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July 2007

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**DARPA Does Downtown — Page 12**

**TECHNOLOGY**

- 36** Advancing Hydraulic Hybrids
- 46** Retiring A Common Problem
- 54** The Next Stop In Electrification
- 58** Ultracapacitors Give Truckers A Jump Start

**INDUSTRY NEWS**

- 12** DARPA Does Downtown
- 32** A Smooth Ride Into 2007
- 50** Idle Threats For APUs?

**PRODUCTS**

- 4** Aiming A Bullet At The Work Truck Markets
- 6** Reducing Air Conditioning Overload
- 22** More Details On MaxxForce Big Bores
- 26** Driving Toward New Heights

- 30** Ashcroft Adds New Range Of Pressure Monitoring Options
- 44** Mack Aims To Clean Up With New TerraPro Series

**COLUMNS**

- 2** *Top Dead Center* — Robots Through Baghdad
- 10** *Trendlines* — The Ever-Changing Face Of Rental
- 66** *Emissions & Alternatives* — Cash Available For Clean Diesel Projects ... Hydrogen Buses For Orlando ... CWI Engines For China Buses
- 68** *Global Business Notes* — Deere Buys Chinese Tractor Manufacturer ... AGCO Buys Into Italian Harvester Co. ... Fiat And DaimlerChrysler In Truck Engine Deal

**dp BULLETINS**

- 9** Dateline
- 49** Product Information Center
- 60** Advertisers' Index
- 62** Marketplace
- 65** Diesel HR
- 65** Powerlines

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**TOP DEAD CENTER****Robots Through Baghdad**

Okay, I gotta come clean, I'm a real geek about some of this stuff.

That's actually a bad thing, because on page 11 of *How to Be a Journalist* we are told to be dispassionate, uninvolved observers of the world around us.

We're not supposed to be opinionated.

Oops.

Having said that, I will freely and honestly admit to members of the committee (sorry I've been watching too much C-SPAN); I will freely and honestly admit that there are some things going on out there that are just flat out cool and exciting.

In the pages that follow you'll find the first of our four-part series on Oshkosh Truck developing its TerraMax robotic vehicle for the DARPA Urban Challenge in November.

This is just cool stuff. Oshkosh and 53 other people are developing all shapes and sizes of vehicles that operate without any human interface. No joysticks, no telemetry, just flip on the computers and watch it drive away.

The first time DARPA issued the challenge to do this, most of the vehicles barely made it off the starting line. Twelve months later they were driving in and out of tunnels, careening around the desert and going up and down mountains like they've been doing it forever.

Now these robotic vehicles confront the ultimate nightmare — city driving.

It would be bad enough if they mocked up L.A. or Boston or N.Y.C., but while not saying so exactly, the DARPA Urban Challenge will involve driving through a mock Baghdad. Baghdad.

Again, there are no people involved. Via cameras and some other technologies I only kinda understand, TerraMax and the 20 or so other finalists will be turned loose on faux city streets, with traffic circles, intersections and who knows what else.

The trucks will have to figure out what to do at a four-way stop, with all kinds of other vehicles and maybe pedestrians either real or simulated. They have to merge into traffic. They have to make decisions about the vehicles around them. They have to perform logistics tasks.

All without a hand on the wheel or a foot on the pedals.

That just blows me away.

Engineers at Oshkosh Truck Corp. are letting us look over their shoulders as they develop TerraMax. And like engineers everywhere, they are casually cool about how they do everything. "Yeah, we take some input from cameras and LIDARs and chunk it through this software and then the truck turns or accelerates or stops."

Oh, that's all? Like that happens all over the place, every day?

Well actually at Oshkosh, and one would assume at the other DARPA competitors, it kinda does. One of the throwaway comments during our first interview was the fact that a huge truck driving around a parking lot in Oshkosh, Wis., without anybody driving was now pretty much a daily occurrence.

Wow.

When you think about vehicle engineering in a macro sense, this is just incredibly neat stuff. And we're only at the front end of the development curve.

How very, very cool.

Sorry, how unjournalistic of me. **dp**

Mike Osenga

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## DARPA DOES DOWNTOWN

Third autonomous vehicle challenge confronts the worst operating environment, city traffic; robots for Baghdad?

Team Oshkosh is developing its TerraMax truck for the third of DARPA's series of challenges. The team has taken a vision-based systems approach using a customized LIDAR (light detection and ranging) system combined with cameras and GPS/IMU navigation. The cameras can be seen at the front and sides of the grill, with the LIDARs at each end of the front bumper.

### TERRAMAX:



### TEAM OSHKOSH

**Editor's Note:** *The efforts of the U.S. Defense Advanced Research Projects Agency (DARPA) to develop robotic vehicles is one of the most fascinating mobile equipment design programs ever undertaken.*

*Oshkosh Truck is allowing Diesel Progress to "ride along" as it develops its TerraMax truck for the DARPA Urban Challenge in November, the third of the agency's "grand challenges." This is the first of three articles on the development of TerraMax, leading up to our coverage of the Urban Challenge itself in our December issue.*

**BY MIKE OSENGA**

The first time, no one went eight miles. The second time, only a year later, five unmanned vehicles drove nearly 132 miles through the desert, in and out of tunnels, over dry lake beds and down a nasty mountain pass.

When those five vehicles successfully completed the course, DARPA de-

clared that its challenge had been met.

Well, apparently not. Because now DARPA has decided to leave the desert and move the challenge into town.

The DARPA Grand Challenge is one of the most interesting and innovative vehicle technology and engineering programs ever mounted. DARPA — the U.S. government's Defense Advanced Research Projects Agency, the birthplace of the Internet, the stealth fighter and unmanned aerial drones, among others, develops advanced technology for military purposes.

It is an agency whose director once described it as, "where we take the technical, 'it can't be done,' excuse off the table."

Such is the goal of the DARPA's new Urban Challenge, to continue the development of unmanned, robotically operated vehicles, but this time adding the challenge of driving in city traffic.

Rarely do the technologies developed through DARPA's various pro-

grams remain the exclusive property of the military. Once unleashed, the technologies can end up in all sorts of applications both commercial and military. And so likely will the technology required to turn a normal vehicle into an autonomous robotic vehicle.

To quickly review, the U.S. National Defense Authorization Act of 2001 called for one-third of "operational ground combat vehicles" to be unmanned by 2015. Jump forward to Iraq and Afghanistan where a significant number of deaths and injuries are being incurred during convoy duties. The impetus to develop unmanned vehicles for convoy operation thus has become more than just an engineering exercise. There is an urgency that, in part, has spurred the expansion of this series of DARPA challenges. There is a compelling need to do this right.

These are definitely not remote-controlled cars and trucks. There's no telemetry or joysticks here. These are robotic vehicles that have to see the



**Team Oshkosh with the TerraMax truck being developed for the Urban Challenge. The TerraMax is based on Oshkosh's Medium Tactical Vehicle Replacement (MTVR) platform. Developed originally for use by the U.S. Marine Corps, the MTVR is designed to carry 15 tons on-highway and 7 tons off-road and is one of the military's baseline logistics vehicles.**

world around them, judge the operating environment, make decisions and complete the assigned missions, without any human input.

The 2001 mandate to create unmanned military vehicles led to the inaugural DARPA Grand Challenge in 2004 in the desert near Barstow, Calif. None of the 15 teams made it past the eight-mile marker, many not even half that distance.

Yet only a year later, at the second DARPA Grand Challenge in the Mojave Desert outside of Primm, Nev., five robotic vehicles out of 23 completed the 131.2 mile course. At the end of that event, DARPA's Director, Dr. Anthony Tether, declared that the challenge had been met.

Well, not yet. At least not completely.

"If you look at a supply route in Iraq, it usually runs from a base to a city, or between cities," said Chris Yakes, director advanced products for Oshkosh Truck Corp. "The first two Grand Challenges focused on that — off-road, point-to-point autonomous operation. And we proved that was possible.

"The DARPA Urban Challenge is based on a new mission. To complete

the mission now, convoys have to go into, or through a city. DARPA has identified a 60 mile supply route through Baghdad where TerraMax will have to deliver a payload and perform other tasks."

Since 2004, the challenge has grown from figuring out if robotic vehicles were even practical, to dodging tumbleweed and cactus, negotiating sandstorms and carefully picking their way down mountainsides. Now comes an even bigger challenge — city traffic.

The DARPA Urban Challenge will require the vehicles to maneuver in a mock city environment, execute simulated military supply missions while merging into moving traffic, navigating traffic circles, negotiating busy intersections and avoiding obstacles. In other words, following proper rules of the road.

Plus, while not obviously stated, if the mock urban environment DARPA will create is indeed an Iraqi city, the underlying assumption is that some of the traffic may not be friendly.

By successfully completing and finishing first in the 2005 Grand Challenge, the Stanford University entry, a diesel-powered Volkswagen

Touareg, nicknamed "Stanley," won a \$2 million first prize.

This time, DARPA has divided the entries into two "tracks." The 11 teams that have qualified as Track A participants (see accompanying list) will receive funding of up to \$1 million to develop their vehicles. The remaining 42 Track B teams are entirely self-supporting.

The field of 53 will be winnowed down to 30 teams that will move on to the National Qualification Event (NQE) in October. From there, the top 20 teams will advance to the finals to be held on Nov. 3. Both events will be held at locations that DARPA will identify only as being in the "Western U.S."

As with the other DARPA challenges, the site of the finals will be announced only a short time before the event, and the exact routes and missions to be performed will be known only hours before the start. DARPA is offering \$2 million for the fastest qualifying vehicle, \$1 million for second place, and \$500,000 for third.

Looking at Team Oshkosh's TerraMax development program for the DARPA challenges, the first assumption is that the Oshkosh, Wis., commercial and military vehicle manufacturer would design an integrated, purpose-built truck just for the DARPA challenges.

And in fact, many in the final field will build exactly those sorts of vehicles, some of which resemble souped-up ATVs or lunar landing modules more than anything commonly seen on- or off-highway.

Yet in the midst of all this exotic vehicle designing and engineering, Oshkosh has approached the DARPA challenges by developing add-on kits. Autonomous operation kits designed to be retrofitted on existing vehicles or built into new production trucks.

All this high-end engineering for an add-on kit?

"That's exactly what we proved in the second DARPA Grand Challenge and will be confirming in the Urban Challenge," said Yakes. "We're interested in



The second DARPA Grand Challenge in 2006, which TerraMax successfully completed, involved navigating nearly 132 miles of desert terrain including tunnels, dry lake beds and a mountain pass.

developing a kit design that can be installed into all our products, so we are able to sell it and provide autonomous functionality on our trucks.

“We might be at a little disadvantage with purpose-built vehicles, but we have long-term goals beyond winning the DARPA Urban Challenge, and that is developing and fielding a system for production. And we are really focused on that goal.”

“When you think about what we’re doing and what Oshkosh’s business and objectives are, a ground-up autonomous vehicle would certainly have been possible, and may even have offered an advantage or two,” said Oshkosh Truck’s Gary Schmiedel, vice president, Advanced Product Engineering. “But what relevance would it have had? We’re building tactical wheeled vehicles that move 5, 10 or 100 tons from point A to point B. If you want to have a broad application of the technology and a broad acceptance of the technology, we thought it was a better path to have it be suitable for existing vehicles in the fleets.”

In the months following TerraMax’s successful completion of the second DARPA Grand Challenge, Oshkosh Truck did exactly that. The company took the vision systems and controls from TerraMax and applied it to one of the company’s palletized load system (PLS) trucks that are designed to load and unload cargo without the need for other material handling equipment.

Oshkosh successfully demonstrated the use of the technology for the Army in Yuma, Ariz., in January 2006, about 60 days after the end of the second Grand Challenge.

“The Army saw we could put a system together within a period of weeks and get it operational,” Yakes said.

“At Yuma, we ran a 7 mile loop repeatedly, all day long, on an autonomous run and loaded and unloaded the PLS,” said John Beck, chief engineer, unmanned systems for advanced products and the project leader for Team Oshkosh. “We

demonstrated the vehicle could run autonomously and still do all its functions.”

Like the truck for the second DARPA Grand Challenge, the TerraMax being developed for the Urban Challenge is based on Oshkosh’s Medium Tactical Vehicle Replacement (MTVR) platform. Developed originally for use by the U.S. Marine Corps, the MTVR is designed to carry 15 tons on-highway and 7 tons off-road. It is one of the military’s baseline logistics vehicles.

Typically a 6x6 truck, for the Urban Challenge TerraMax is a 4x4, with rear steering, which shortens the wheelbase tremendously and provides better handling and maneuverability, an important change for driving in the city instead of the desert. In fact, Yakes said this TerraMax has a 21 ft. turning radius, 42 ft. curb-to-curb, about the same as a Ford Explorer.

The MTVR is powered by a 425 hp Caterpillar C12 ACERT diesel with an ADEM III electronic control module. Caterpillar is a Gold Sponsor of Team Oshkosh’s development of TerraMax.

The TerraMax has all-wheel drive with Oshkosh’s TAK-4 independent suspension and central tire inflation as standard. The transmission is an Allison HD407OP seven-speed automatic driving through an Oshkosh-built transfer case to Oshkosh axles.

Despite all the vehicle engineering, the DARPA challenges have always been a race to see who can compute the maximum amount of input from the operating environment the fastest and most efficiently. Then the challenge is to convert all that input and control a motor vehicle safely and successfully over whatever course and tasks it is required to do.

And now they have to do it in traffic.

A key feature in converting the input from the sensing package and computing power to physical truck operation is Oshkosh’s Command Zone drive-by-wire technology. The multiplexed Command Zone allows the computers to control, via CAN, the steering through a servomotor, as well as direct electronic control of the accelerator, brakes and transmission.

To see the environment and make TerraMax truly autonomous, the components that comprise Oshkosh’s kit include a “trioocular” vision system with cameras. One of Team Oshkosh’s partners on the project, VisLab from the University of Parma in Italy, is developing the multidirectional vehicle vision system.

A customized LIDAR (light detection and ranging) system developed by project partner IBEO Automobile Sensor GmbH is another key element of the autonomous system. The LIDAR system uses IBEO’s Alasca XT sensors.

GPS/IMU navigation is also integral, and another partner, Auburn University, is integrating the GPS/ IMU package and assisting with vehicle control.

Finally, all this is held together by high-performance algorithms supporting mission and path planning and high-level

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vehicle management provided by project partner Teledyne Scientific Co. (formerly Rockwell Scientific Co.)

Oshkosh Truck is responsible for hardware integration, modeling and simulation, drive-by-wire, waypoint following and overall design direction.

"We have taken a vision-based systems approach to TerraMax versus a sonar-type system," Yakes said. "Our primary approach is to use a vision system for obstacle detection and recognition, mostly because it's a more passive system. It's not emitting anything — we don't want to send these trucks out in a

military environment that produce all these signals that somebody can pick up to possibly disrupt the mission.

"We are using LIDARs in combination with the vision system, but going forward we see vision having more use in military applications and LIDAR in possible commercial uses."

"In an urban environment, the challenge is to be able to perceive the world around you entirely," Beck said, "so a lot of extra sensors have been added. In the first two challenges, we had one LIDAR looking out the front and one looking out the back. For the Urban

Challenge we're using three LIDARs, which gives us a 360° view, which are supported by numerous cameras.

"Before, we used three stereo pairs of cameras. Now, we have an additional close-range stereo pair in the front and rear. The rear and lateral view system allows TerraMax to detect obstacles at intersections, and obstacles or vehicles that either we're overtaking or are overtaking us in an adjacent lane. We're not dealing with rocks and bushes this time, we're interacting with other vehicles.

"TerraMax has to have very good perception of the world around it, so it can make decisions and try and predict the behaviors of other vehicles, as well as how to interact with those vehicles," Beck added. "Look at a stop sign intersection as an example.

"You know there is another stop sign and a lot of obstacles in front of you. The software becomes a lot more involved as the vehicle answers the questions. Are they moving? Do we need to pass them? Do we need to wait our turn? It's a lot different than going from waypoint to waypoint and deciding, 'oh that's a rock' and determining if you can go around or over it."

## Autonomous Ambulances?

While the DARPA Urban Challenge has as its goal the creation of autonomous vehicles for military use, Oshkosh Truck Corp. — besides being a major military vehicle manufacturer — also makes everything from ambulances to concrete trucks, as well as refuse vehicles, snowplows and fire-rescue trucks.

Through its efforts in the various DARPA challenges, Oshkosh is also seeing commercial possibilities for some of the technology being developed.

"Beyond the military applications, we have our sites set on some commercial applications for these sorts

of capabilities," said Joaquin Salas, defense marketing communications manager. "We're looking at the application of, if not the entire unmanned package, some elements of those technologies to make things safer, easier and more productive for our commercial customers."

As one example, Salas cited accident mitigation/accident avoidance for emergency vehicles. "Driving emergency vehicles is dangerous because they generally need to get somewhere quickly," he noted. "The technologies being developed through the DARPA programs can help emergency vehicles detect lanes, tell if the road is

blocked, if a driver is not paying attention, a lot of different things that are very usable outside of the military.

"In both military and emergency or crash/rescue vehicles there are times when you have information overload. There are a lot of things that are happening, a lot of things that have to be done. Flipping a switch, for example, and allowing the vehicle to drive itself autonomously, even for a brief period of time, can be very helpful.

"Plus, there are some operations such as runway snow plowing where complete autonomous operation could be extremely practical and productive." **dp**



Within 60 days of successfully completing the second DARPA Grand Challenge, Oshkosh Truck took the vision system and controls from TerraMax and applied it to one of the company's palletized load system (PLS) trucks. The company ran a PLS truck in a demo project for the military over a seven mile loop all day, loading and unloading the truck, all autonomously.



#### TRACK A DARPA URBAN CHALLENGE TEAMS

**Autonomous Solutions** — Young Ward, Utah

**California Institute of Technology** —  
Pasadena, Calif.

**Carnegie Mellon University** — Pittsburgh, Pa.

**Cornell University** — Ithaca, NY

**The Golem Group** — Santa Monica, Calif.

**Honeywell Aerospace Advanced Technology**  
— Minneapolis, Minn.

**Massachusetts Institute of Technology** —  
Cambridge, Mass.

**Oshkosh Truck Corp.** — Oshkosh, Wis.

**Raytheon** — Tucson, Ariz.

**Stanford University** — Palo Alto, Calif.

**Virginia Polytechnic Institute and  
State University** — Blacksburg, Va.

*DARPA has designated 11 teams as Track A participants in its Urban Challenge. All 11 will receive up to \$1 million in development funds from DARPA. There are 42 Track B teams that are entirely self-supporting.*

One of the fascinating parts of Team Oshkosh's development of TerraMax is that much of the hardware used is off-the-shelf technologies, admittedly knitted together with some very high-level software and algorithms.

"The computing power is commercial off-the-shelf, mainstream equipment," Beck said. "We're not using supercomputers or blade servers. We are using today's technologies. We're taking advantage of what's readily available, but we're not going to extremes."

"We're interested in a more robust design, less computational with less hardware requirements," Yakes said. "Because that is what ultimately will help us when we go into the field."

"We're actually putting more and more of the technology into our lower-level controls so that we can get away with less computing-type hardware on the higher end," Beck said. "The advances in the overall computer world allow us to capitalize and use high-resolution cameras for instance, because now we have the processing power to take that data and process it fast enough to be useable."

Oshkosh is developing the Urban Challenge TerraMax via a multistage release process similar to what the

company does in designing more normal vehicles. Beck said the process is constantly being developed and reviewed, moving from concept generation to prototype to verification/validation, and then to production.

"As we speak, six or seven months before the NQE, we're very much in the concept and prototype stage," Beck said. "We were at the verification/validation stage with the last challenge. Now we've taken a step back, and in some cases, started over, since we have new requirements for the Urban Challenge."

"When we get to the point this summer when we prove out the capability, we'll advance to the verification/validation stage, which is probably where we'll be at the end of the Urban Challenge."

"What the DARPA program brings to the table is a beautiful framework for development," Yakes said. "They have clear goals, they have clear milestones. Plus, there are stretch goals we wouldn't necessarily have picked for our own developments. It's definitely pushing us."

"We know what we have to do and when we have to do it. It's a competition, which is great because you get all the extra publicity related to that."

"But it does put a beautiful framework in place. It has customer involvement. DARPA, the military, gets to see how we perform. Plus, we can show off a little bit." **dp**

**NEXT: DARPA Comes To Oshkosh**

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**Team Oshkosh & TerraMax**

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**The DARPA Urban Challenge**

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