

ENGINEERING **RESEARCH** REVIEW 2017



SOUTH DAKOTA STATE UNIVERSITY

Office of Engineering Research



Dear Colleagues,

Each issue of our Engineering Research Review focuses on a particular theme. New faculty, collaborative research and nonfederal funding are a few examples. In contrast, this year's report spans a variety of topics and, to some degree, celebrates the variety of research going on in the Jerome J. Lohr College of Engineering. Let me show you what I mean.

Our lead article focuses on development of more accurate blood glucose sensors for diabetics by assistant professor Hyeun Joong Yoon in our electrical engineering program. Results from this project could improve lifestyles for millions of Americans. Algal blooms are becoming increasingly common, affecting inland waters from the Great Lakes to our state's prairie potholes, and can wreak havoc with drinking water. Fortunately, instructor Kyungman "Karen" Min and assistant professor Guangi Hua from our civil and environmental engineering program are addressing ways to mitigate this problem.

Associate professor Chris Saunders in our mathematics and statistics department develops remarkably flexible algorithms that can predict anything from fish movement to solar insolation, while assistant professor Tim Hansen from electrical engineering and computer science develops methods to reduce peak electric power usage and professor Huitian Lu in our construction and operations management department develops methods to improve management of lithium-ion batteries. Lastly, our feature article shows that even 21st century old-fashioned wooden bridges are under review for improved structural designs—and the results can make a difference for rural transportation networks.

Considering the wide range of research our faculty members are pursuing, perhaps the theme for this year is simply new projects. As we reflect on this for just a moment, isn't this the essence of research? Developing new ideas, testing new approaches and generating new results are at the core of our engineering research. Additionally, new faculty members who bring their new ideas to our college enhance this emphasis. They exemplify the theme of this year's publication.

While many are concerned about the uncertainties that surround us—from changes in the federal government and its impact on research to the unrest and volatility in many parts of the world, our research horizon remained essentially the same as last year. We wrote about the same number of proposals as last year, 103, and received awards totaling \$5.1 million. Typically, about 44 percent of our proposals are funded each year, and last year was no exception. On a positive note, the number of graduate students has increased significantly over the past three years.

Rather than worry about the future, we will seize the opportunities given us today and, with the bright new faculty members who have joined us, along with our accomplished senior researchers, we will continue building our key research strengths and seek those new niches where we can contribute to the health and well-being of our state and nation.

As always, we look forward to hearing from you. Please let us know if the Jerome J. Lohr College of Engineering can be of service to your growing research and development needs.

Dennis Helder, Ph.D.
Associate Dean for Research
Distinguished Professor of Electrical Engineering

ENGINEERING RESEARCH REVIEW 2017

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About the cover

High reliability and safety are major requirements for lithium-ion battery cells used in aircraft and weapons systems. Professor Huitian Lu of the Department of Construction and Operations Management is collaborating with Space Information Labs (SIL) of Santa Maria, California, to develop algorithms to predict remaining useful life. The algorithms will be integrated into SIL's battery management system, which balances and monitors each individual battery cell of the company's Li-Ion Polymer Intelli-Pack Battery®. The research is funded through the Navy Small Business Technology Transfer (STTR) Program.

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New sensor

design more accurately determines blood glucose levels

More than 20 million diabetics must monitor their blood sugar using a portable glucose meter, according to 2012 statistics from the Centers for Disease Control and Prevention. For these patients, the accuracy of those glucometer readings is essential to maintaining their health.

Revised 2016 Food and Drug Administration guidelines require new personal glucometers to measure blood glucose levels within 15 percent of the true lab-measured value at least 95 percent of the time. That's a 5 percent smaller margin of error than in the 2013 FDA guidelines.

Accuracy is especially important for those who manage their diabetes using insulin therapy, explained Bev Cotton, a registered nurse and diabetic education coordinator at Brookings Health System. Diabetics use a glucometer to check their blood sugar multiple times a day to determine how much insulin they need to inject.

To develop devices that meet these FDA guidelines, assistant professor Hyeun Joong Yoon of the Department of Electrical Engineering and Computer Science is designing and fabricating sensors to more accurately measure blood sugar levels. The research is supported by grants from the South Dakota Board of Regents and Sanford Health, totaling nearly \$100,000. The two-year project began in 2016.

Yoon came to SDSU in 2015 from the University of Michigan, where he was a postdoctoral researcher in the Department of Chemical Engineering.

Designing sensor

The sensor uses two glass substrates coated with silver, silicon dioxide and an aluminum spacer of controlled thickness. Silicon dioxide makes the liquid flow easily over the sensor surface, according to graduate student Nezam Uddin, who wrote

his thesis on the development and testing of the sensor. He completed his master's degree this summer.

Most current sensors based on Fabry-Perot techniques use optical fiber, according to Yoon. The disadvantages of optical fiber-based sensor are low sensitivity and complex structure.

The first design, which did not have a microfluidic chamber, had limitations when it came to increasing sensitivity and selectivity. In addition, it was difficult to flow the liquid in the cavity as well as to know whether the cavity was filled with the glucose-laced test solution.

The researchers' latest design uses a microfluidic structure with inlet and outlet ports. Yoon used this microfluidic technology in his research at Michigan and holds two U.S. patents for microfluidic devices in circulating tumor cell isolation applications.

"With the microfluidic chamber, I can see the liquid coming out of the port, so I know it is filled," Uddin explained. "With this new structure, we can easily change the reflectance/transmittance using different silver layer thicknesses—and there is no electromagnetic interference."

Using refractive index to test sensor

The researchers measure the refractive index of sugar solutions, varying from 20 to 500 milligrams per deciliter. "The concentration level of the glucose in the solution changes the refractive index and a small change in the refractive index can be directly detected from optical interference," explained Uddin.

Yoon elaborated, "The refractive index is determined from the shift of peak wavelength in the transmission spectrum." This index is used to calibrate the sensor and to determine its accuracy.

By plotting the refractive index vs. solution concentration, the researchers can

determine the glucose level of an unknown solution based on the refractive index value. "The accuracy of the sensor depends on accurate refractive index measurements," Yoon said.

The researchers also bought a commercially available glucometer with which they can compare their sensors. They found that the commercial device's accuracy decreased as the sugar levels in the test solution increased. A 50 mg/dL solution, for instance, produced an output of 55, while a 200 mg/dL solution produced a 246, according to Uddin. That is 6 points greater than the allowable accuracy range, even when using the lower 2013 FDA standards.

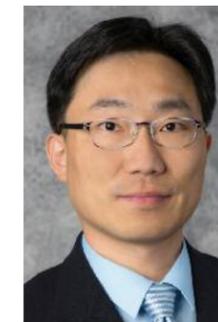
Moving toward improved accuracy

The sugar-water test solution also contains sodium and potassium, which are normally present in blood. The sensor can detect glucose, sodium and potassium.

The first sensor design was within the FDA's 15 percent of true value range approximately 90 percent of the time, but the new microfluidic structure has greater potential for increased accuracy. Though the design is still being refined, some of the sensors have attained 95 percent accuracy; however, the results have, thus far, been inconsistent.

Once the researchers get consistent results using the test solution, their collaborator, biology and microbiology professor Xiuqing Wang, will prepare blood samples with different glucose levels to further test their device. Wang is an expert in glucose analysis.

In addition to improving sensor performance, the microfluidic design is more compact, Yoon noted. "The simple structure will also be advantageous when it comes to commercialization."



Hyeun Joong Yoon

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LEFT: Graduate student Nezam Uddin, left, and assistant professor Hyeun Joon Yoon position a substrate in the sputtering machine as part of research to design and fabricate a sensor that can more accurately measure blood sugar levels.

1. Graduate student Nezam Uddin carefully cuts the glass substrate onto which the silver layer will be applied.

2. Uddin places the substrate into the sputtering machine where the silver layer will be applied.

3. By changing thickness of the silver layer on the sensor, the researchers can fine-tune the reflectance.

4. Uddin uses a sugar solution, varying from 20 to 500 milligrams per deciliter to evaluate the sensor's performance.

5. Yoon checks the sugar-laced solution flowing through the sensor as Uddin measures the reflective index based on peak wavelength to calibrate the sensor and determine its accuracy using a spectrophotometer.

6. The glucose solution in the tubing flows into the microfluidic chamber of the sensor and then through the outlet port when the chamber is full.



Capping material helps alum inactivate phosphorus in lake water



An emerald lake may sound romantic, but no one wants to swim, boat or fish in green slime. Algae blooms, which can release harmful toxins, occur in bodies of water that have high levels of phosphorus and nitrogen.

Unlike nitrogen, once phosphorus gets into a lake, it is difficult to remove, explained Kyungnan "Karen" Min, an instructor in the Department of Civil and Environmental Engineering. Use of aluminum sulfate, a chemical treatment designed to capture phosphorus and reduce algae growth, has provided only short-term relief in two small South Dakota lakes due to the release of phosphorus from lake sediment.

Min and assistant professor Guanghui Hua are investigating whether sediment capping will increase the effectiveness of the chemical treatment. This emerging technology uses a layer of phosphorus-binding particles on top of sediment to minimize re-suspension and reduce phosphorus release.

Through laboratory experiments, Min and Hua are testing three inexpensive, readily available natural minerals—limestone, zeolite and sand—as capping materials. The two-year project is supported by the U.S. Geological Survey 104b program administered through the South Dakota Water Resources Institute with matching funds from the East Dakota Water Development District and South Dakota State University.

Dealing with internal loading

The researchers gathered sediment and water samples from Lake Kameska, near Watertown, for their experimental work in October. Roger Foote, coordinator for the Upper Big Sioux River Watershed Project, reported that on Oct. 5, 2016, Lake Kameska had a total phosphorus level of 0.65 milligrams per liter, while nitrate levels were low, 0.30 to 0.32 mg/L. Lakes with phosphorus concentrations higher than 0.1 mg/L are considered hypereutrophic.

"In these conditions, nitrate is the limiting factor," he explained. "All it takes is a significant runoff event to increase nitrate levels and the possibility of algae blooms will be there again."

Most South Dakota lakes are phosphorus-rich, according to Paul Lorenzen, an environmental scientist at South Dakota Department of Environment and Natural Resources. "When we're looking at lake data, nitrogen limitation is generally what we see. Most of the nitrogen in our water is in organic form and algae

need it in an inorganic form to proliferate. Furthermore, through different nitrogen cycle conversions, it can be lost to the atmosphere," he said.

The combination of shallow prairie lakes nestled among farmland makes this a common problem in eastern South Dakota, according to Jay Gilbertson, manager of the Eastern Dakota Water Development District. "Even if we could completely stop inputs from agricultural runoff today, there is still a tremendous amount of phosphorus in lakes already."

Min explained, "Phosphorus just keeps accumulating—there is no path out to the air. It's an

unending cycle, known as internal loading." When algae die, the phosphorus is released back into the water. Dissolved phosphorus also attaches to sediment.

Using alum treatment

In the water, the coagulant aluminum sulfate, also known as alum, forms a fluffy substance called floc, which binds with phosphorus and settles to the bottom of the lake, thus reducing the phosphorus concentration in the lake water.

In the early 2000s, alum was applied to Lake Mitchell, a man-made reservoir in Davison County, and Lake Oliver in Deuel County. However, Lorenzen said, "We did not get the results we were looking for." Phosphorus levels dropped initially, but then rebounded.

"Alum makes the particles bigger," Min explained. However, in shallow lakes, the particles can be easily disturbed by wind, storms and water vehicles, such as motor boats.

"Turbulence can cause the floc to come up, releasing the phosphorus," she said. In addition, low oxygen levels in the lake can trigger phosphorus release. This research is designed to address the resuspension issue and increase the alum treatment efficiency.

Testing capping material

The researchers tested alum coagulation, followed by adding sand, limestone or zeolite as a capping material and compared their performances to a commercial product designed to prevent phosphorus release. Zeolite is used in water softeners and filters, and limestone, as part of a fertilizer mix, helps decrease soil acidity.

After determining the correct alum dosage for coagulation, doctoral student Sepideh Sadeghi performed column testing using sediment and overlaying the Lake Kameska water samples.

First, Sadeghi spiked the simulated lake water columns with *Anabaena* sp., a common cyanobacteria, supplied by the SDSU Department of Biology and Microbiology. Next, she treated the water columns with alum, followed by adding the capping material. During the 80-day experiment, Sadeghi used a mixer to agitate the water every 10 days for five minutes at a speed of 500 rpm to simulate the passage of a motor boat.

All alum-capping material combinations helped the floc settle to the bottom, resist turbulence and prevent resuspension better than alum alone, according to Min. However, limestone and zeolite produced results similar to those from the more expensive commercial product.

All capping materials were in the 0.1 to 1 millimeter size range, except for limestone, which was tested in three sizes—ranging from 0.2 to 2 mm. The smallest size, 0.2 to 0.5 mm, produced the best limestone results, according to Sadeghi.

"The results are promising," said Hua. However, Min cautioned, "This is not a permanent solution, but can extend the time required before reapplication is needed." The next step will be to perform a cost evaluation and test the most promising combination in a South Dakota lake.

Admittedly, chemical solutions, such as alum, have their limitations, but even a modest dredging project to remove nutrient-laden sediment can cost millions of dollars, according to Gilbertson.

"Increasing the efficiency of alum treatments will help us make the best of a bad situation," he concluded. "We can do a better job, but in an agricultural setting such as eastern South Dakota, we are still left with the legacy as well as the ongoing activity."



Kyungnan "Karen" Min

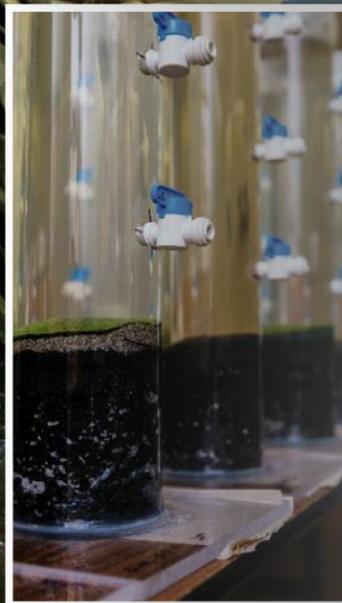
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OPPOSITE: Assistant professor Guanghui Hua, left, and Roger Foote, coordinator for the Upper Big Sioux River Watershed Project, collect sediment from Lake Kameska near Watertown that will be used to test capping materials.

INSET LEFT: These experimental columns, which contain sediment and water from Lake Kameska, have been spiked with cyanobacteria and then treated with alum followed by a capping material—limestone, zeolite or sand.

INSET RIGHT: Doctoral student Sepideh Sadeghi and instructor Kyungnan "Karen" Min use a mixer to agitate the water in the column to simulate the passage of a motorboat.



Statistician develops efficient predictive algorithms



Carp and solar energy seem worlds apart—unless we're talking predictive algorithms. The complex patterns of fish movement and solar irradiation can be modeled using varying types of Markov-switching models, according to associate professor Chris Saunders.

Developing computationally efficient algorithms for statistical learning and pattern recognition is one of the ongoing themes of the statistician's research. For his work, Saunders was recognized with the Young Investigator Award from the Jerome J. Lohr College of Engineering this spring. (See profile p. 16.)

During the last nine years, he has been principal investigator or co-principal investigator on approximately \$10 million in research funding, with \$2 million of that coming from the National Geospatial Intelligence Agency and the National Institute of Justice.

Predicting carp movement

Saunders and graduate student Doug Armstrong evaluated two modeling approaches to describe the movement of carp in a South Dakota lake during the winter. The Bayesian Hierarchical Markov model produced better results than the multinomial model.

The statisticians used ultrasonic tracking data on common carp movements, gathered for 168 days beginning November 2007 and for 128 days beginning in November 2008 by Department of Natural Resource Management researchers, associate professor Michael Brown and graduate student Matthew Hennen.

To reduce the complexity of the modeling, the statisticians transformed the raw data, collected from under-ice stationary receivers, to a function of

discrete time measured in days and combined detection zones to reduce the number from 10 to five.

"Fisheries scientists can answer basic questions, but when it comes to extensive modeling approaches that add certainty to your conclusions, it's wise to consult with the people who do this on a daily basis," Brown said. Fisheries managers need to determine the best time and location to capture and remove a maximum number of this invasive species from lake systems.

The Markov model assumes that where a carp is on a given day is a function of its location(s) the previous day, while the multinomial model predicts movement independent of current location, which makes it less sensitive to changes in the system. Consequently, the more complicated Markov model detected a sudden increase in carp activity in mid-February 2007 that the other model did not.

Results of their collaboration were published last year in *Ecological Modeling*, an international journal. "This work gave us more confidence in our findings," Brown said.

Estimating solar energy output

With minor extensions, the same Markov switching model can be applied to solar power forecasting, Saunders explained. To do this, he and his colleague, assistant professor Semhar Michael, collaborated with assistant electrical engineering professor Reinaldo Tonkoski, whose research focuses on integrating renewable energy into microgrids in remote areas that rely on diesel generators.

To develop statistical correlations, most models require long-term historical

data that is not readily available for remote areas, Tonkoski noted.

The Markov switching model Saunders and Michael developed uses clear-sky irradiance, expressed as the intensity of direct sunlight on a cloudless day. Fourier basis expansions are used to capture daily and yearly variations. The model is trained and validated using historical solar-irradiance data, which can easily be obtained from SolarAnywhere, a web-based service, for any location.

Using the Bayesian Information Criterion, the researchers found the model fit was best with three states. Tonkoski characterized these states as sunny, partly cloudy and cloudy.

"This method is simple and beautiful," he said. The model produces a rough day-ahead estimate of solar energy during the period of time when these sources are most likely to be available—after the first four hours of the day. The researchers presented their findings at the 2016 IEEE Energy Conversion Congress and Exposition and an article was published in *IEEE Transaction on Sustainable Energy*, one of the top 10 publications in power engineering.

"Chris uses modern statistical tools that process data efficiently. He gives us this edge—we can bring a unique solution that will suit the data," Tonkoski said. This work provides a foundation for further research to increase the accuracy of the model for predicting solar irradiance.

In future work, Michael said, "We will try to relax the assumptions, making it more flexible, so we can apply it in other areas where we don't have lot of datasets to train and validate the model."



Chris Saunders

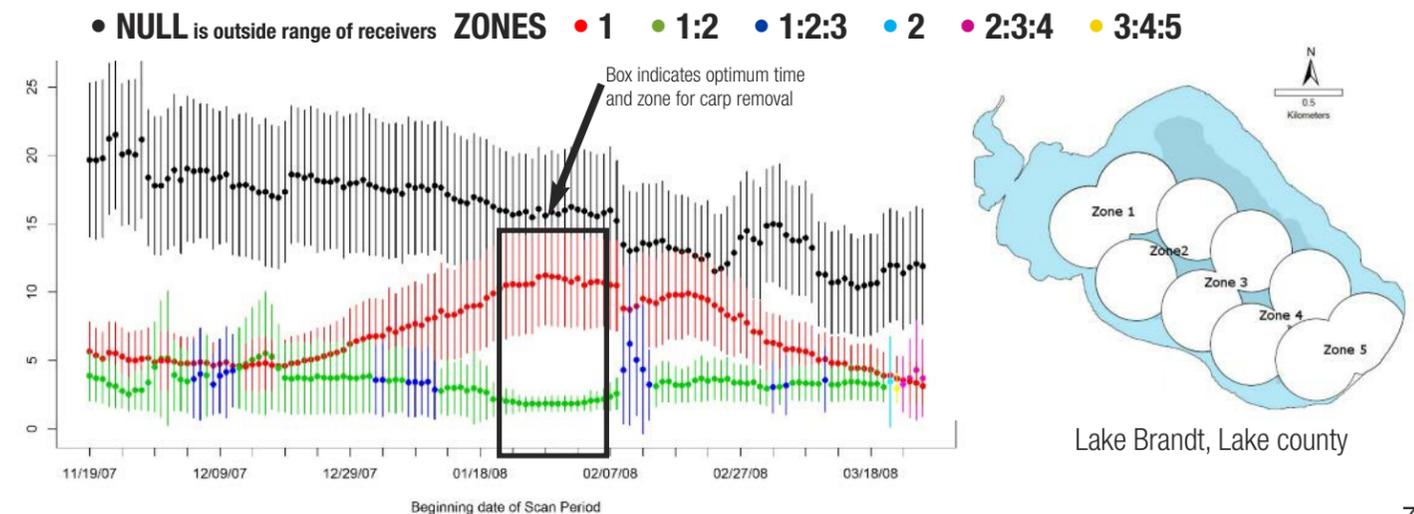
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LEFT: Varying types of Markov-switching models can be applied to provide a rough day-ahead estimate of solar energy and to determine the best time and location to remove carp, an invasive species, from a lake.

BELOW LEFT: Though the tagged carp spent a majority of time in the NULL zone, outside the range of the ultrasonics receivers, or in zone 1 during November and December 2007, the Markov simulation shows that efforts to remove carp would be most successful in zone 1 during the latter two weeks in January (see box).

BELOW RIGHT: The original 10 zones that the natural resource management researchers used were combined into five zones to reduce the complexity of the model.



Timber Bridges

viable option for county, township roads

Glulam timber bridges are viable, cost-effective options for replacing bridges on low-traffic county and township roads.

That's what researchers at the Jerome J. Lohr Structures Lab concluded after testing two full-scale glulam timber structures—a girder bridge and a slab bridge. Glulam, short for glued laminated, means the structural members are made of layers of wood strips bonded with glue.

Both structures, which were made of Southern Yellow Pine, showed satisfactory performance and minimal damage under cyclic loading equivalent to 75 years of service, explained assistant civil engineering professor Mostafa Tazarv, who was the project co-principal investigator. "To our knowledge, this is the first time that full-scale testing has been done on glulam timber bridges," he said.

The two-year, more than \$160,000 project investigated the feasibility and performance of two timber bridges and a fully precast concrete inverted bulb-tee bridge for use on local roads (See story p. 11). The project was co-sponsored by the U.S. Department of Transportation through the Mountain Plains Consortium and the South Dakota Department of Transportation. Gruen-Wald Engineered Laminates of

Tea donated the two timber bridges, while Gage Brothers of Sioux Falls supplied the inverted bulb-tee bridge.

The project provides alternatives to the conventional precast double-tee bridge, for which there is only one local supplier in the state, explained Aaron Breyfogle, South Dakota Department of Transportation project manager. In the last six years, he has worked with SDSU researchers on 10 to 15 structural projects.

"The structures lab is an exceptional resource for a state of our size," he said.

Saving time, money using wood

Both bridges were designed for American Association of Highway and Transportation Officials (AASHTO) HL93 truck load, according to Nadim Wehbe, structures lab director. The John M. Hanson Endowed Professor in Structural and Construction Engineering is also head of the Department of Civil and Environmental Engineering and was co-principal investigator for this project.

Glulam manufacturers layer the wood to reduce material variability that is inherent in natural wood and increase strength by placing higher quality material on the outer portions where the stress demand is greatest, according to the U.S. Department of

Transportation. "They can tailor the layers to fit the performance objectives," Wehbe said.

The initial construction costs for a glulam timber bridge can be anywhere from 25 to 50 percent less than a conventional bridge, Tazarv explained. Typically, the bridge can be installed in a day without the need for specialized equipment or specially trained personnel.

In addition, he explained, "The way wood is treated and the type of material used for the treatment these days are more environmentally safe." However, Breyfogle pointed out, the lab testing does not account for environmental conditions, a concern when using a biodegradable material, such as timber.

Overall, Tazarv concluded, "Timber bridges are structurally viable, low-cost, sustainable and durable." In addition, they are easy and relatively fast to construct, which shortens the road-closure time.

Testing a girder bridge

A glulam girder bridge, which can span up to 80 feet, consists of transverse glulam deck panels supported on longitudinal glulam girders. The specimen tested was 50 feet long and 9.5 feet wide and was composed of 13 deck panels



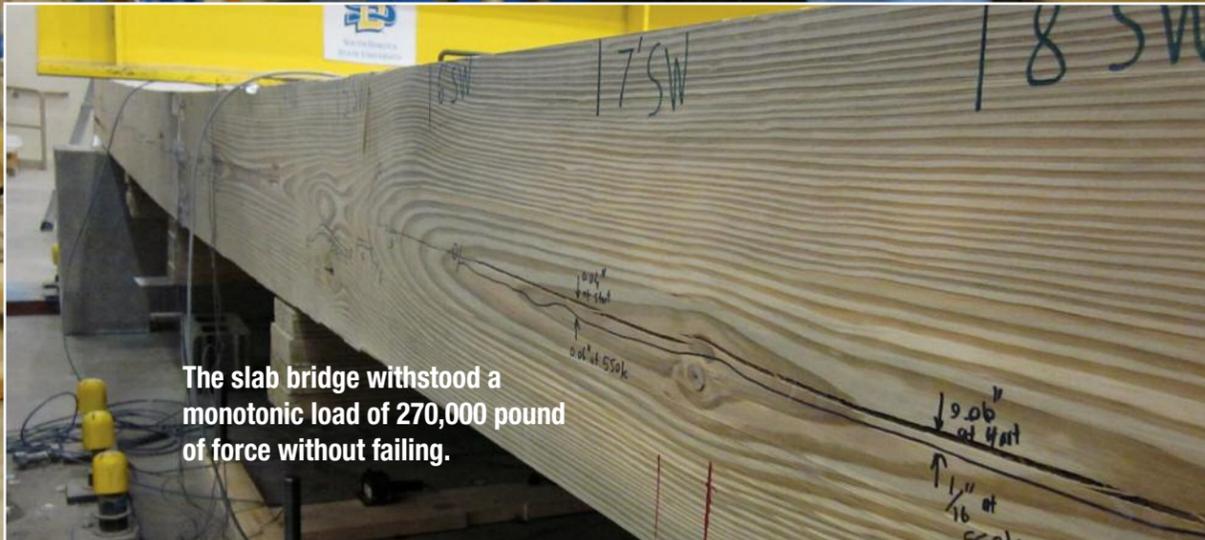
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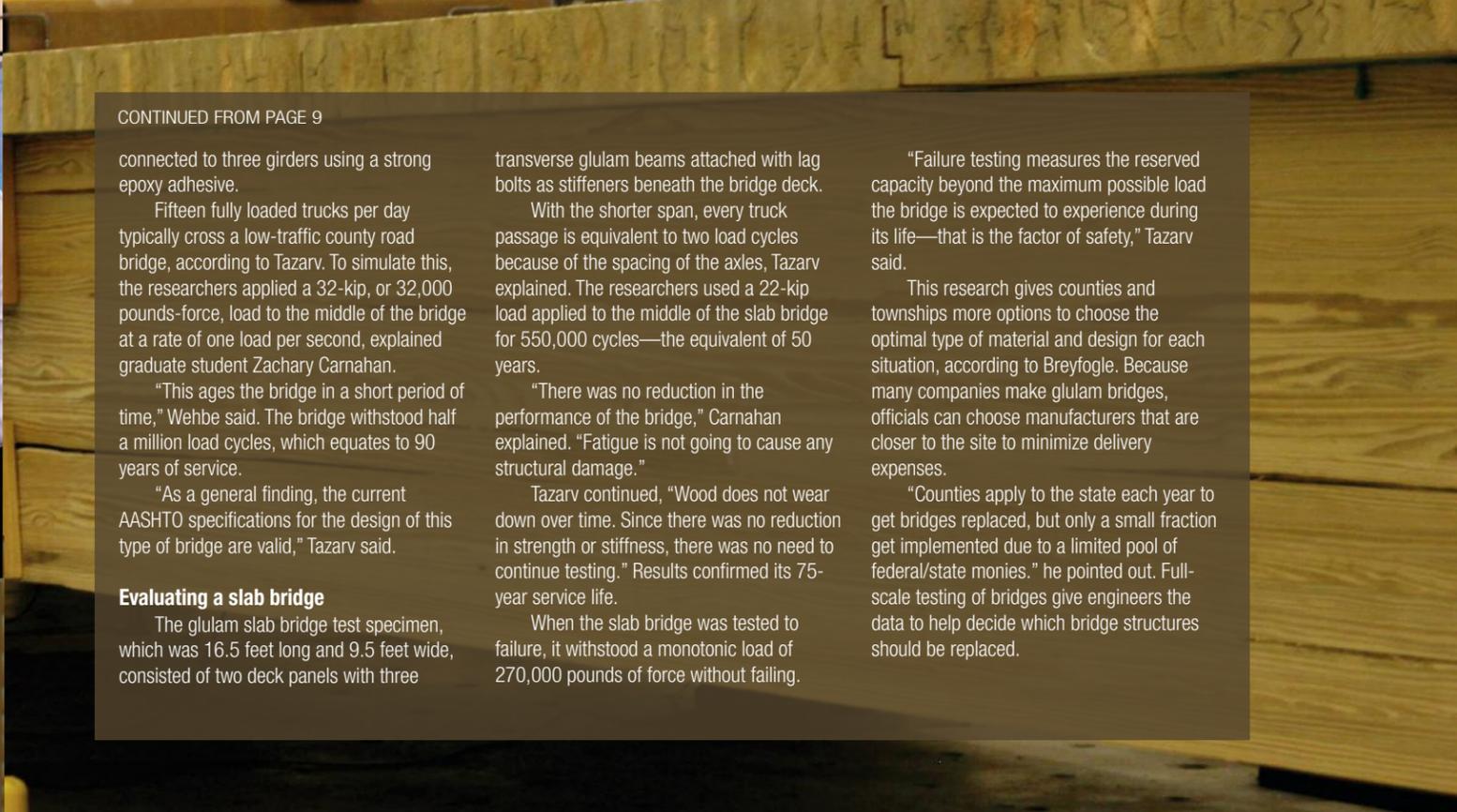
"To our knowledge, this is the first time that full-scale testing has been done on glulam timber bridges."

CONTINUED PAGE 11



The slab bridge withstood a monotonic load of 270,000 pound of force without failing.

Background photo: An increasing monotonic load was applied to the glulam timber girder bridge until failure occurred.



CONTINUED FROM PAGE 9

connected to three girders using a strong epoxy adhesive.

Fifteen fully loaded trucks per day typically cross a low-traffic county road bridge, according to Tazarv. To simulate this, the researchers applied a 32-kip, or 32,000 pounds-force, load to the middle of the bridge at a rate of one load per second, explained graduate student Zachary Carnahan.

"This ages the bridge in a short period of time," Wehbe said. The bridge withstood half a million load cycles, which equates to 90 years of service.

"As a general finding, the current AASHTO specifications for the design of this type of bridge are valid," Tazarv said.

Evaluating a slab bridge

The glulam slab bridge test specimen, which was 16.5 feet long and 9.5 feet wide, consisted of two deck panels with three

transverse glulam beams attached with lag bolts as stiffeners beneath the bridge deck.

With the shorter span, every truck passage is equivalent to two load cycles because of the spacing of the axles, Tazarv explained. The researchers used a 22-kip load applied to the middle of the slab bridge for 550,000 cycles—the equivalent of 50 years.

"There was no reduction in the performance of the bridge," Carnahan explained. "Fatigue is not going to cause any structural damage."

Tazarv continued, "Wood does not wear down over time. Since there was no reduction in strength or stiffness, there was no need to continue testing." Results confirmed its 75-year service life.

When the slab bridge was tested to failure, it withstood a monotonic load of 270,000 pounds of force without failing.

"Failure testing measures the reserved capacity beyond the maximum possible load the bridge is expected to experience during its life—that is the factor of safety," Tazarv said.

This research gives counties and townships more options to choose the optimal type of material and design for each situation, according to Breyfogle. Because many companies make glulam bridges, officials can choose manufacturers that are closer to the site to minimize delivery expenses.

"Counties apply to the state each year to get bridges replaced, but only a small fraction get implemented due to a limited pool of federal/state monies," he pointed out. Full-scale testing of bridges give engineers the data to help decide which bridge structures should be replaced.

Above: Graduate student Zachary Carnahan, assistant professor Mostafa Tazarv and professor Nadim Wehbe, director of the Jerome J. Lohr Structures Lab, check damage and strain gauges on the timber bridge deck. The bridge withstood half a million load cycles, which equates to more than 75 years of service.

Above right: Tazarv and Wehbe examine the joints in the bridge deck for damage.



Structural engineers test fully precast concrete bridge for local roads

Engineers have another option when designing a bridge to span more than 80 feet on a local road—the inverted bulb-tee precast concrete bridge.

"The goal was to develop a new concrete bridge that is fully prefabricated for long spans," explained assistant civil engineering professor Mostafa Tazarv, who was the project co-principal investigator. "All components are prefabricated and can be shipped to the site piece by piece."

Testing of the inverted bulb-tee bridge was part of a more than \$160,000 project that also evaluated timber bridges as alternatives to the double-tee bridge for low-traffic roads. It was sponsored by the U.S. Department of Transportation through the Mountain Plains Consortium and the South Dakota Department of Transportation. Gage Brothers of Sioux Falls fabricated and donated the precast concrete bridge.

The inverted bulb-tee bridge has precast concrete deck panels and prestressed concrete girders. The test specimen was 50 feet long and 9.5 feet wide, consisting of five full-depth deck panels supported on two inverted bulb-tee girders.

When fully assembled inside the Jerome J. Lohr Structures Lab, the specimen weighed close to 90,000 pounds. The prototype bridge was designed based on American Association of Highway and Transportation Officials HL-93 specifications for an average traffic load of 15 trucks per day with a 75-year design life.

Tazarv and graduate student Michael Mingo applied 27.7-kip, or 27,700 pounds-force, at a rate of one load per second to the test bridge. It withstood 650,000 load cycles—the equivalent of 119 years of service. "We did not see any major damage," Tazarv noted.

According to Mingo's estimates, the materials and fabrication costs for the inverted bulb-tee are around 10 percent higher than for the same size double-tee bridge. However, Tazarv pointed out, "This design promises to be more durable because the joints are not exposed."

The researchers also compared the conventional means of attaching the girders, known as open full-depth pockets, with a new hidden-pocket design. "We made two holes with PVC pipes and then a void a few inches below the surface," Tazarv explained. In his thesis, Mingo concluded that the hidden pocket was more durable than the full-depth pocket.

When the bridge was tested to failure, the structure was four times stronger than the maximum possible load demand on the bridge, according to Tazarv. "We could not fail the bridge."

That is good news for Aaron Breyfogle, South Dakota DOT project manager. "This gives the counties more options," he said, noting multiple companies in the state make the inverted bulb-tee bridge components.

FAR LEFT: Graduate students Lucas Bohn and Michael Mingo, on the deck, and Jharna Pokhrel, Ishtiaque Ahmed Tuhin and Zachary Carnahan, on the ground, mark cracks in the inverted bulb-tee precast concrete bridge that is being subject to cyclic loading.

Remaining-useful-life algorithms

enhance lithium-ion battery management system



U.S. Navy personnel will be able to monitor—in real time—the remaining useful life of lithium-ion batteries in fighter jets and unmanned aircraft systems, thanks to collaboration between Space Information Labs (SIL) of Santa Maria, California, and professor Huitian Lu of the Department of Construction and Operations Management.

Lu is developing algorithms to predict remaining useful life that will be integrated into the SIL battery management system, which balances and monitors each individual battery cell of the company's Li-Ion Polymer Intelli-Pack Battery®. This monitoring capability is not available with lead acid and nickel cadmium batteries currently used in these aircraft for functions, such as opening a cockpit or starting an engine.

The research is funded through the Small Business Technology Transfer (STTR) Program, which supports collaboration between small businesses and nonprofit educational institutions.

SIL, an aerospace engineering company, develops and manufactures products for rockets, missiles, small satellites, unmanned aerial vehicles and aircraft since 2003. Edmund Burke, SIL president and CEO, met Lu in 2012 at a NASA Aerospace Battery Workshop sponsored by the Marshall Space Flight Center in Huntsville, Alabama.

"We started a discussion at that time, so when I wrote the Navy STTR, I reached out to him to work with me on Li-Ion battery prognostics," Burke said.

"He's both knowledgeable and passionate about this research."

The researchers received Phase I funding in August 2015 to begin developing a prototype battery management system for a fighter jet, an unmanned helicopter and a weapons system for Naval Air Systems Command. The first phase determined the scientific and technical merit, as well as feasibility of the design concept for F/A-18 and Fire Scout platforms. The subsequent Phase IA portion of the project focused on the prognostic algorithms.

In October 2016, the researchers received two-year Phase II funding to further develop the algorithms and implement the Li-Ion battery and internal, advanced battery management system on an F/A-18 fighter jet and an unmanned Fire Scout aircraft.

Monitoring battery health

High reliability and safety are major requirements for lithium-ion batteries used in aircraft, according to Lu. "We need to make sure the battery has the power required to complete the mission." These batteries require management systems to monitor their operating conditions and health for safety and reliability purposes.

As part of Phase IA, Lu and mechanical engineering graduate student Suresh Daravath worked on algorithms to predict state of charge, state of health and remaining useful life for the prototype battery management system. They received

approximately \$27,000 in funding to support this portion of the STTR project.

State of charge means how much charge is left in the battery, explained Lu. "It's like the fuel gauge on a car." The battery management system monitors in real time the energy in the battery, which charges while the aircraft is in use. "This adds to the complexity of the modeling because the power demand is random," he added.

State of health refers to the current capacity of the battery or how much energy can be put back into the battery each time it is charged. "As the battery degrades, its capacity will decrease," Lu said.

When the capacity decreases to approximately 80 percent of the original design capability, the aircraft's battery must be replaced. "At any time, we will estimate the specific amount of life that the battery has before it is degraded based on the degree of reliability necessary for this particular application," he said.

Developing mathematical model

"Battery dynamics are complicated," Lu noted. Most studies use electrochemical models, which analyze conditions within the battery, but for online assessment/control, the research team selected an equivalent circuit model, which is capable of better handling the variables of the Li-Ion battery online.

To explain the dynamics of the battery, the researchers chose the state-space model, a group of first-order differential equations. This model uses

automatic recursive filters to provide a step-by-step approach to estimating battery state across time, from which battery health is calculated.

"Everything has to follow the statistical and mathematical rules, but we need to make reasonable assumptions," Lu said. The Sequential Monte-Carlo Method, known as particle filter, is the algorithm for online filtering to estimate state of charge and state of health. That is then used to predict remaining useful life.

Lu, Burke and Daravath presented this part of their work at the Industrial and Systems Engineering Conference in May. The SDSU researchers are working with SIL to develop a graphic user interface that displays state-of-charge and state-of-health estimations as well as remaining useful life for the battery management system.

Advancing toward commercialization

Through Phase II funding, Lu and his team received \$100,000 to continue refining the battery

prognostic algorithms. "We will use a statistical method to model the load as a random type," Lu said. Two graduate students will work on the project this summer and one during the school year.

Burke said, "These prognostic algorithms—run on SIL's Li-Ion Battery Management System internally to the battery—will increase the reliability, maintainability and safety of our product."

Through these collaborative STTR projects, universities can offer small businesses analytic support while training students to use applied mathematics to fulfill the needs of industry, Lu pointed out.

In the long run, what the SIL and SDSU researchers are developing will be used to monitor Li-Ion batteries for many commercial applications, including electric vehicles, robotic machines, portable power and solar and wind energy.



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The 10-ampere-hour cells that make up a lithium-ion battery are connected to the tester, which will discharge the power at various rates to provide data to develop the prognostic algorithms.

Mechanical engineering graduate students Rakesh Ade, left, and Suresh Daravath, right, discuss battery-test data with professor Huitian Lu, center, which will be used to develop prognostic algorithms that will be incorporated into Space Information Labs' battery management system to predict remaining useful life for its Li-Ion Polymer Intelli-Pack Battery®.

For safety and reliability purposes, the battery management system monitors the operating conditions and health of these 10-ampere-hour cells that make up the lithium-ion battery.

Balancing energy demand

can reduce peak power usage

An incentive program that shifts electricity usage for low-priority activities to nonpeak times could save money for utilities companies and consumers, according to assistant professor Tim Hansen of the electrical engineering and computer science department.

Through a \$153,689 National Science Foundation grant, Hansen is examining how an end-user distribution plan could help balance the demand for electricity and ease pressure on aging transmission lines.

He collaborates with Colorado State University electrical engineering researchers—professor and department head Anthony Maciejewski, distinguished professor Howard Siegel and associate professor Siddharth Suryanarayanan, who received a separate NSF award. Total funding for the three-year project is \$425,000.

“This project is a formal method for trying to balance consumption with minimal intrusiveness based on customer willingness to reduce electricity demand during peak times,” explained Hansen, who completed his doctorate at Colorado State before coming to SDSU in 2015. That could mean, for instance, changing the time and day a person does laundry.

The researchers are also working with the University of Technology of Belfort-Montbéliard in France, the National Renewable Energy Lab, Siemens Corporation and a Fort Collins, Colorado, utility company.

Reducing peak loads

Utility companies pay less for nonpeak energy because more efficient generators, including renewables, such as wind and solar, are in use, Hansen pointed out. All energy generators, whether coal plants or solar panels, are hooked to the same power grid.

However, that power system must have enough production capacity to meet the highest energy demand it will ever see, Hansen explained. By

altering consumers’ energy-usage habits, those peaks can be reduced—and a portion of the money utility companies save can be passed on to their customers.

Reducing peak usage also will relieve some of the pressure on the nation’s transmission lines, many of which were constructed in the ’70s and have exceeded their estimated 30-year life span. Constructing a new power line can take more than a decade from planning to approval and then installation, Hansen explained. In the meantime, new gadgets and devices increase the demand for power.

Simulating impact of load-shifting

The research project takes a simulation-based approach. “We know how the power market works and energy prices are assigned,” he said. That is then paired with how consumers normally use energy.

Using algorithms, the researchers determine when and how much energy must be shifted to balance the energy draw and reduce pressure on the transmission grid. Two doctoral students are working on the project.

This type of demand-response system involves aggregators, middlemen who sign up customers willing to alter their energy-consuming habits in exchange for cost savings, according to Hansen. The aggregators then work with the utility companies to reduce electricity usage during peak times.

“Aggregators combine many small changes in energy consumption to meet the bid requirements of the bulk power market,” he said. One of the challenges is to calculate the economic value of aggregators.

Calculating savings

Hansen and his collaborators simulated the demand-response system using smart-grid resource allocation to model electricity consumption on a simulation-test system using data from July 2011. They discussed their results during a presentation at the seventh International ENERGY Conference and Workshop in Venice, Italy, in May.

The case study involved a representative community of 5,555 houses equipped with smart technologies, which allow appliances to be controlled via the internet. The goal was to reduce usage of two

5-megawatt peak-load units within the power structure.

Each smart home had 18 controllable and 31 noncontrollable appliances customers used daily. Each household in the study consumed, on average, 3.6 kilowatts of peak power daily.

During the 31-day period, the total profits for the aggregators were \$33,684. The energy savings for all the customers was \$21,736. Average customer savings were \$3.91. However, the simulation did not include the heating, ventilating and air conditioning load or seasonal variations in use, which will be considered in future work through this grant.

The simulation, which was carried out on the IEEE Roy Billinton Test System, showed the capacity factor of the peak power generators was reduced from 19.92 to 4.96 megawatt hours, a relative change of 75 percent. “These are the most expensive to run and, are, hypothetically, the most emission-intensive units,” Hansen said.

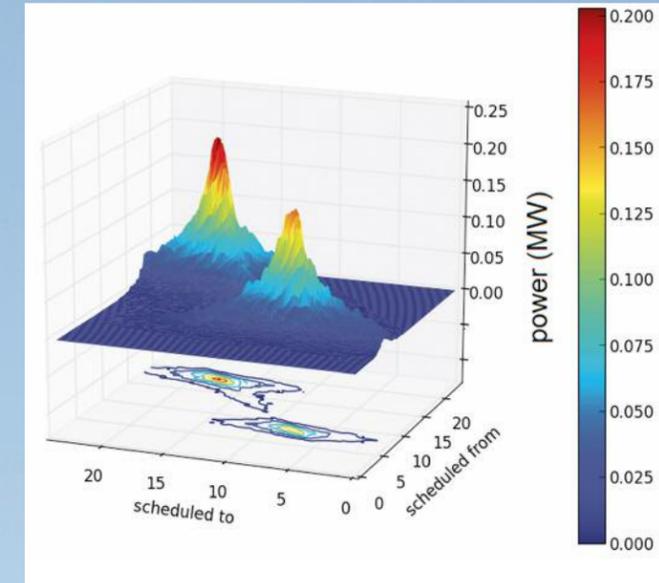
In future work, carbon emissions will also be calculated for energy generation to determine reduction in greenhouse gases.

Capitalizing on demand balancing

Energy systems can become more efficient through demand balancing, according to Hansen. “The issues aren’t so much technical anymore, but are regulatory and social in nature.”

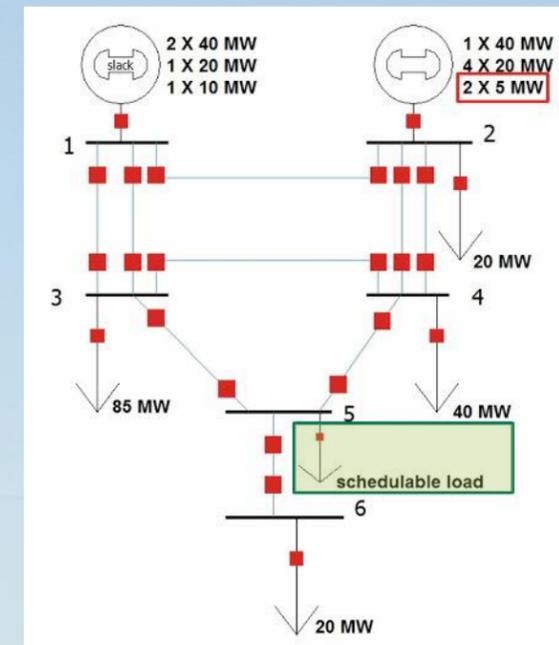
Policymakers must be convinced about the benefit of this system to change regulations and consumers want assurances regarding information security when using smart technologies. “It’s about changing mindsets,” he said. One of the solutions is a control system in each home, rather than being connected through a network.

Because demand balancing relies on an energy market with multiple suppliers competing for customers, it is better adapted to an urban than a rural setting, according to Hansen. “As with most innovations, we’ll have to begin small and build from there.”



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In the 3-D contour plot, in which the colors represent power magnitude, the load has been moved to reduce peak-energy demand, in red, by scheduling low-priority activities at nonpeak times.

Using a representative community of 5,555 houses equipped with smart technologies and data from July 2011, the researchers simulate the demand-response system. In this power grid, the goal is to reduce usage of two 5-megawatt peak-load units, boxed in red in the upper right, working with schedulable loads on Bus 5 designated by the green box.

AWARDS

Engineering researchers receive college, university awards



Chris Saunders

College recognizes Saunders with Young Investigator Award

Whether you're trying to catch a crook or a carp, the work that mathematical statistician Chris Saunders does can give you the advantage. The associate professor of statistics specializes in statistical pattern recognition, signal processing and forensic identification of source problems. For his research, Saunders was recognized as the 2016-2017 Young Investigator of the Year in the Jerome J. Lohr College of Engineering.

While completing his doctorate in mathematical statistics at the University of Kentucky in 2006, Saunders was recruited to support the FBI and broader intelligence community as an Intelligence Community Postdoctoral Research Fellow in pattern recognition and handwriting identification. He spent the next two years at George Mason being trained in machine learning, statistical pattern recognition and the interpretation of forensic evidence. After the fellowship ended, Saunders continued as an assistant research professor in the document forensics lab at George Mason until coming to SDSU in 2012.

Since 2009, Saunders has been the principal investigator or co-principal investigator for approximately \$10 million research funding, with \$2 million of that from the National Geospatial Intelligence Agency and the National Institute of Justice. Since 2014, Saunders and his colleague, assistant professor Cedric Neumann, have been evaluating statistical models designed to determine probability values for crime scene evidence through a three-year, \$780,300 National Institute of Justice grant. They are the first SDSU statisticians to do this type of work. In addition, Saunders has fostered collaboration and developed computationally efficient algorithms that are reinforcing conclusions and fueling innovation for researchers in other departments and colleges (see story p. 6).



Nadim Wehbe

Wehbe named Researcher of the Year for second time

Professor Nadim Wehbe, head of the civil and environmental engineering department, was named the Jerome J. Lohr College of Engineering Researcher of the Year at the university's Celebration of Faculty Excellence in February. This is the second time Wehbe has received the honor; the first was in 2011. He also became the first recipient of the John M. Hanson Professorship in Structural and Construction Engineering, an endowed position, in 2014.

Wehbe, who has been at SDSU since 1998, was instrumental in designing and equipping of the Jerome J. Lohr Structures Lab in Crothers Engineering Hall in 2002. As lab director, Wehbe has supervised research and structural testing on large- and full-scale test specimens for private companies and government entities for more than a decade. Since 2006, SDSU civil engineering faculty and students have helped solve transportation-related problems as one of eight universities in the Mountain Plains Consortium Transportation Center Program.

Research that improved the performance of double-tee bridge girders in South Dakota received national recognition in 2015 as one of 16 high-value research projects in the nation. Other projects have focused on identifying viable, cost-effective alternatives to the double-tee for bridges on low-traffic county and township roads (see p. 8).

Wehbe has secured external funding from the National Science Foundation, the U.S. Department of Transportation, the South Dakota Department of Transportation and private-sector institutions. He is also a fellow of the three civil engineering institutes—American Society of Civil Engineers, the American Concrete Institute and the Structural Engineering Institute.



Qiquan Qiao

Qiao receives award for international research

Encouraging the development of solar energy technologies worldwide has earned electrical engineering professor Qiquan Qiao the university's award for Faculty Engagement in International Research. The Harold C. Hohbach Endowed Professor in Electrical Engineering has hosted students and faculty from Israel, Egypt, Pakistan and China in the last seven years. These projects have brought about \$630,000 in research funding to SDSU, which provides materials, equipment and facilities, as well as technical support.

"These countries experience energy shortages, but have a lot of sun," Qiao said. "We help them boost their utilization of renewable energy."

Through the National Academy of Sciences and the U.S. Agency for International Development, Qiao has worked with researchers from Egypt on two projects. For the most recent project, two graduate students from Damietta University in Egypt will be at SDSU during the upcoming academic year. A visiting scientist from the Weizmann Institute of Science fabricated a device from a new organic material through a project with the U.S.-Israel Binational Science Foundation.

Since 2013, Qiao has helped researchers from Ghulam Ishaq Khan Institute of Engineering Sciences and Technology in Pakistan learn basic techniques for developing dye-sensitized solar cells through a grant from the National Academy of Sciences. Scientists from Tianjin University of Technology, Anhui Agricultural University and Anhui Polytechnic University have done research at SDSU through support from the Chinese government.

In addition, visiting professors and students from Indian Institute of Technology Ropar and Indian Institute of Technology Delhi have performed joint research projects at SDSU with financial support from the Indian government.

"These projects, not only increase SDSU's international reputation but also help us recruit these top students," said Qiao, who is the coordinator of the electrical engineering graduate program.

Grantwinship Award Winners



Faculty members in the Jerome J. Lohr College of Engineering who secured or had research expenditures of \$100,000 or more during the 2016 fiscal year are—front row, from left, Cedric Neumann, Zhong Hu, Fereidoon Delfanian, Qiquan Qiao, Suzette Burckhard, Guanghui Hua and Chris Schmit; and back row, Chris Saunders, Sung Shin, Reinaldo Tonkoski, Ross Abraham, Rich Reid, Sharon Vestal, Nadim Wehbe, Greg Vavra and Dennis Helder. Not pictured are Stephen Gent and John Puetz.



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