SPRING 2016

florida department of transportation

# Research Showcase

## IMPROVING PEDESTRIAN SAFETY

/PG 1

florida department of transportation

# Research Showcase

The Florida Department of Transportation *Research Showcase* is published to provide information regarding the benefits of FDOT-funded research.

**Managing Editor**
J. Darryll Dockstader

**Editor**
Jessica VanDenBogaert
*jessica.vandenbogaert@dot.state.fl.us*

**Writers/Graphic Design**
Charles Brown
Jessica VanDenBogaert

**Printer**
Durra-Print

**Front Cover**
A pedestrian crossing sign in District 7
*seefloridago.com*

**Governor**
Rick Scott

**Secretary of Transportation**
Jim Boxold

**FDOT Research Center**
605 Suwannee Street, MS 30
Tallahassee, FL 32399-0450
(850) 414-4615
http://www.dot.state.fl.us/research-center/

# IN THIS ISSUE

# Research in Action:
# IMPROVING PEDESTRIAN SAFETY

Crashes involving pedestrians are a major safety concern in Florida. With pedestrians accounting for approximately one in every five traffic-related fatalities, the Florida Department of Transportation is employing many different methods to increase pedestrian safety and work towards zero fatalities.

Improving pedestrian safety specifically is a difficult challenge. Trends in pedestrian crashes are wholly distinctive from vehicular traffic trends and are more dependent on external factors, including surrounding land use, population demographics, and socioeconomic factors, among other influences. Also, pedestrian crashes are often more severe but harder to quantify, as determining pedestrian exposure is very expensive and difficult to obtain.

FDOT is tackling improving pedestrian safety proactively by attempting to identify potentially problematic intersections before a pedestrian crash occurs. Can statewide patterns be identified? Which locations are proving the most problematic? What features of an intersection contribute to a pedestrian crash? And what can be done to mitigate these risks?

## IT STARTS WITH RESEARCH

To answer these questions, Florida International University researchers studied three years of crash data from 2008-2010. They identified 7,630 crashes as vehicle-pedestrian crashes and reviewed in detail the police report for each crash to collect information that may not be available in crash summary records.

The following information was collected:

- » Age of pedestrian
- » Injury severity of the pedestrian
- » At-fault party
- » Location of the crash
- » Pedestrian signals in the vicinity
- » Presence of raised median or pedestrian refuge area
- » Crosswalk presence and type
- » Pedestrian use of crosswalk
- » Pedestrian activity (crossing the street or walking along roadway)

While most of this information could be obtained from the police reports, some data points, especially the presence and type of crosswalks at signalized intersections, was not readily available. Researchers used various GIS layers, Google Maps aerial photography, and Google Street View to collect the needed information, which included the following:

- » Total number of intersection legs
- » Number of legs with pedestrian signals
- » Number of legs with pedestrian refuge areas
- » Number of legs with types of crosswalks

Once all of the pertinent information related to pedestrian crashes was gathered and verified, the researchers began identifying patterns for an overall look at statewide pedestrian crashes. From 2008 to 2010, 6,434 crashes involving pedestrians occurred. Of those, 81.5% resulted in injury and 10.3% were fatal. This extrapolates to 124.7 total crashes per million population and 13 fatal crashes per million population annually. Of the different age groups, young pedestrians (16-25 years) experienced the highest number of pedestrian crashes per million population.

Both lighting level and level of urbanization played a role in crash severity. While 3.2% of fatal pedestrian crashes occurred during the day, 14.8% of fatal pedestrian crashes happened at night with street lights and 27.9% of fatal crashes occurred at night without street lights. Similarly, while the majority of pedestrian crashes occurred in urban, and mostly metropolitan, areas, the percentage of fatal crashes in rural areas was disproportionately high. For example, 70.9% of total pedestrian crashes occurred in metropolitan areas, but only 8.6% resulted in fatalities; conversely, only 3.4% of total pedestrian crashes occurred in rural locations, but 22.5% resulted in fatalities.

## IDENTIFYING CRASH VARIABLES

One of the challenges faced in implementing safety measures is identifying locations that may experience a high pedestrian crash rate before the crashes occur. In this project, once pedestrian crash data was collected and verified, the researchers used it to create a method to identify locations with potential to experience high pedestrian crash rates.

The researchers split the total number of crashes into those that occurred at signalized intersections and those that occurred at a non-signalized intersection or midblock. In total, 7,630 crashes were identified as vehicle-pedestrian crashes. However, about 35% of these crashes had to be excluded due to insufficient information, leaving 4,923 to be analyzed. Of these, 2,360 occurred at signalized intersections and 2,282 at non-signalized intersections. The location of the remaining 281 was unknown and excluded from further analysis.

**Table 5-5: Mixed Logit Model Estimates at Signalized Locations**

| Variable Description | Simulated Maximum Likelihood Estimate | Standard Error | P-Value | Severe Injury Elasticity (%) |
|---|---|---|---|---|
| ***Random Parameters*** | | | | |
| Percentage of Trucks | 0.381 (1.490)[a] | 0.183 (0.463)[a] | 0.037 (0.001)[a] | 1.370 |
| Speed Limit | 0.671 (1.115)[a] | 0.177 (0.591)[a] | 0.000 (0.059)[a] | 1.221 |
| Very Young Pedestrians[b] | -0.308 (1.966)[a] | 0.186 (0.533)[a] | 0.097 (0.000)[a] | -0.029 |
| ***Fixed Parameters*** | | | | |
| Intercept for Severe Injury | -0.797 | 0.063 | 0.000 | --- |
| Ln(AADT) | 0.023 | 0.004 | 0.000 | 15.680 |
| Very Old Pedestrians[b] | 0.049 | 0.007 | 0.000 | 30.858 |
| Pedestrian At-fault[b] | 0.367 | 0.089 | 0.000 | 3.445 |
| *Weather Condition*: Clear[b] | -0.263 | 0.112 | 0.019 | -3.056 |
| Rainy[b] | 0.353 | 0.184 | 0.055 | 0.385 |
| *Lighting Condition*: Dark with Street Light[b] | 0.733 | 0.118 | 0.000 | 4.666 |
| Dark with No Street Light[b] | 1.637 | 0.215 | 0.000 | 1.523 |
| Night/Dawn Off-Peak Hour (8:00 pm-6:59 am)[b] | 0.441 | 0.118 | 0.000 | 2.654 |
| ***Number of Observations*** | | 2,360 | | |
| ***Log-Likelihood at Convergence*** | | -1,287.33 | | |
| ***Log-Likelihood at Fitting the Intercept*** | | -1,635.83 | | |
| ***McFadden's Pseudo $R^2$*** | | 0.21 | | |
| ***AIC*** | | 2,604.66 | | |

[a] Standard deviation.
[b] Binary categorical variables inserted as "1" if true; "0" otherwise.

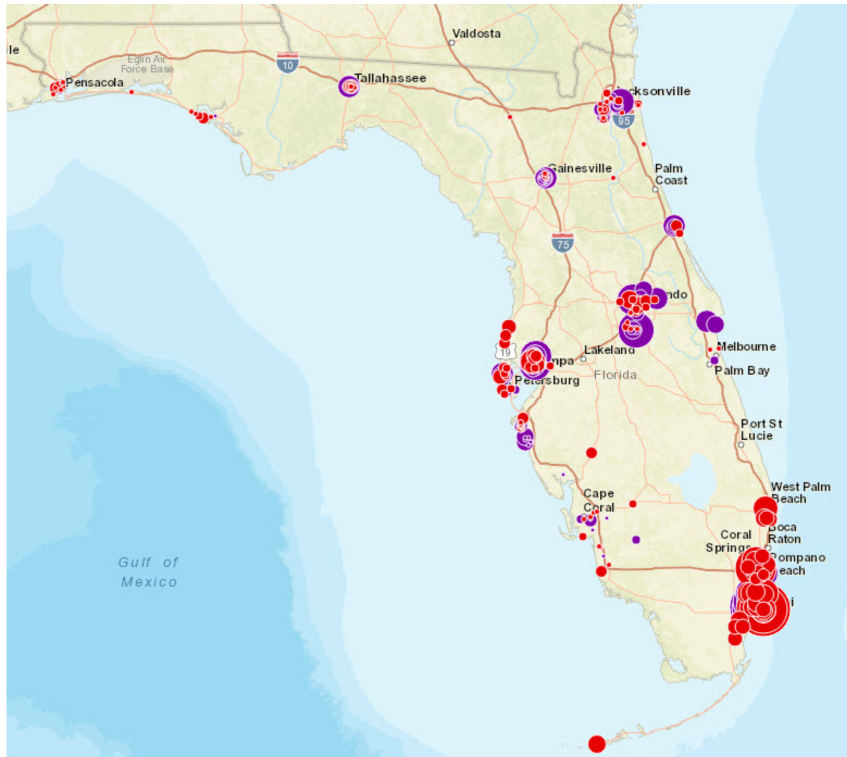
Table 5-5 provides the elasticity among variables - the measurement of how one variable responds to a change in another.

**Table 5-1: Summary Statistics of Explored Variables at Signalized Locations**

| Category | Variable Name | Summary Statistics[1] |
|---|---|---|
| | *Dependent Variable* | |
| Response | Pedestrian Injury Severity | *F* (Non-Severe Injury) = 1,555 (*65.89%*); *F* (Severe Injury) = 805 (*34.11%*) |
| | *Continuous Independent Variables* | |
| Traffic | Ln (AADT) | *M* = 10.42, *SD* = 0.49 |
| | Speed Limit | *M* = 40.35, *SD* = 6.07 |
| | Percentage of Trucks | *M* = 4.56, *SD* = 2.58 |
| | *Categorical Independent Variables* | |
| Environmental | Lighting Condition | *F* (Daylight) = 1,289 (*54.62%*); *F* (Dusk) = 56 (*2.37%*); *F* (Dawn) = 29 (*1.22%*); *F* (Dark Street Light) = 839 (*35.55%*); *F* (Dark No Street Light) = 134 (*5.67%*); *F* (Unknown) = 13 (*0.55%*) |
| | Weather Condition | *F* (Clear) = 1,821 (*77.16%*); *F* (Cloudy) = 373 (*15.81%*); *F* (Rainy) = 152 (*6.44%*); *F* (Foggy) = 2 (*0.08%*); *F* (Other) = 12 (*0.51%*) |
| Traffic | Presence of Pedestrian Signals? | *F* (Yes) = 2,166 (*91.78%*); *F* (No) = 160 (*6.78%*); *F* (Not Sure) = 34 (*1.44%*) |
| | Hour of Crash | *F* (Morning Peak) = 384 (*16.27%*); *F* (Morning Off-Peak) = 558 (*23.64%*); *F* (Afternoon Peak) = 609 (*25.81%*); *F* (Night/Dawn Off-Peak) = 809 (*34.28%*) |
| Geometric | Road Surface Condition | *F* (Dry) = 2,102 (*89.07%*); *F* (Wet/Slippery) = 243 (*10.29%*); *F* (Other) = 15 (*0.64%*) |
| | Land Use Type | *F* (Urban/Suburban) = 2,345 (*99.36%*); *F* (Rural) = 15 (*0.64%*) |
| | Presence of Ped. Refuge Area? | *F* (Yes) = 1,420 (*60.17%*); *F* (No) = 914 (*38.73%*); *F* (Not Sure) = 26 (*1.10%*) |
| | Crosswalk Type | *F* (No Crosswalk) = 166 (*7.03%*); *F* (Solid) = 7 (*0.29%*); *F* (Standard) = 1,042 (*44.15%*); *F* (Ladder) = 215 (*9.11%*); *F* (Continental) = 641 (*27.16%*); *F* (Zebra) = 8 (*0.34%*); *F* (Dashed) = 4 (*0.17%*); *F* (Other) = 277 (*11.74%*) |
| Pedestrian/Driver -Related | Pedestrian Age | *F* (Very Young, Age ≤ 19 years) = 303 (*12.84%*); *F* (Young, 20 years ≤ Age ≤ 24 years) = 225 (*9.53%*); *F* (Middle, 25 years ≤ Age ≤ 64 years) = 1,491 (*63.18%*); *F* (Old, 65 years ≤ Age ≤ 79 years) = 266 (*11.27%*); *F* (Very Old, Age ≥ 80 years) = 75 (*3.18%*) |
| | Who is At-fault? | *F* (Ped.) = 1,372 (*58.14%*); *F* (Driver) = 605 (*25.64%*); *F* (Both) = 29 (*1.23%*); *F* (Not Sure) = 354 (*15%*) |
| | Pedestrian Maneuver Before Crash | *F* (Crossing Street) = 2,175 (*92.16%*); *F* (Walking along Roadway) = 48 (*2.03%*); *F* (Not Sure) = 137 (*5.81%*) |
| Vehicle-Related | Driver's Vehicle Type | *F* (Passenger Cars) = 802 (*33.98%*); *F* (Vans) = 89 (*3.77%*); *F* (SUVs and Pick-ups) = 194 (*8.22%*); *F* (Medium Trucks) = 7 (*0.29%*); *F* (Heavy Trucks) = 6 (*0.25%*); *F* (Buses) = 12 (*0.51%*); *F* (Bicycles) = 1 (*0.04%*); *F* (Motorcycles) = 6 (*0.25%*); *F* (Other) = 1,243 (*52.67%*) |

[1] *F* = Crash frequency (*italicized %* in parentheses), *M* = Mean, and *SD* = Standard deviation.

Table 5-1 details the significant factors that the researchers determined had an affect on the number and severity of pedestrian crashes experienced at signalized intersections.



Each crash was mapped to determine location clusters. Red dots represent crashes on road segments while purple ones represent crashes located at an intersection. Crashes are concentrated in heavily urban areas and in beach locations.

The researchers then analyzed each crash to determine the significant factors that affected injury severity. For modeling purposes, injury severity was characterized as one of two types: non-severe (i.e., no injury, possible injury, or non-incapacitating injury) and severe (i.e., incapacitating and fatal injuries). Several variables were identified and categorized, including traffic, geometric, environmental, and vehicle type, among others. The researchers found that each variable acted independently and that there was little to no correlation between the variables.

They developed a mixed-logit model that, using the variables identified previously, emulates and predicts the pedestrian safety of an intersection. As an example, using the model, an intersection with a higher percentage of truck traffic is associated with a higher probability of severe pedestrian injury. The severe injury elasticity is 1.37%, which means that a 1% increase in truck traffic increases the probability of severe injuries by about 1.37%. Higher speed limits were also found to increase the likelihood of severe injury. A one mile per hour increase in the speed limit increases the probability of severe injuries by 1.2%.

The researchers identified the top locations for pedestrian crashes, for each district and by each intersection type, signalized and unsignalized. Countermeasures were recommended for each type of crash (those involving left turning vehicles, right turning vehicles, etc.).

## AND ENDS WITH IMPLEMENTATION

The FDOT Safety Office used the results of this research as a basis for aggressively identifying high crash locations and implementing countermeasures. They began by expanding their data set – using crash data from 2008 to 2012. The Top 20 pedestrian crash locations were identified for each FDOT district and statewide.

### Biscayne Blvd Corridor

The Top 20 lists were distributed to district staff, who set to work to improve these locations. The intersection with the most pedestrian crashes in the state is Biscayne Blvd at NE 33rd St in Miami, where 14 pedestrian crashes occurred between 2008 and 2012. At this location, Biscayne Blvd sees an average annual daily traffic (AADT) between 29,500 and 30,000 vehicles with a high concentration of pedestrian activity in the surrounding areas. Following a safety study, FDOT staff identified a number of improvements – including short-term, long-term, and non-infrastructure enhancements – that could be implemented to mitigate these crashes.

In the short-term, high-emphasis crosswalks were added to each leg of the intersection. Additional signage was installed, including "Turning Vehicles Yield to Pedestrians" and "Use Crosswalk" signs to alert both drivers and pedestrians. Similar enhancements are planned for other cross streets in this corridor.

Long-term solutions are either in progress or planned as part of a corridor improvement project. Medians on Biscayne Blvd are being added or reworked, including mid-block pedestrian refuge medians, and rapid rectangular flashing beacons are being installed to alert drivers to the presence of pedestrians. Permissive/protected left-turn facilities will also be added at the intersection with NE 33rd St.

In addition to infrastructure enhancements, FDOT employs other techniques to improve pedestrian safety, notably education and awareness outreach. The Florida Bicycle/Pedestrian Safety Initiative hosted an on-site pedestrian education campaign on October 3, 2014. For more information about the consortium and "Alert Today Alive Tomorrow," please visit http://www.alerttodayflorida.com.

### Statewide Lighting Initiative

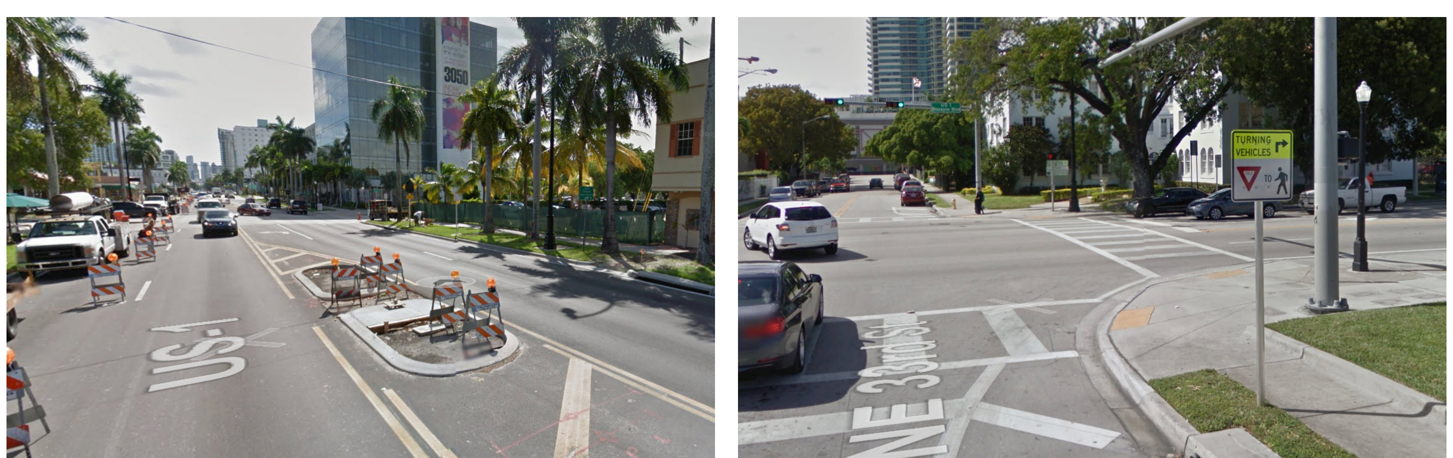
One of the major takeaways of the research was the strong correlation between a low lighting level and crashes. Dark conditions, both with and without street lights, were associated with an increase in the probability of severe injuries occurring at both signalized and non-signalized intersections. Over 14% of fatal pedestrian crashes happened at night with street lights while nearly twice as many, 27.9% of fatal crashes, occurred in the dark without street lights.

To tackle this issue, FDOT is working towards increasing lighting system-wide. Efforts include initiatives to more accurately measure the lighting level throughout the state system and identify dark areas, and investigations into different lighting types and methods to illuminate the state highway system using cost-effective solutions.

Data is still being gathered to accurately measure the impact of the pedestrian safety improvements being made across the state, but anecdotal information indicates an overall improvement.

For more information on the FDOT safety program, please visit http://www.dot.state.fl.us/safety/. ▪

*Final Report available at: www.dot.state.fl.us/research-center*



The Biscayne Boulevard corridor in Miami, specifically the intersection with NE 33rd St , was ranked the number one intersection for pedestrian crashes. Efforts to improve the safety of this location included new signage, high emphasis crosswalks, and mid-block pedestrian refuge medians. *Source: Google Street View*

In addition to educational activities, the Florida Bicycle/Pedestrian Safety Initiative also provides mass public outreach, including billboards such as this one.

# MAINTAINING STORMWATER PONDS TO IMPROVE FLORIDA'S WATER QUALITY

As rainfall moves across or through the ground, it can pick up and transfer various pollutants which can then end up in streams, rivers, lakes, wetlands, and ultimately, the aquifer. These pollutants directly impact water quality, promote excess vegetation growth, and rob the water of oxygen and suffocate marine animal life.

Delivering a safe transportation system that "preserves the quality of our environment" is an agency mission objective. FDOT's active stormwater management program plays an important part in meeting this objective. Currently, FDOT manages a number of stormwater treatment facilities, including ponds, which are an integral part of the program, allowing nutrients and other potential pollutants to be filtered from the water before it moves out into the wider ecosystem. However, these ponds require maintenance and upkeep to ensure they are functioning appropriately.

In a series of projects, researchers from the University of Central Florida Stormwater Management Academy studied wet detention ponds across the state with severe maintenance issues to determine the best practices to mitigate these issues. Their observations and recommendations were cataloged into a handbook to provide detailed guidance for FDOT maintenance staff to improve wet detention ponds across the state.

In the first phase of the research, detention ponds with severe maintenance issues were analyzed to determine the pollutant levels in the water. While pollutants could range from pesticides, hydrocarbons, *E. coli*, suspended solids to heavy metals, analysis conclusively indicated excess nutrients as the source of pollution in the ponds. According to the United States Environmental Protection Agency, this is in keeping with the most common form of water pollution found in Florida.

## MEDIA BED REACTORS: ZOLFO SPRINGS, EAST PALATKA, AND ORLANDO

Three ponds experiencing high algae growth were tested with media bed reactors of differing configurations to find which worked best. A media bed reactor is essentially a filter, installed in or near a pond, which acts as a catalyst for adsorption, the process by which contaminants break their bonds with water molecules and chemically adhere to the filter media in the reactor.

In District 1, a pond in Zolfo Springs was chosen for study. This 0.49-acre pond showed excessive algae and an overgrown littoral zone. The littoral zone is the area near the shore where sunlight can penetrate all the way to the sediment, which then allows aquatic plants to grow. An overgrown littoral zone can block necessary sunlight and allow for potentially toxic algal blooms and exotic or nonnative plants to grow in place of beneficial aquatic plant growth. For this specific pond, a sloped media bed reactor (SMBR) with 50% expanded clay and 50% tire chunk was installed to remove nutrients from the water. A solar-powered pump moves water from the pond through the filtration media and back to the pond.

Since the installation of the SMBR, three storm and three non-storm samples were taken and analyzed. Judging from the data, the SMBR appears consistently to reduce phosphorus by 21.5% and ammonia by 27.7%, while removal rates for nitrogen varied, with an average reduction rate of 28%.

The solar panel on top of the floating media bed reactor installed in the East Palatka pond powers a pump that moves water through the filtration media and back into the pond.

At the Ruskin pond, a researcher catalogs the health of the various plant species on the floating treatment wetlands installation. At this pond, invasive species were discovered, removed, and the filtration plants were replaced with seedlings.

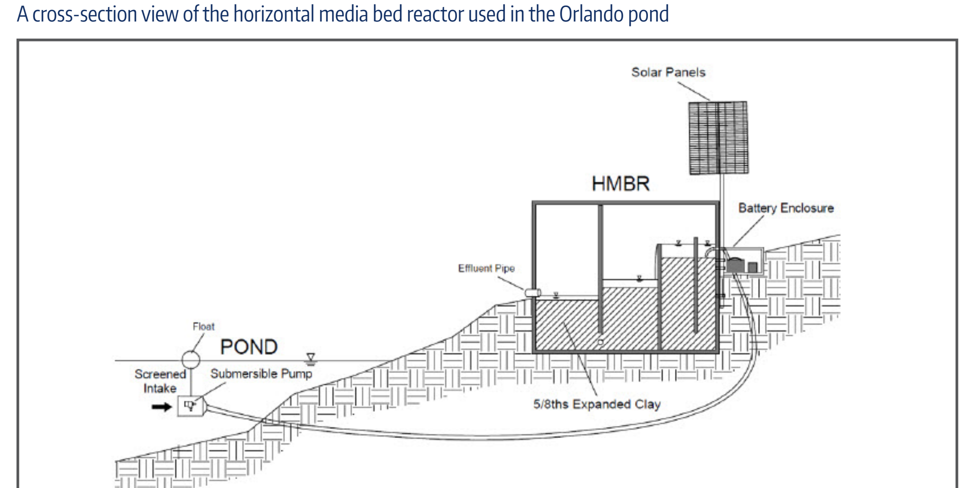
In District 5, two ponds, one in East Palatka and one in Orlando, were chosen for study. The East Palatka pond was small, 0.11 acres, and experiencing high sediment loads, algae growth, and nuisance vegetation. A floating media bed reactor (FMBR) was installed approximately two thirds of the distance from the inlet to the outlet. The media mix in this reactor was made up of 50% sand, 20% tire crumb, 20% fine expanded clay, and 10% limestone. Like the Zolfo Springs reactor, the FMBR uses a solar pump to move water through the reactor. After six readings, soluble phosphorus was reduced by 37.1% and total phosphorous reduced at a rate of 52%.

The Orlando pond, a 0.98-acre pond split by a berm, suffered from high algae and cattail growth as well as a heavily overgrown littoral zone. After the nuisance vegetation was removed, a horizontal media bed reactor (HMBR) was installed with a media mixture similar to the one used in the Zolfo Springs pond: 50% 5/8ths expanded clay and 50% tire chunk. Nitrous oxide was consistently removed at a rate of 63%, and both total phosphorus and total nitrogen experienced notable removal efficiencies.

## FLOATING TREATMENT WETLANDS: GAINESVILLE AND RUSKIN

In District 2, a 0.58-acre pond in Gainesville was chosen for study. This pond is at a low point between two hills, and runoff which pools at the low point of State Road 26 to the south is discharged into the pond through stormwater pipes. Major algae growth and significant amounts of floating debris were hindering the performance of the pond.

A cross-section view of the horizontal media bed reactor used in the Orlando pond




To combat these issues, three floating treatment wetlands (FTW) were installed. The use of FTWs is an innovative and emerging management practice for stormwater ponds. Plants, specifically canna, juncus, and agrostis, are grown on floating mats, rather than on the bottom of the pond, so that they interact with suspended nutrients in the water column. The roots of these plants are exposed and offer a larger surface area for nutrient removal and capture of suspended solids. On average, the non-storm phosphorus removal capacity of the pond was greatly improved along with a reasonable improvement in the removal of dissolved nitrogen and phosphorus during storm events.

The Ruskin pond studied is unique as it is bordered on the western and southern edges by active tomato fields. As such, this pond is exposed to very high nutrient concentrations as fertilizers are washed from the field into the pond, typically resulting in severe algae growth and a heavily overgrown littoral zone.

The researchers installed a floating treatment wetland in the Ruskin pond in January 2014. Over a seven-month period that included an even mix of storm and non-storm events, the researchers took six samples that showed a notable improvement in soluble nutrient removal. This change suggests that FTW is improving water quality in this nutrient-heavy environment.

## BANK STABILIZATION: ROYAL PALM ESTATES

A larger pond, 1.69 acres, located immediately north of State Road 80 in Palm Beach County, was experiencing erosion problems, specifically erosion of the banks and at the inlet structure. Researchers chose to install Tri-Lock once water levels in the pond dropped enough to allow for construction. Tri-Lock is an interlocking concrete block system that forms a continuous, flexible retaining wall. Pre-cast blocks are installed over a geotextile base and provide reinforcement for an eroding bank.

The pond was monitored over the next year. No clear signs of erosion were noted, and vegetation was growing in and around the blocks, further improving the erosion control. Though Tri-Lock seemed to have a negligible effect on removing sediment levels in the water, construction in the area and seasonal fluctuations in the water level of the pond may have skewed the readings.

## MAINTENANCE HANDBOOK

At the end of the monitoring period, the researchers prepared a handbook, *Best Maintenance Practices for Stormwater Runoff*. This handbook provides guidance on the most efficient ways to manage stormwater ponds, including direction on choosing and implementing management practices based on the specific problems facing a particular pond. The document is directed at maintenance crews and is currently being used by each of the FDOT districts; it also has been distributed to other state agencies. This handbook is available online at

http://www.dot.state.fl.us/statemaintenanceoffice/RDW/BestMaintPracticesSWRunoff.pdf

Protecting water resources is critical to guaranteeing the continued health of Florida's environment and economy, and FDOT is committed to doing its part to manage its stormwater facilities appropriately and promote increased water quality. ▪

*Final Report available at: www.dot.state.fl.us/research-center*

The Royal Palm Estates pond was experiencing severe erosion, as evidenced in the photograph on the left. After being graded, Tri-Lock, a concrete bank stabilization product was installed and vegetation allowed to grow in the cracks. In the months following installion, no evidence of erosion was found.



# FIBER-REINFORCED POLYMER REPAIR METHOD FOR UTILITY POLES SAVES TIME AND MONEY

A dented utility pole in Tallahassee was chosen as a field test of the FRP pole repair system. Left: The pole was dented but still usable. Middle: After sanding, the dent is filled with epoxy. Right: After FRP application and painting, the pole is back in service without major maintenance of traffic operations.

The poles used by FDOT to support mast arms, traffic signals, and overhead lighting are susceptible to damage by vehicle collision. While this damage does not always cause immediate failure of the pole or loss of stability, the impacted structure must be repaired or replaced to remain in service. However, replacing these poles can be costly and time consuming. Removal and replacement operations require, for example, maintenance of traffic activities, equipment, worker hours, and cranes, and they can significantly impede traffic on the roadway. The costs associated with replacement, both direct and indirect, led the FDOT Structures team to look for options that can be performed on-site, without the need to block traffic for a significant amount of time, to repair a utility pole.

Fiber-reinforced polymer, or FRP, is a composite material in which fibers, either stranded or interwoven, are reinforced with a polymer, typically an epoxy or resin. FRP, commonly used in the aerospace, automotive, marine, and ballistics industries, has been increasingly used in the transportation sector. Previous studies have found that FRP repairs, specifically for concrete, can be installed with minimal labor costs and without service interruption.

In a recent research project, University of Central Florida researchers evaluated FRP as a repair technique and established repair guidelines to effectively and economically restore a damaged utility pole to a safe working condition. FRP systems were selected to minimize the number of layers of product required and evaluated for the specific challenges of repairing utility poles as well as their performance under static and dynamic loads.

The researchers sought to answer two questions: what FRP system can be used to repair utility poles, and how should these systems be installed? Researchers investigated the different FRP systems available. In general, an FRP repair system consists of multiple layers: a filler material to restore the circular cross-section of the pole, a primer or adhesive layer, an impregnated FRP laminate, and a final coating to restore the pole's appearance.

To choose the best system, the researchers evaluated each layer of several different FRP repair systems for its material characteristics. Tests included standard tensile bond and compression tests on laminates, dent fillers, and steel/aluminum substrates. High-density bidirectional glass and basalt fabrics, either fabric pre-impregnated with polyurethane or a standard dry fabric for field impregnation with either polyurethane or epoxy resin, were recommended by the researchers as good candidates for pole repair. Dent filler was chosen with a purposely high viscosity to prevent gravity slump, and primers/adhesives were chosen with setting times that were conducive to working with any potentially complicated pole geometry.

Once each layer of material was characterized, the researchers applied each FRP system to pole segments. Both aluminum and steel pole segments with differing dent geometries were used. Once a pole segment was repaired with FRP, that segment was tested to failure. Dents approaching 30% to 40% of the original pole diameter could be successfully repaired with a single layer of FRP. However, larger diameter dents repaired with FRP did not perform as well.

Full-scale tests reinforced the effectiveness of the small-scale test. A majority of repaired poles showed the repair system to have strength comparable to original, undamaged poles. Specimens were subjected to more than 2 million cycles of weight loading and a constant stress level with minimal effect. The stress levels were then increased by 1,000-cycle increments until failure occurred. The FRP repair stayed strong – the tube-to-plate weld was always the point of failure.

The location and geometry of the access ports (commonly called hand holes) relative to the locations of the dent also played an important role in the mechanical behavior of the repaired pole. If the hand hole was located in a place that limited the length of the FRP wrap or if the hand hole was not reinforced, the effectiveness of the FRP proved to be diminished substantially.

The researchers used the results of this project to develop guidance on the number of layers to apply and the geometry of repair based on dent depth. FDOT is planning to expand and develop these guidelines for statewide distribution to advance implementation of this cost-saving repair method. ▪

*Final Report available at: www.dot.state.fl.us/research-center*

# meet the project manager:
# GREG SHOLAR, BITUMINOUS MATERIALS ENGINEER

Greg Sholar has a complicated problem – asphalt. As State Bituminous Engineer for the Florida Department of Transportation, he is involved in all of the asphalt materials research at the State Materials Office (SMO) in Gainesville. Also, any problems in the field that can't be solved at the local or district level find their way to Sholar.

Sholar originally trained in building construction, receiving his degree from the University of Florida (UF) in 1988. He found work in Atlanta, but, after a couple of years in the big city, he returned to Gainesville, continuing to work in contracting. He had hoped the return to Gainesville would renew his waning interest in contracting, but he felt more strongly that he needed something else. In 1993, he returned to UF to pursue a civil engineering degree. In 1996, he was nearing graduation and working as a professional engineer trainee in the FDOT concrete section when an opportunity became available in the state professional engineer training program in the asphalt division. The work suited Sholar's interests and talents, and he has grown with it for 20 years. In addition to his field and laboratory responsibilities, Sholar is also responsible for the state specifications related to asphalt materials, including regular, multilevel review and update of the specifications.

He often collaborates with University of Florida professor Dr. Reynaldo Roque, an asphalt specialist. Greg quotes Roque as saying that asphalt is "the most complicated civil engineering material in use." Sholar explains that what makes asphalt so complicated is its dual nature: it behaves as an elastic material that, like rubber, can recover from deformation when it is cold or when pressure is applied and relieved quickly (for instance, a tire rolling quickly over the road surface); but when asphalt is hot or the loading is slow (think stalled summer traffic at a toll plaza or intersection), asphalt becomes more viscous and deformations are permanent. There are ways to make asphalt harder, but that then makes it more vulnerable to cracking; if fewer hardeners are used, asphalt is vulnerable to rutting. It is a complicated and delicate balance.

FDOT is responsible for thousands of miles of roads, and anything that reduces maintenance and improves asphalt performance can save millions of dollars. There has been a lot of progress made in asphalt during the past 20 years, primarily the Superpave method, a set of specifications that apply the latest research to each step in the preparation, storage, and application of asphalt. Nevertheless, challenges remain. Sholar says that the primary problem affecting most asphalt roads in Florida is top-down cracking. He and his colleagues at SMO study this problem constantly.

Asphalt mixes can be categorized as either open graded or dense graded. Sholar explains that, when magnified, open graded asphalt looks like a layer of popcorn. Its open structure is designed to allow water to drain away from the surface quickly on multilane, high speed roads. It tends to last about 12 years before small patches, and then larger patches, tear away from the surface in a process called raveling. Dense graded asphalt is used on other types of roads. It has a compact surface and lasts 16 to 18 years. FDOT would like to improve the durability of all asphalts, especially open graded asphalt. However, the problem of engineering a material that must meet all the requirements of a high speed road is not easily solved.

One challenge to testing possible new asphalt formulations is that little progress would be made if the pace of research was controlled by the natural lifetime of asphalt surfaces, which is now more than a decade. Methods for accelerating the aging of asphalt, and simulating the effects that Florida's traffic, weather, and heat have on it are critical. Currently, SMO uses its Heavy Vehicle Simulator (HVS) and partners with the National Center for Asphalt Testing (NCAT) Pavement Test Track at Auburn University to perform such research.

The Heavy Vehicle Simulator (HVS) resembles a very large bus and is capable of applying a 9,000 lb. load. The electrically powered HVS runs back and forth on a track about 20 feet long and, in a matter of weeks, it can induce on a test section of pavement the amount of rutting that would take years to occur on in-service roads. In addition to simulating the weight and wear of traffic over time, the HVS also has the capability of heating the track to simulate the intense heat in Florida.

FDOT partners with NCAT through a pooled fund study that allows participants to test their mixes. NCAT's 1.7-mile oval test track is instrumented and divided into 200-ft test sections built to study participant specifications. The heavily-loaded vehicles that run the track can simulate up to ten years of wear in two years. Between the two facilities, SMO can continuously research the durability of asphalt. Sholar describes the NCAT Pavement Test Track at Auburn as the asphalt research world's version of the Daytona Speedway.

The Daytona analogy describes the track, but it also expresses Sholar's enthusiasm for his work – 20 years and going strong. ▪

# meet the principal investigator:
# PEI-SUNG LIN, UNIVERSITY OF SOUTH FLORIDA

When asked what attracted him to transportation in graduate school, Dr. Pei-Sung Lin answered "making a difference in people's lives." He has pursued that goal for 20 years, first for Sarasota County and now for 11 years at the Center for Urban Transportation Research (CUTR) at the University of South Florida, where he currently serves as Director of Intelligent Transportation Systems, Traffic Operations, and Safety. Dr. Lin demonstrates an infectious enthusiasm and commitment to his work, which has produced proven results in improving traffic efficiency and saving lives.

Lin describes as possibly his most challenging project to date, a study of trip internalization in mixed-use developments (BDK84-977-10). Mixed-use developments (MXDs) have many advantages for residents by offering multiple land uses such as residential, retail, office, restaurant, and more within the development's plan. Developers seeking approval for any development must work through a process of governmental review which requires estimates of the development's impact on adjacent roadway networks. Specifically, developers must address the question of how much additional traffic the development will contribute to the roadway network.

Traditionally, internal trip capture rates are used to estimate trip generation on mixed-use developments by adjusting the single land use estimates, which tend to overestimate the trip generation behavior for mixed-use developments. In this project, internal trip data from four mixed-use developments in Florida was collected and analyzed using a methodology developed by a National Cooperative Highway Research Program (NCHRP) project. The researchers developed a series of predictive tests to assess the contribution of the unconstrained internal trip capture rates supplied by the FDOT study with the accuracy of the trip generation estimates generated by the NCHRP methodology. Lin and his team found that using revised unconstrained internal trip capture rates based on combined NCHRP and FDOT data can considerably improve the prediction capability of trip generation prediction methods from an MXD.

Lin has also tackled several other projects for FDOT at CUTR: work on a comprehensive pedestrian and bicycle safety program, naturalistic bicycling behavior pilot study, understanding the interaction between drivers and pedestrian features at signalized intersections, development of statewide guidelines for implementing leading pedestrian intervals in Florida, and others. He described the Advanced Lighting Measurement System (ALMS), a new mobile device he and his colleagues have developed to measure street lighting levels at night on the roadway. Sponsored by FDOT District 7, ALMS was developed to help safely, accurately, and efficiently measure lighting levels with two data points every 10 feet on each lane along any selected corridors and identify where inadequate lighting levels may be contributing to crash problems. ALMS allows efficient real-time assessment of highway lighting levels at 300 times faster than traditional methods and much safer for workers and drivers. FDOT's Advanced Lighting Measurement System was honored with a National Roadway Safety Award in November 2015 in Washington, D.C.

Dr. Lin likes to gain a first-hand appreciation for the problems he works on. He was very excited about a project to address wrong-way driving fatalities. A series of wrong-way collisions in the Tampa area occurred when drivers attempted to use an exit ramp to enter a highway – usually at night when the number of impaired drivers or confused drivers is higher and when there is less traffic to act as a guide. Lin and his team evaluated red rapid rectangular flashing beacons (RRFBs) implemented by FDOT to deter wrong-way drivers. They coupled the RRFB with large "Wrong Way" signs to alert drivers to their error, once the wrong-way driving is detected. Lin conducted opinion surveys with nearly 300 people to determine and suggest the best configuration of sign and flashing beacon for red RRFBs deployed by FDOT.

Lin further investigated to see how the implementation of red RRFBs affected traffic on the adjacent arterial that was not turning. To evaluate the effect of red RRFB implementation on adjacent arterial traffic, with freeway off-ramps temporarily closed, Lin and his colleague Dr. Seckin Ozkul each drove an accumulated total of nearly 500 times in three nights from 11:00 PM to 4:00 AM, making wrong-way turns from arterials onto freeway off-ramps to simulate wrong-way driving. These wrong-way turns triggered RRFBs. The researchers observed the behaviors of drivers on the adjacent arterials to the seemingly sudden activation of the RRFB. Lin likes to say that he and Ozkul "have the most wrong-way driving experience in Florida!" ▪

# FURTHER READING

## Improving Pedestrian Safety

**BDK80-977-32** Comprehensive Study to Reduce Pedestrian Crashes in Florida

*Project Manager: Joe Santos, Safety*
*Principal Investigator: Albert Gan, Florida International University*

## Best Practices for Stormwater Maintenance

**BDK79-977-09** Maintenance Practices for Stormwater Runoff

**BDV24-977-02** Maintenance Practices for Stormwater Runoff, Phase 2

*Project Manager: Tim Allen, Maintenance*
*Principal Investigator: Ni-Bin Chang, University of Central Florida*

## Fiber Reinforced Polymer Utility Pole Repair

**BDK78-977-08** Repair of Impact Damaged Utility Poles with FRP

**BDV24-977-04** Repair of Impact Damaged Utility Poles with Fiber Reinforced Polymers (FRP), Phase II

*Project Manager: David Wagner, Structures*
*Principal Investigator: Kevin Mackie, University of Central Florida*

**Research Center**
605 Suwannee Street, MS 30 Tallahassee, FL 32399-0450
(850) 414-4615
http://www.dot.state.fl.us/research-center/