

**2014 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY  
SYMPOSIUM  
AUTONOMOUS GROUND SYSTEMS (AGS) TECHNICAL SESSION  
AUGUST 12-14, 2014 - NOVI, MICHIGAN**

**AMAS TECHNICAL DEMONSTRATIONS AND CAPABILITY  
ADVANCEMENT DEMONSTRATIONS**

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**ABSTRACT**

*This paper will describe the demonstrations that the Autonomous Mobility Appliqué System (AMAS) program has completed to date. First providing a high level technical overview of the system to understand how the system and its subsystems work. The paper will then describe the demonstrations and a summary of the results of the demonstrations.*

**INTRODUCTION**

The Autonomous Mobility Appliqué System (AMAS) is a complete set of hardware and software designed from the ground up to provide a low-cost, low-risk, modular kit-based solution to retrofit autonomy capabilities onto any vehicle in the fleet. With the use of these autonomy capabilities, vehicular accidents will be reduced if not eliminated, saving lives and reducing injuries, loss of materiel, and missed opportunity costs. Additionally, as the Warfighter is relieved of the continuous driving task at higher levels of autonomy, their expertise can be applied to other tasks.

The AMAS Joint Capability Technology Demonstration (JCTD) program will validate the vehicle-agnostic kit design by equipping tactical wheeled vehicle (TWV) platform types with the kits, and conducting two Technical Demonstrations (TDs) and an Operational Demonstration (OD) over the two-year duration of the JCTD program. The JCTD program serves as a risk-reduction activity for the Automated Convoy Operations (ACO) program of record (PoR). The United States (US) Army Tank Automotive Research, Development and Engineering Center (TARDEC) is the acquiring agency and technical manager for the JCTD. As a joint program, the end users will be Warfighters from the US Army and Marine Corps. Figure 1, illustrates the AMAS kit paradigm and the progression of the JCTD program.

As shown in Figure 1, the AMAS JCTD kit paradigm will develop By Wire Active Safety Kit (BWASK) and Autonomy Kit, and equip a number of tactical vehicles with the kits for modernization and equipping the fleet with autonomy capabilities. The JCTD program features two Technical Demonstration events with increasing capability,

as well as an Operational Demonstration in which Warfighters from the US Army and Marine Corps will operate the system. The AMAS will eventually encompass a number of add-on expansion and payload kits that enable the system to implement a variety of mission profiles.



**Figure 1: AMAS System Overview.**

The BWASK is composed of automotive commercial off the self (COTS) driver warning and driver assist devices, navigation sensors, control actuators, a control computer, data logging, and dashboard operator control interface (DOCI) devices. When installed on a vehicle, the BWASK permits control of all primary vehicle controls (steering, throttle, brake, transmission), provides feedback and control of platform components (e.g., readout of engine temperature, turn headlights on, etc.), and provides active and passive safety mechanisms to the driver to aid the driving task and increase safety.

The Autonomy Kit is composed of low cost perception sensors, a suite of computers for processing sensor data for implementing high level autonomy behaviors, data logging,

and a data radio for communicating with other assets. When installed on a vehicle in addition to the BWASK, the Kit transforms the vehicle into a robotic asset that is able to perform various mission profiles autonomously or semi-autonomously.

### **AMAS MODES**

The BWASK and Autonomy Kit functionalities were tested on the AMK23 Medium Tactical Vehicle Replacement (MTVR), M915A3, M1070A1 Heavy Equipment Transport (HET), RG31 MK5E Mine Resistant Ambush Protected (MRAP), M1084A1 Medium Tactile Vehicle (MTV), and M1075A1 Palletized Load Systems (PLS) vehicles. These functionalities were related to the four BWASK operational modes, Manual Driver, Driver Warning, Driver Assist, Tethered Remote Control, and four Autonomy Kit modes, Wireless Remote Control, Teleoperation, Waypoint and Leader / Follower.

#### ***BWASK Modes:***

**Manual Driver (MD) Mode** – The primary function is to record vehicle data with the AMAS system in a non-emissive and non-actuating state. During this mode, all emissive sensors are powered down and no Driver Warning or Driver Assist functionality is available to the operator except for Electronic Stability Control (ESC) that is inherent in vehicle actuation upgrades and is independent of mode. Note: ESC was not demonstrated TD1 or TD2.

**Driver Warning (DW) Mode** – This mode provides audible and visual warnings to the driver. The following functions are part of the Driver Warning Mode: Backup Warning, Cross Traffic Warning, Forward Collision Warning, Blind Spot Warning, Lane Departure Warning, Pedestrian Detection Warning, Slick Surface Warning, and Automatic Wiper Assist. Note: the Automatic Wiper Assist is the only Driver Warning Mode functionality which allows actuation (it actuates the windshield wipers).

**Driver Assist (DA) Mode** – This mode provides audible and visual warnings to the driver along with automated actuation commands to the vehicle to assist with vehicle control. The following functions are part of the Driver Assist Mode: Backup Assist, Cross Traffic Assist, Collision Mitigation Braking Assist, Lane Change Assist, Lane Keeping Assist, Adaptive Cruise Control Assist, Automatic Wiper Assist, Emergency Brake Assist, Hill Descent Assist, and Hill Hold Assist.

**Tethered Remote Control (TRC) Mode** – This mode provides manual control of vehicle ignition, steering, transmission, braking, and throttle with a COTS gamepad controller.

#### ***Autonomy Kit Modes:***

**Wireless Remote Control (WRC) Mode** – This mode provides the capability for personnel to use one AMAS system to remotely and wirelessly control the actuation of another AMAS vehicle. This mode does not provide video to the remote AMAS station, requiring the operator to have a line of sight to the vehicle in order to control the remote vehicle.

**Teleoperation (TO) Mode** – This mode provides the capability for personnel to use one AMAS system to remotely and wirelessly control the actuation of another AMAS vehicle. Teleoperation mode provides video to the remote AMAS station, allowing the operator to control the remote vehicle without a line of sight.

**Waypoint (WP) Mode** – This mode provides the capability for an AMAS vehicle to follow a path of pre-defined GPS waypoints.

**Leader / Follower (LF) Mode** – This mode provides the capability for an AMAS vehicle to lead other autonomous follower vehicles, and/or to become an autonomous follower behind another AMAS vehicle.

### **TECHNICAL DEMONSTRATION I**

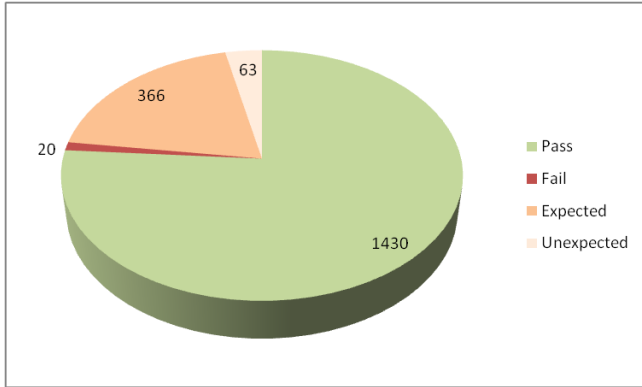
Overall the Technical Demonstration I (TD1) event was very successful. The ability to integrate a reliable actuation system on a variety of tactical vehicles was demonstrated; along with a number of COTS based driver warning and driver assist functions. The demonstrated ability to reliably control vehicle actuation and integrate COTS functions was shown to degree to confidently continue the JCTD through integration on additional platform variants, and the incorporation of an Autonomy Kit.

BWASK control of actuation appeared reliable on M915 and MTVR. The BWASK was designed for safety and one of the primary requirements was to maintain positive control of actuation during all modes. During TD1, the AMAS system successfully demonstrated actuation control safety and supported the continued integration of an Autonomy Kit for TD2. This will allow the continued analysis of similar actuation control over increasingly complex autonomous vehicle control functions.

This confidence in the ability to integrate COTS based functions supports further installations on additional platform variants, allowing further data capture and characterization of system functions.

It is important to consider that these DW and DA functions are intended to be an extension of the driver's ability to operate, providing potentially useful information or action to him. These functions are not intended to replace the driver's ability to manually operate a vehicle. Information from TD1

supports the ability for COTS based systems integrated onto tactical vehicles to provide information and action to a driver. However, instances exist where additional vehicle-specific calibrations could yield improved performance. This result is expected. Commercially, care is taken to tailor and calibrate driver assist functions like lane keeping and emergency braking to a specific vehicle model. Due to time availability of this JCTD, these COTS based systems are integrated onto different platforms in a more general sense, with varying platform-specific tailoring.



**Figure 2: TD1 Results.**

As depicted in the Figure 2, TD1 collected a total of 1879 data points. These decompose into 1450 pass/fail data points with a 98.6% pass rate, and 429 expected / unexpected characterization data points.

**TECHNICAL DEMONSTRATION II**

The objective of the Technical Demonstration II (TD2) was to demonstrate the technical feasibility and maturity of the integrated BWASK and Autonomy Kit technology on six vehicle variants, and identify the system’s current status, progress, and readiness in the development process.

TD2 is the second opportunity to formally observe the system in operation, for the purpose of evaluating AMAS system compliance with technical requirements. The test activities of TD2 were organized by TARDEC personnel, and carried out by Government participants. Lockheed Martin personnel served a supporting role during TD2, including organizing equipment transportation, providing contract drivers for the demonstration, troubleshooting hardware and software issues during TD2, giving safety and training briefs to TD2 participants, and fielding technical questions and feedback from observers.

The Savannah River Site (SRS) in South Carolina was chosen by TARDEC as the site for TD2, due to its extensive network of primary, secondary, and unimproved roads and trails. The road network is secure and the public does not

have access. This allowed the team to exercise the system without the need to block or close roads during TD2.

Each test vehicle was manned with a test crew consisting of a driver and a data collector as a minimum. In addition to the basic AMAS hardware as installed on the vehicle, an engineering laptop was utilized to monitor data during demonstration, and to record demonstration results in an electronic TD2 procedure. The engineering laptop was also utilized to tag data being recorded to the data logger for data reduction purposes.

A ground crew was also utilized to provide support including monitoring the demonstration runs for safety as well as test target setup and operation of privately owned vehicles (POVs). Two way radio communication was always present for communication between all test vehicles, ground crew, the POVs, and the command and control (C2) base.

As part of the test documentation process, an identical copy of the electronic TD2 procedure was assigned to each of the ten test vehicles and used for data collection throughout the demonstration. The TD2 procedure files for each vehicle was marked in real time with a pass, fail, not tested, data collector comments, and/or other data to record the result of each test run for that vehicle: space for up to 5 runs was given for each vehicle. In addition, if the test step required additional information, or changes were made to the procedure on-the-fly, data collectors generally captured the necessary information as comments. These comments provide data for a more accurate disposition of findings.

After each day of demonstration, the test results from each test computer was downloaded and archived. The results for each AMAS vehicle were then analyzed, and data collector errors were corrected by analyzing test taker comments, where available. In most cases this was done to change runs marked as “Failed” to “Pass” or “Not Tested” whenever supported by data collector comments. Next, procedural errors were corrected by changing “Failed” runs to “Not Tested” in cases where an issue with the test procedure caused functionality to be improperly tested, or corrupted the test results in some other way.

After the demonstration results were corrected for data collector and procedural errors, they were analyzed in relation to each AMAS functionality. To achieve this, each run of a subsection of the procedure was considered independently as follows: if a run contained a line marked “Fail”, the entire run was counted as a “Fail”; if a run contained a “Not Tested”, the entire run was counted as a “Not Tested”; if a run had data but no “Fail” or “Not Tested” results, the entire run was counted as a “Pass”. After categorizing each run in this manner, the run results were grouped and summarized by the functionality tested during that run, and then the summarized functionality results were traced to the AMAS specifications.

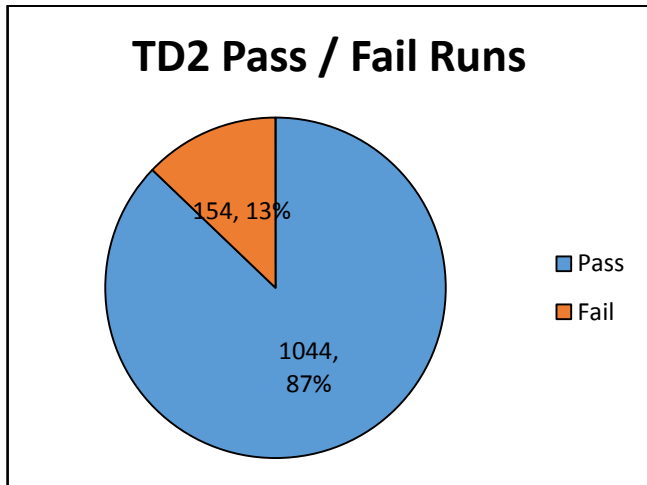
Note that, despite using the same test procedure, some differences between results are unavoidable. This is due to differences in the test course, daily environmental conditions, and even differences between one human data collector and the next. Care was taken to standardize the conditions for both tests as much as possible.

All representations of TD2 demonstration results are given using data that has already been corrected for data collector errors and procedural errors as described above.

intersections, encounter live traffic, obstacles and pedestrians throughout the demonstration.



**Figure 4:** CAD1 vehicle on Boaz MOUT Site.



**Figure 3:** TD2 Results.

After correcting for data collector and procedural errors, the final distribution of “Pass” and “Fail” results for the TD2 demonstration a high level roll up is given in Figure 3. The initial pass rate TD2 functionality is seen to be 87%. Additionally, more detailed analysis is currently being completed on the data.

**CAPABILITES ADVANCEMENT DEMONSTRATION I**

The purpose of the AMAS Capabilities Advancement Demonstration I (CAD1) was to demonstrate the capabilities requested in the III Corps Operational Needs Statement (ONS) (Memorandum for Commander, US Army Forces Command (AFOP-CS), Operational Needs Statement for Tactical Wheeled Vehicle Operator Assist and Leader Follower Capability Appliqué System, July 3, 2012) and to inform senior US Army Training and Doctrine Command (TRADOC) leadership of the current robotic capability.

The CAD1 was conducted at the Boaz Military Operations on Urban Terrain (MOUT) site in Fort Hood, TX. The site provided an operations building for the team in addition to roadways, obstacles, and structures for course operations, and facilitated the full range of testing of the CAD1 objectives. CAD1 vehicles had the opportunity to negotiate

Three vehicles were used during CAD1; one M915A3 and two 1075A1 PLSs. All three vehicles were equipped with AMAS JCTD technology and the AMAS CAD1 system was installed on the two PLSs. A High Mobility Multipurpose Wheeled Vehicle (HMMWV) was used for C2.

Eight Soldiers from the 3<sup>rd</sup> Calvary Regiment (CR), Fort Hood, participated in the CAD1. Two of the eight participating soldiers had over 6 years each of military experience and two operational deployments. The remaining six soldiers had an average of 13.5 months of military experience and no deployments. All soldiers were Motor Transport Operators.

The AMAS CAD1 completed over 84% of the objectives as derived from the III Corps ONS. The technology provided obstacle detection and obstacle avoidance (ODOA) capabilities, interval spacing control and dynamic speed and interval spacing in LF Mode. The TARDEC/LM team successfully demonstrated the use of unmanned PLS convoy leader vehicles along with PLS and M915 follower vehicles. Validated a fully autonomous convoy capability that can successfully operate in urban environments. While the aim of the AMAS JCTD is augmenting the safety and security of human drivers in a convoy mission, the CAD1 was able to completely remove the Soldier from the cab. The observers saw the CAD1 vehicles navigate various hazards, including passing parked vehicles, oncoming traffic, road intersections, pedestrians and more, in both rural and urban areas.

**CAPABILITES ADVANCEMENT DEMONSTRATION II**

The purpose of the AMAS Capabilities Advancement Demonstration II (CAD2) was to demonstrate a line haul mission with more vehicles at higher speeds than CAD1 with

additional autonomy. CAD2 took advantage of the same road network at SRS used for TD2.

Seven vehicles were used during CAD2; one AMK23 MTRV, two M915A3, one M1070A1 HET, one M1084A1 MTV and two M1075A1 PLSs vehicles. Only the MTV was equipped with the CAD software and hardware, the other six vehicles had the base JCTD system installed.

The AMAS CAD2 successfully demonstrated a seven vehicle robotic convoy performing a line haul mission at 40 mph; farther demonstrating capability objectives from the III Corps ONS.



**Figure 5:** CAD2 Convoy on Road B at SRS.

The CAD2 demonstration included an unmanned lead vehicle. To achieve this, an additional sensor, Velodyne 64, was installed on the lead vehicle. This allowed the lead vehicle to map the environment to a higher fidelity than the TD2 equipped vehicles.

The following vehicles were of the same configuration as the TD 2 configuration. The length of the convoy was originally slated to be 10 vehicles long. During testing, convoys of 9 following vehicles and 50 mph were recorded. However, problems with the radio communications between the vehicles limited the convoy to 7 vehicles. Each following vehicle had a ‘ghost’ driver to monitor system behavior.

On the day of the VIP demonstration, there were several runs demonstrated along the convoy route. During the first run, the lead vehicle was unmanned and the followers only had ‘ghost’ drivers. On subsequent runs, VIPs rode in each of the vehicles, which were all manned but operating autonomously. The VIPs were able to see first-hand the performance of the system and to ask questions of the engineer who was behind the steering wheel. During the VIP demonstration, there were no system overtakes with over 550 miles logged during the demonstration.

## OPERATIONAL DEMONSTRATION

The culmination event for the JCTD will be the Operational Demonstration (OD). The ten JCTD systems will be handed over to Soldiers and Marines for six week to perform their mission augmented by the AMAS capability. First the Warfighters will be trained on the systems capabilities, its operation and the PMCS of the system.

The convoy commander will receive their operational orders 24 hours in advance to prepare and plan their mission and the modes they will employ to accomplish their task. The event is being designed by the US Army CASCOM, independently evaluated by the Marine Corp DAT for the US CENTCOM to recommend if this technology improved the capability of the Warfighters.

## SUMMARY

The AMAS Technical Demonstrations has successfully proven that the technology is applicable to a wide variety of Tactical Wheeled Vehicles. Further, the Driver Warning and Driver Assist technologies can be adapted from the Commercial Automotive industry to improve the safety of operations for Warfighters

The Capabilities Advancement Demonstrations has demonstrated that the AMAS vehicles can be outfitted with a small number of advanced sensors to increase the range of performance of the systems. The CAD showed operations in urban environments with traffic, obstacles, pedestrians and intersections as well as the ability to remove drivers from the vehicles.

It remains for the Warfighters to determine when or where the system can best be utilized in real operations. What is clear is that the AMAS modes provide a range of operational capabilities that will increase the safety of the Warfighter, either through Driver Warning and Driver Assist all the way up to removing many drivers from the convoy.

## REFERENCES

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- [3] Memorandum for Commander, US Army Forces Command (AFOP-CS), Operational Needs Statement for Tactical Wheeled Vehicle Operator Assist and Leader Follower Capability Appliqué System, July 3, 2012

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