, 2018

Summary

The goal of this project was to investigate the Wheelchair Pathway Roughness Index (WPRI) values of 96 various concrete permeable and non-permeable concrete paver surfaces in the Pittsburgh, Philadelphia/New Jersey, and Northern Virginia areas. Data regarding joint width, chamfer width, imagery, and WPRI values were collected. WPRI values were collected by pathVu's PathMeT technology according to ASTM E3028. The results were compared against published suggested thresholds by Duvall et al. According to those thresholds, 77 surfaces performed within the acceptable WPRI range, 19 performed with the cautioned range, and 0 were found to be in the unacceptable range. A correlation between joint width, chamfer width, and WPRI was evident. Joint and chamfer width appear to be significant factors in determining WPRI.

Background

ASTM E3028

ASTM E3028[1], *Standard Practice for Computing Wheelchair Pathway Roughness Index as Related to Comfort, Passability and Whole Body Vibrations from Longitudinal Profile Measurements,* methodology was used to determine Wheelchair Pathway Roughness Index (WPRI) for this study. WPRI is "an index computed from longitudinal profile measurements using a standard 70 mm (2.5 in.) diameter wheel with no deformation and no affects from speed. The index represents the total vertical deflection of that wheel as it travels over a surface...WPRI is reported in either millimeters per meter (mm/m) or inches per foot (in/ft)."

PathMeT

PathMeT is pathVu's proprietary device used to collect high-quality, high-resolution pathway data. PathMeT was used in data collection and testing to develop ASTM 3028. PathMeT is a manually propelled three-wheeled device (Figure 1). PathMeT contains numerous sensors, including laser displacement measurement tool, wheel encoder, 9 degrees of freedom inertial measurement unit, camera, and GPS. PathMeT's laser is a single-point laser, allowing the technician to accurately collect the correct centerline and complying with ASTM 3028 requirements. The profile is collected at a millimeter resolution or better in order to collect all of the details the surface, not missing any joint widths. Besides WPRI, PathMeT identifies tripping hazards, running slope, cross slope, and depressions.

[1] Accessible at: https://www.astm.org/Standards/E3028.htm

Figure 1: Picture of PathMeT

Suggested WPRI Thresholds

In 2016 Duvall et al.[2] investigated the effects WPRI further. The study reports that increased whole-body vibration exposure to wheelchair users can lead to increased neck and back injury. Consequently, Duvall et al. considered the ISO 2631-1 standard, *Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibrations* when conducting their research. The study found that there is a direct correlation between whole-body vibrations experienced by wheelchair users and the surface WPRI. As a result, Duvall et al. used ISO 2631-1 to identify suggested WPRI thresholds to ensure wheelchair user comfort and safety. Duvall et al. suggests threshold limits of 100 mm/m for surface segments less than 3 m and 50 mm/m for surface segments of 100 m or greater.

Note: These suggested WPRI thresholds, although published in a peer-reviewed journal, are not officially adopted or enforced by any agency. They are only the author's and pathVu's suggested thresholds.

Testing Methodology

In 2017 and 2018, 96 different concrete paver surfaces in the Pittsburgh (36), Philadelphia/New Jersey (28), and Northern Virginia (32) regions were investigated as part of this project. Concrete paver surfaces were both permeable (36) and non-permeable (60). Data collection in each location occurred in warm weather, 70°F - 85°F, on mostly sunny days, with calm winds.

---

[2] Jonathan Duvall MS, Eric Sinagra MS, Rory Cooper PhD & Jonathan Pearlman PhD (2016) Proposed pedestrian pathway roughness thresholds to ensure safety and comfort for wheelchair users, Assistive Technology, 28:4, 209-215, DOI: 10.1080/10400435.2016.1150364

The pathVu team collected the following data for each surveyed surface: two random joint widths between pavers, two random paver chamfer widths, one image, and at least 2 data collection runs with PathMeT along typically different centerlines. The centerline of the surface was never located in the gap between lateral pavers. The image was taken from the perspective of the direction of travel.

For each surface, the pathVu technician (Eric Sinagra in each case) would follow the steps below. For PathMeT data collection, the technician would walk at a pace of approximately 1 m/s (2 mph) and made sure that the device laser never went in between lateral gaps. The technician would avoid any sticks, leaves, or debris if necessary. If possible, the technician cleaned the pathway ahead of time. Runs with errors were discarded and not included in analysis. Figure 2 shows an image of data collection with PathMeT.

Data collection procedures:

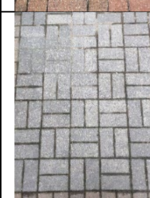
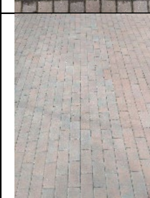
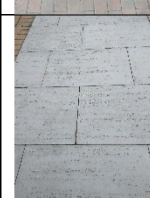
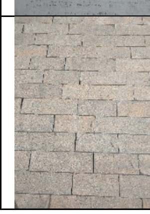
1) Record the weather
2) Record the joint widths
3) Record the chamfer widths
4) Take image
5) Record device serial name/number
6) Identify centerline to be collected
7) Collect at least two PathMeT data collection runs
8) Return to the office to process data

Figure 2: Picture of PathMeT Data Collection

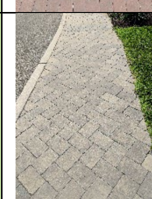
Results

Table 1 shows the results of data collection for this project. The location, type (permeable [PICP], non-permeable [ICP]), average joint width, average chamfer width, average WPRI, and image are shown for each surface. Data is organized by increasing WPRI. WPRI is color-coded based on the suggested thresholds by Duvall et al.: green (<50 mm/m), yellow (>=50 mm/m & <100 mm/m), red (>=100 mm/m). Of the 96 surfaces tested, 77 performed in the green range and 19 performed in the yellow range, while 0 performed in the red range. These WPRI values were also accepted by the U.S. Access Board (insert reference to paper by Scott Windley.)

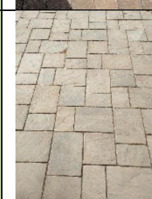
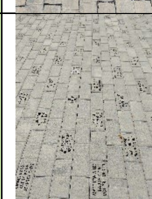
Table 1: WPRI results from PathMeT data collection over 96 concrete paver surfaces

Location	Type (ICP, PICP)	Avg Joint Width (mm)	Avg Chamfer Width (mm)	Avg WPRI (mm/m)	Image
Pittsburgh	ICP	2.7	None	16.4	
Pittsburgh	ICP	2.6	6.9	17.5	
Philadelphia/NJ	ICP	1.7	5.3	18.5	
Pittsburgh	ICP	3.8	1.2	19.7	
Pittsburgh	ICP	3.5	None	22.0	

Philadelphia/NJ	ICP	3.3	6.5	22.2	
Pittsburgh	ICP	3.3	None	24.7	
Pittsburgh	ICP	11.7	None	24.7	
Pittsburgh	ICP	2.9	5.2	25.0	
Philadelphia/NJ	ICP	2.5	3.1	25.5	
Pittsburgh	ICP	3.1	None	25.7	
Pittsburgh	ICP	1.9	None	25.9	
Northern Virginia	PICP	10.3	None	27.0	

Philadelphia/NJ	ICP	2.5	3.5	27.5	
Northern Virginia	PICP	2.7	5.8	28.0	
Philadelphia/NJ	ICP	3.9	None	30.0	
Philadelphia/NJ	ICP	2.3	5.9	30.3	
Philadelphia/NJ	ICP	3.7	2.3	30.6	
Pittsburgh	ICP	6.1	5.7	30.7	
Northern Virginia	ICP	4.2	7.2	31.0	
Northern Virginia	PICP	6.1	4.5	31.9	

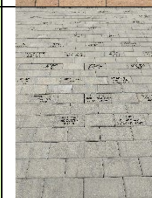
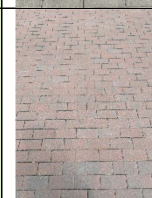
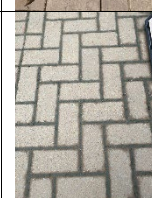
Northern Virginia	PICP	3.5	5.8	31.9	
Philadelphia/NJ	ICP	5.8	3.7	32.3	
Pittsburgh	ICP	7.7	5.7	32.7	
Northern Virginia	PICP	10.3	None	32.8	
Pittsburgh	ICP	5.3	1.4	33.1	
Northern Virginia	PICP	6.3	4.3	33.3	
Philadelphia/NJ	ICP	2.0	5.9	33.4	
Northern Virginia	PICP	2.2	7.7	33.4	

Pittsburgh	PICP	2.8	3.5	33.6	
Pittsburgh	ICP	15.6	9.0	33.9	
Philadelphia/NJ	ICP	4.1	2.9	34.0	
Pittsburgh	ICP	6.8	2.1	34.1	
Northern Virginia	PICP	8.5	4.2	34.4	
Philadelphia/NJ	ICP	3.7	6.7	34.9	
Northern Virginia	PICP	3.9	None	34.9	
Pittsburgh	ICP	5.5	5.8	35.1	

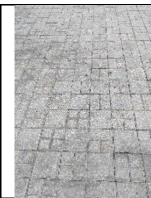
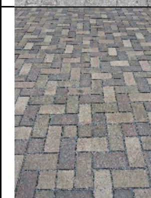
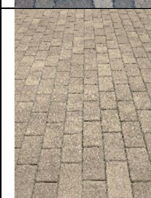
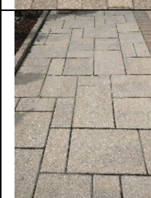
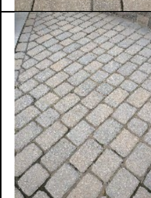
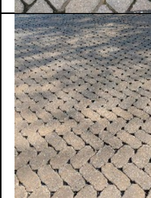
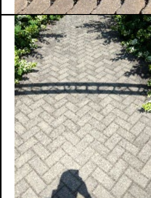
Philadelphia/NJ	ICP	2.1	5.4	35.3	
Northern Virginia	PICP	4.5	4.0	35.4	
Pittsburgh	ICP	10.1	None	35.6	
Northern Virginia	PICP	10.9	4.5	35.6	
Pittsburgh	ICP	8.7	5.1	35.8	
Northern Virginia	PICP	5.0	3.9	35.9	
Philadelphia/NJ	ICP	2.3	5.6	36.1	
Northern Virginia	PICP	10.5	None	36.1	

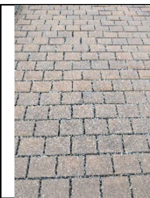
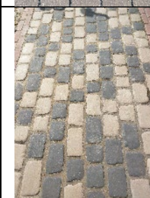
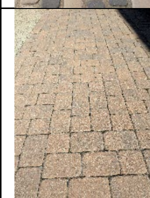
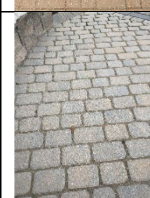
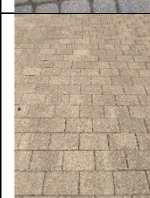
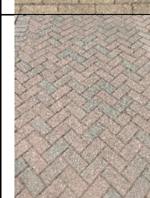
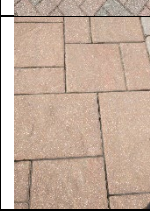
Northern Virginia	PICP	4.6	4.5	36.1	
Northern Virginia	PICP	5.9	3.4	36.4	
Northern Virginia	PICP	5.5	3.7	37.0	
Northern Virginia	PICP	7.8	5.7	37.1	
Northern Virginia	PICP	3.0	6.3	37.2	
Northern Virginia	PICP	11.1	4.1	37.5	
Northern Virginia	PICP	5.9	4.4	37.8	
Pittsburgh	ICP	5.6	6.7	38.7	

Northern Virginia	PICP	7.0	8.2	39.7	
Pittsburgh	ICP	3.0	None	39.9	
Philadelphia/NJ	ICP	2.6	5.6	40.0	
Northern Virginia	PICP	5.0	3.9	40.1	
Northern Virginia	PICP	2.6	None	40.6	
Northern Virginia	PICP	4.8	4.6	40.6	
Northern Virginia	PICP	4.6	3.5	41.2	
Pittsburgh	ICP	2.3	6.2	41.3	

Pittsburgh	ICP	4.8	2.0	41.8	
Philadelphia/NJ	ICP	2.3	7.5	42.1	
Philadelphia/NJ	ICP	6.5	6.3	42.3	
Pittsburgh	ICP	6.9	3.3	42.6	
Pittsburgh	ICP	2.4	5.8	43.0	
Philadelphia/NJ	ICP	2.7	4.6	44.3	
Philadelphia/NJ	ICP	2.8	5.9	44.5	
Philadelphia/NJ	PICP	15.2	5.2	44.7	

Northern Virginia	PICP	4.7	4.3	45.4	
Pittsburgh	ICP	6.3	4.1	45.6	
Pittsburgh	ICP	3.9	6.3	45.7	
Pittsburgh	ICP	7.2	3.6	46.3	
Philadelphia/NJ	ICP	2.7	8.8	48.6	
Philadelphia/NJ	PICP	14.2	4.6	48.8	
Philadelphia/NJ	ICP	2.5	5.7	48.9	
Pittsburgh	ICP	7.2	5.9	49.7	

Philadelphia/NJ	ICP	2.9	6.6	50.4	
Northern Virginia	PICP	11.1	None	52.1	
Northern Virginia	ICP	2.9	8.3	54.1	
Pittsburgh	ICP	6.9	4.8	54.3	
Pittsburgh	PICP	13.0	9.4	55.0	
Northern Virginia	PICP	2.2	5.1	55.7	
Philadelphia/NJ	ICP	3.0	5.5	56.4	
Philadelphia/NJ	ICP	1.9	5.7	57.1	

Philadelphia/NJ	PICP	15.3	5.3	57.9	
Pittsburgh	ICP	19.7	2.2	58.2	
Philadelphia/NJ	ICP	2.5	7.9	58.8	
Philadelphia/NJ	ICP	2.8	6.5	59.3	
Pittsburgh	PICP	13.0	9.4	60.3	
Northern Virginia	ICP	4.5	9.2	61.8	
Northern Virginia	PICP	3.6	7.7	64.1	
Pittsburgh	ICP	7.0	5.7	65.6	

Pittsburgh	ICP	5.7	None	65.7	
Pittsburgh	PICP	43.2	6.2	68.3	
Pittsburgh	ICP	1.7	5.5	78.0	

A regression analysis was performed to understand if there is a correlation between ICP/PICP, joint width, chamfer width, and WPRI. Table 2 shows the results of the R^2 value and p values for joint and chamfer width.

Table 2: ICP/PICP, joint width, chamfer width, and WPRI regression results

Surface Type	**R^2**	**Joint width p value**	**Chamfer width p value**
All	0.20	0.005	0.00006
ICP	0.15	0.185	0.00258
PICP	0.32	0.011	0.009

Further, correlation graphs (Figures 3-8) were developed to understand how joint width and chamfer width can independently be used to determine WPRI. Graphs are separated by all surfaces, ICP only, and PICP only for joint width and chamfer width. R^2 values are shown for each.

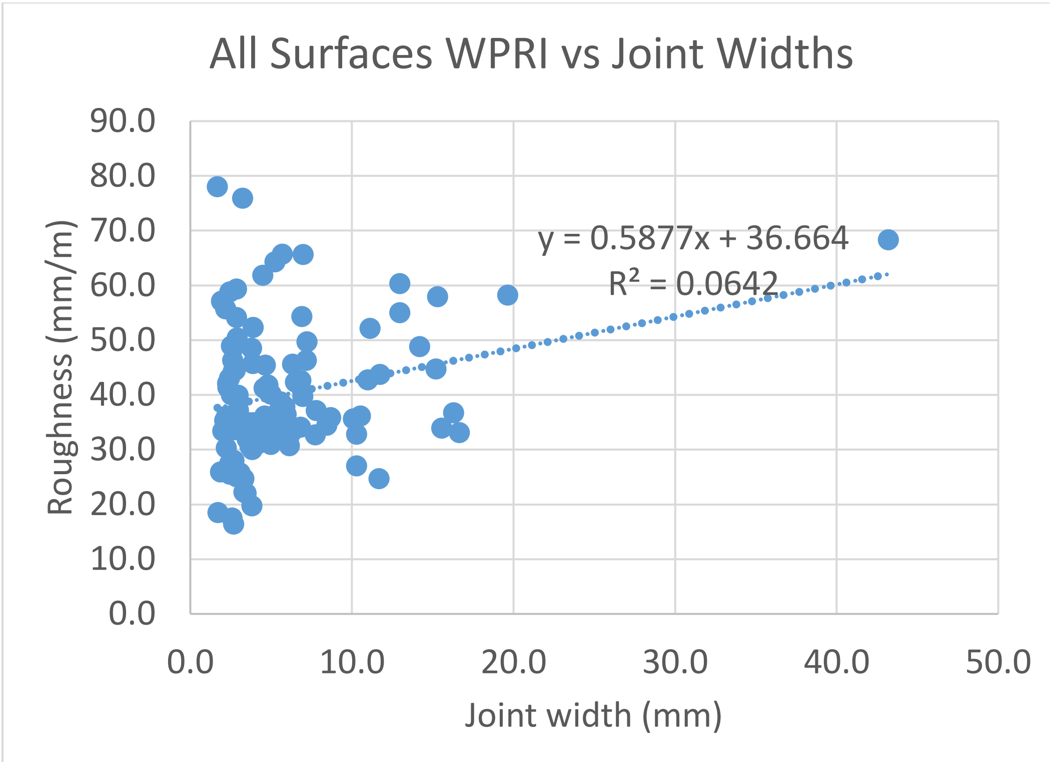


Figure 3: Regression of all surfaces showing WPRI vs joint widths

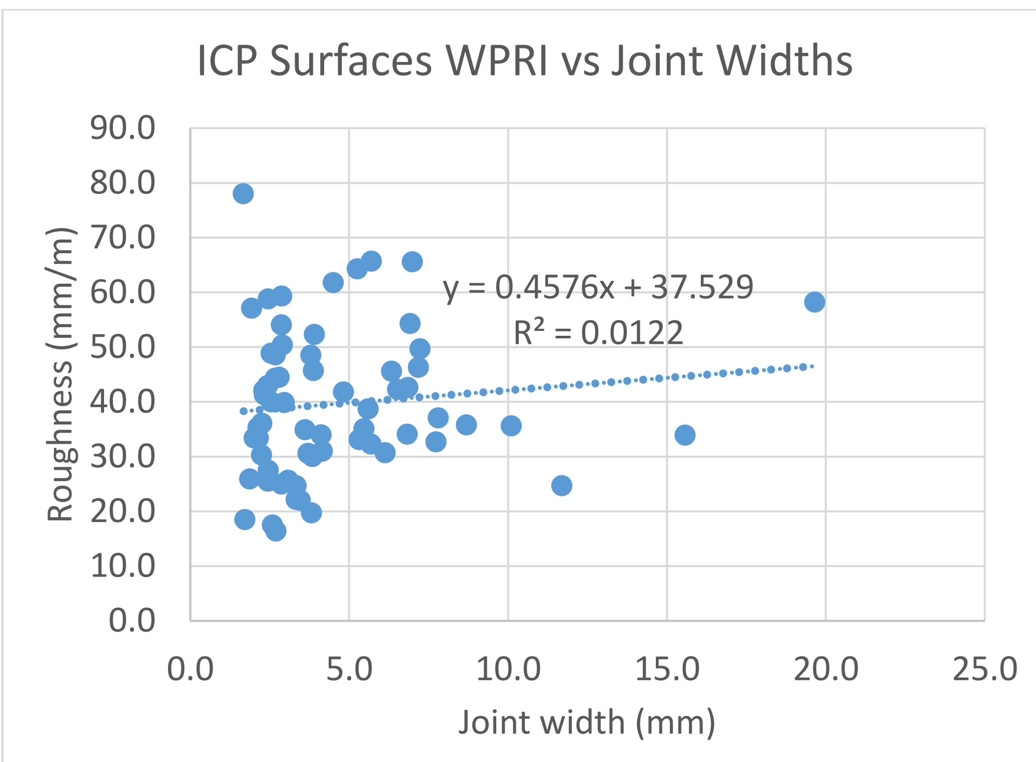


Figure 4: Regression of ICP surfaces showing WPRI vs joint widths

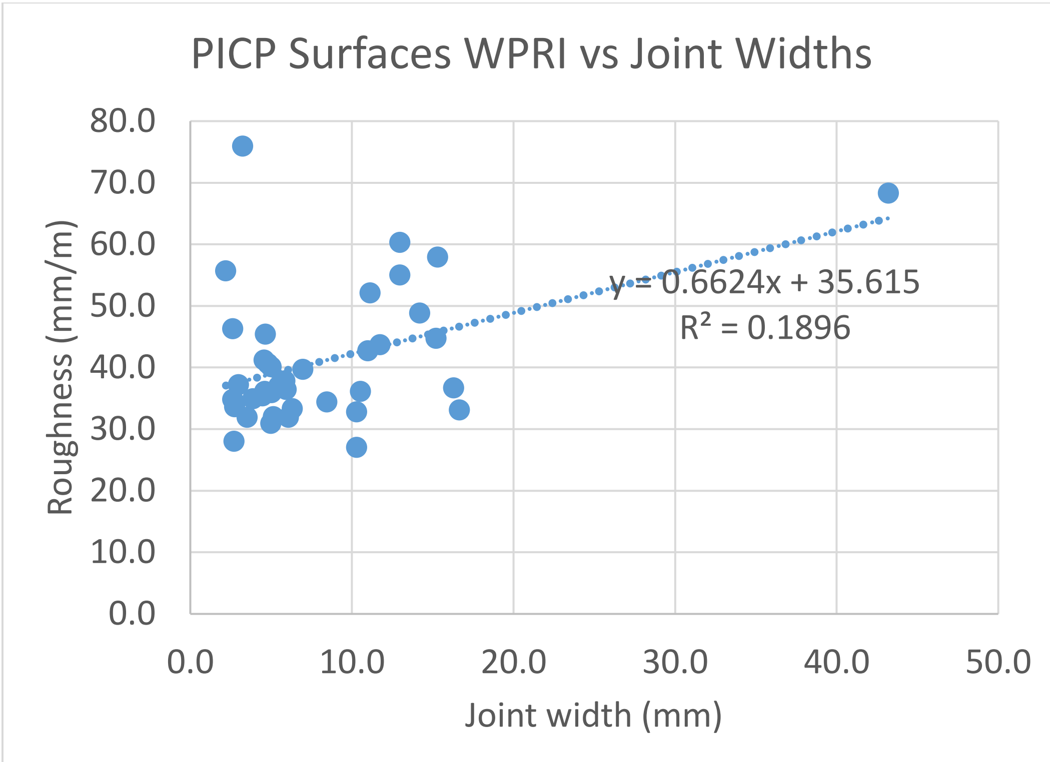


Figure 5: Regression of PICP surfaces showing WPRI vs joint widths

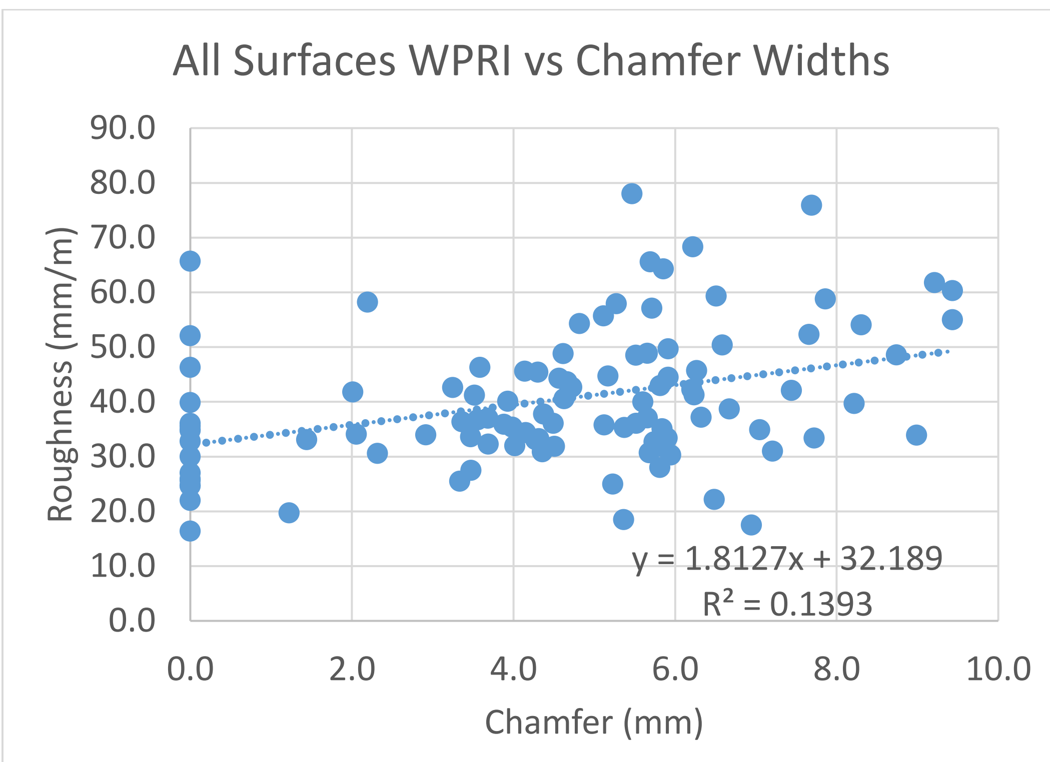


Figure 6: Regression of all surfaces showing WPRI vs chamfer widths

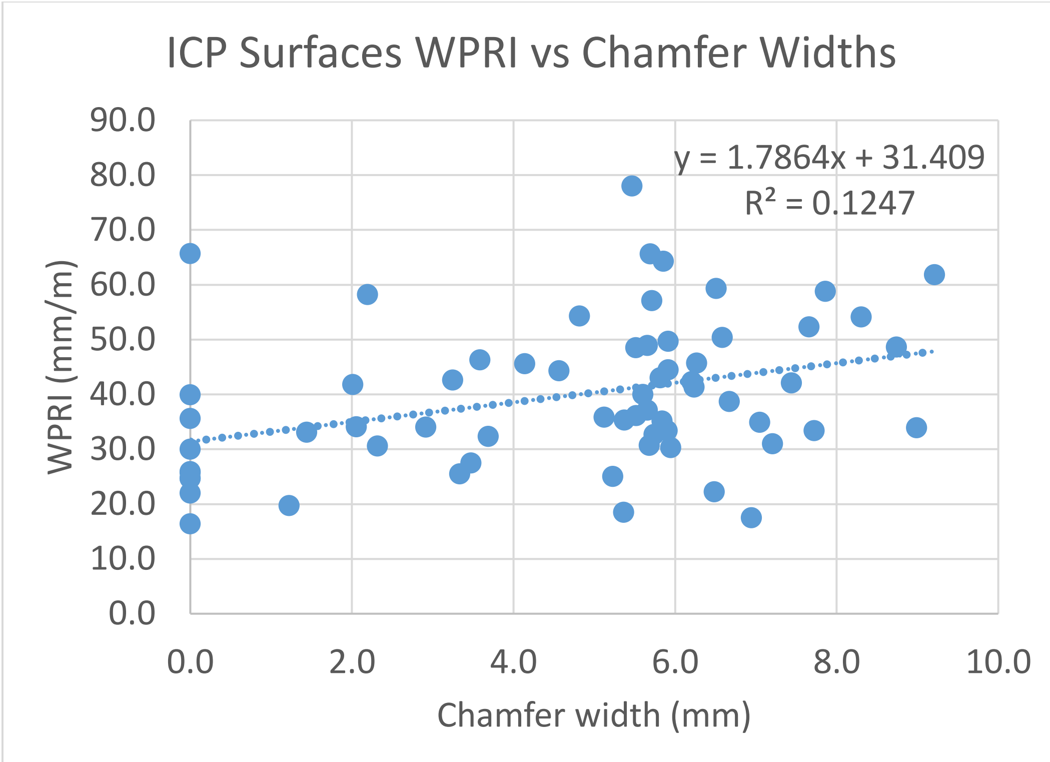


Figure 7: Regression of ICP surfaces showing WPRI vs chamfer widths

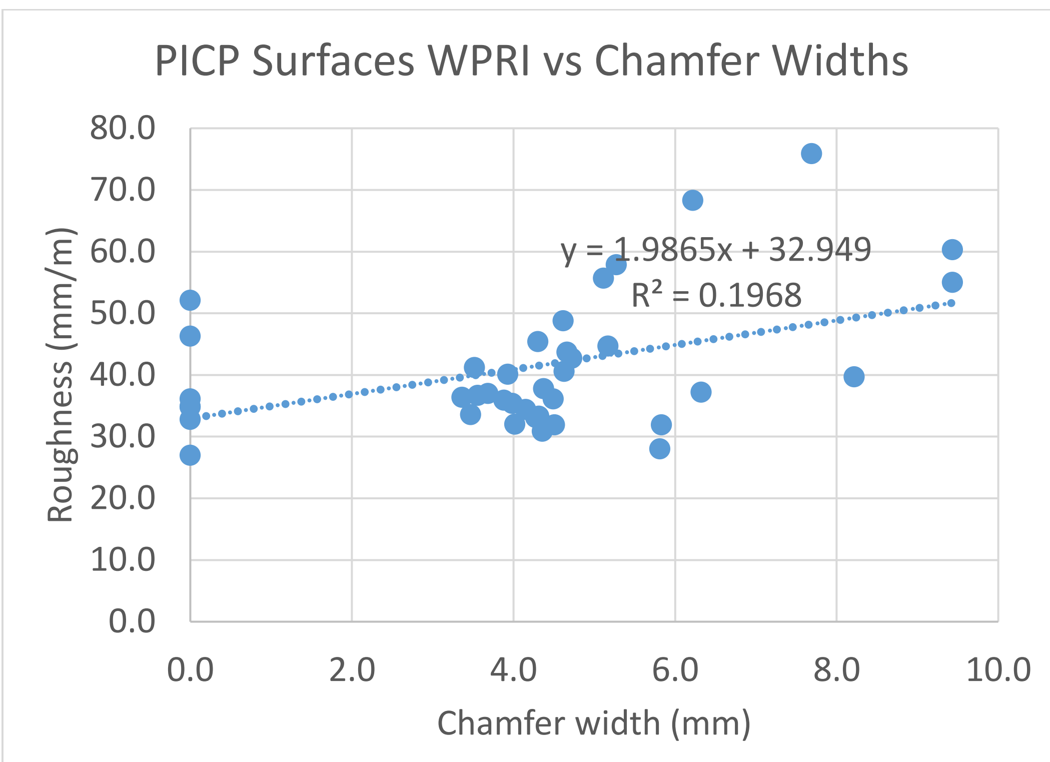


Figure 8: Regression of PICP surfaces showing WPRI vs chamfer widths

Discussion

The regression charts and tables shown in the results show that there is correlation between joint width, chamfer width, and WPRI. Although the R^2 values are low, the graphs and tables do show that as joint and chamfer width increase, so does WPRI. The R^2 values, generally between 0.1 to 0.2, show that the correlation is not very linear. Further, Table 2 showed p values less than 0.05 in each case, except for the ICP joint widths, although the value was still relatively low. This means that joint width and chamfer width are significant factors that affect WPRI. It is recommended to reduce joint and chamfer widths in order to reduce WPRI. Based on these results, these are not the only variables that affect WPRI. Further testing is required to discover additional factors. The objective of this research was simply to collect WPRI data for various surfaces to better understand if they met criteria accepted by the U.S. Access Board.

Possible future work includes additional testing in order to discover additional factors that affect WPRI. Such testing could include testing of additional surfaces in more cities. Other options include re-testing of the surfaces in this report to understand how they change over time. All of the surfaces tested are in climates that experience snow and extreme cold weather; testing in cities that are warm year-round may be beneficial. Possible factors that could affect WPRI include, but are not limited to: age, weather, location, surface bed, paver type, pattern, and maintenance.