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ARMY ROBOTIC CONVOY APPLICATION OF COST EFFECTIVE & PROVEN AUTOMOTIVE ADVANCED SAFETY TECHNOLOGIES

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ABSTRACT

The Army has identified an operational need for a Robotic Convoy capability for its tactical vehicle fleets. The Department of Defense (DoD), with a fleet of over several hundred thousand tactical vehicles, must identify an approach with supporting technology and supply base to procure and support a Robotic Convoy solution at the lowest possible cost. While cost is a key driver, the selected system approach must be proven and robust to ensure the safety of our soldiers and the supply chain. An effective approach is to integrate and adapt the advanced automotive technologies, components and suppliers currently delivering advanced safety technologies into the automotive market. These advanced automotive technologies merged with DoD robotics enhancements in tactical behaviors, autonomous driving, command & control and unmanned systems collaboration will advance the operational utility of robotic convoy application in manned and unmanned modes.

Figure 1: Military Application

The cost effective integration of the automotive and defense technologies are key to fleet acquisition, integration, support and capability growth. MB-technology NA, LLC (MBtech) will bring its automotive-proven techniques and system integration experience in Electronic Stability Control, Rollover Mitigation, Lane Departure Warning, Lane Keeping Assist, Brake Assist, Occupant Protection Technology, Adaptive Cruise Control, Collision Mitigation, Occupant Protection Technology, Vehicle to Vehicle Communication (Vii) and Automated Highway Capabilities. For manned operation, in addition to the above capabilities, other MBtech capabilities which aid the driver include: Night Vision, Adaptive Headlight System and Distracted Driver Support.

SAIC will compliment the MBtech capabilities with the integration of advanced tactical behaviors, autonomous driving, integration of robotic communications into the tactical communication network, compatibility with the JAUS/AS-4 architectures and optional integration of unmanned systems collaboration both ground and air, field integration and support. The approach discussed in the paper by the MBtech/SAIC team will be based on proven technologies, affordable from an established

automotive supply base, proven awareness of military vehicle integration requirements & subsystems and an established field support capability built upon MRAP experiences.

OBJECTIVE

The MBtech/SAIC team leverages advanced engineering and cost effective automotive supply base knowledge. Additionally, Sac's 25+ years in advanced robotics starting as early as the DARPA Autonomous Land Vehicle program through recent DARPA robotics in the Combat Casual Reasoning and PERCEPTOR programs several years ago. MBtech active safety suite and Asics C2 integration, HRI and Unmanned Systems collaboration programs complete subsystem capabilities for Robotic Convoy and Active Safety into the military vehicle fleets.

Figure 2: MBtech Powertrain Development

ORGANIZATION BACKGROUNDS

MB-technology NA, LLC

MBtech is a large business global supplier of engineering services for the automotive and transportation market. They support the entire lifecycle of a vehicle from concept through final production for OEMs, and the major tier suppliers. The company has 2500 employees at locations in Europe, North America and Asia. MBtech is distinguished by the tightly meshed development and consulting services covering the entire automotive value chain. The MBtech brand combines all of its products and services into four segments:

I. Vehicle Engineering
II. Powertrain Solutions
III. Electronics Solutions
IV. Consulting

These provide flexible engineering resources for MBtech's customers worldwide. MBtech has many years of contract experience and the expertise to successfully deliver large, complex programs. Flexible, inter-disciplinary project teams work in close collaboration with customers, suppliers and

Figure 3: MBtech Systems Engineering & Development

cooperation partners for automotive and other industries including but not limited to defense, aerospace and commercial vehicles. MBtech supports manufacturers and suppliers beginning with the detailed specifications, design, modeling and testing to series maturity. MBtech combines these engineering competencies with tailored consulting services which enable customers to best utilize their technologies and innovations.

MBtech's world class facilities in North America locations includes Troy, Michigan, Birmingham, Alabama, the Proving Grounds in Laredo, Texas, and other locations across the United States. The Laredo Proving Ground is capable of accommodating various ranges of vehicle level testing and validation. The facilities are of sufficient size and capacity to allow for the emergency driving range, skid recovery range, and offensive driving techniques range to be operated concurrently without interference from each individual activity or any other group activity.

Figure 4: MBtech Proving Ground - Laredo, TX

SAIC

SAIC's ground robotics experience spanning over 25 years and 20 programs, including Autonomous Land Vehicle (the first DoD autonomous UGV) and PerceptOR (a landmark program for perception and navigation in complex environments).

SAIC conducted the Robotic Convoy Experiment (RCX) activity under the FCS program; this background experiment provides a set of relevant metrics to be used as a starting point for the MBtech/SAIC approach.

The RCX approach included phased experimentation with progressively maturing software to test "Remote Operations", "Leader/Follower", "Move-on-Route" capabilities.

Figure 5: SAIC 25+ year evolution path of Unmanned Ground Vehicle systems

SAIC DARPA Combat Causal Reasoning (CCR) program. SAIC's CCR perception ability provides human recognition and advanced vehicle controls supporting autonomous tactical behaviors.

C2ORE developed and tested HRI integrated Behavior Management Software (BMS) and live UAV/UGV assets. A common control interface, termed the SAIC Vehicle Interface (VI), was enhanced to deal more reliably with live assets. C2ORE had an explicit requirement to support a SOSCOE/SRW communications. C2ORE provided a flexible environment that could adapt to various communications infrastructures.

SAIC lead the UVSI MULE/ARV-A(L), SUGV, and ANS Integrated Product Teams (IPTs) for FCS and have deep working knowledge of the integrated software and hardware technologies (including interfaces to the Systems of Common Operating Environment) and their interoperability in collaborative environments with manned and unmanned systems. SAIC also designed, manages and maintains the UGV software interfaces to FCS distributed systems such as Battle Command System, Sensor Data Manager, and Warfighter Machine Interface.

DRIVER ASSISTANCE SAFETY SYSTEMS:

Convoy Technology - Adaptive Cruise Controls (ACC) Traditional Cruise Control operation is only used with unobstructed driving; that is, all vehicles in path are traveling at or above driver's set speed. Convoy Technology or Adaptive Cruise Control (ACC) allows for increased functionality. ACC follows the preceding vehicle at the defined following distance controlled by the driver. The driver engages system similar to traditional Cruise Control activation; however, the driver has the option to set the following distance. If vehicle path is obstructed, ACC requests brake and/or throttle intervention to slow vehicle and maintain the driver's selected following distance. Once vehicle path is unobstructed, ACC requests throttle intervention to increase vehicle speed until driver's set speed is achieved.

The customer benefits by using an increased operating range over standard cruise control, increased driver comfort by reducing fatigue traffic conditions, increased operating range will improve fuel economy. ACC can be used during normal highway cruising speeds, advanced system allow for usage in heavy stop and go traffic.

Figure 6: MBtech provides expertise in sensor selection and technology integration

Common use of forward-looking sensors by Driver Assistance Systems like Adaptive Cruise Control, and active safety systems such as Collision Mitigation System and Brake Assist drive sensor synergy. This results in a robust system while minimizing cost drivers.

Collision Mitigation System

CMS algorithm is designed to recognize a probable rear-end collision using information from the forward-looking sensors which activates a two-step process. Initially, an optical and/or acoustical collision warning is provided similar to the warning used in the Adaptive Cruise Control system. If driver fails to react accordingly, an autonomous partial braking is started as the next escalating step. Occupant Protection Technology measures are activated after partial braking has been initiated to better protect occupants. Partial braking enhances the driver's remaining time to avoid collision and reduces energy of possible accident.

Through system synergies, radar sensors enable autonomous vehicle reaction depending on traffic situation. Long and short range radar sensors measure distance to preceeding vehicle. Additionally, the systems can detect and classify pedestrians and have improved situation assessment capability.

The driver benefits from the audible warning which alerts the driver to a potentially critical situation and indicates the need for driver intervention to avoid the probable collision. Additionally, autonomous braking minimizes crash severity when there is no driver brake activation and the Occupant Protection Technology belt activation pre-secures occupants to prevent adverse motion during collision situations.

Advanced Brake Assist (ABA)

Advanced Brake Assist is a Collision Mitigation System (CMS) algorithm designed to recognize a probable rear-end collision using information from forward-looking sensors which activates a two-step process: initially an audible warning is activated and then limited autonomous braking. If the driver responds, additional brake pressure is applied to optimize and reduce the effect of the potential collision.

Again, the common use of forward-looking sensors by driver assistance systems and active safety drive system synergy.

Figure 7: MBtech HiL test center operation for control units and networks

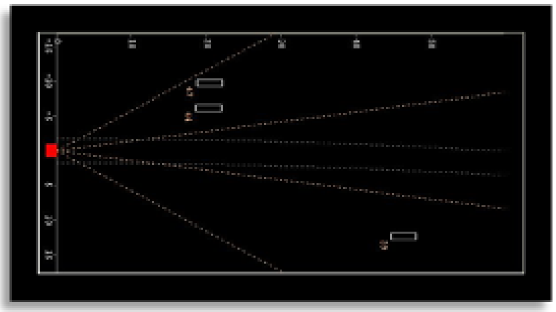

Figure 8: MBtech provides expertise in Driver Assistance System integration

The customer benefits through the audible warning alerts driver to critical situation and indicates the need for driver intervention to avoid the collision; the autonomous braking minimizes crash severity when there is no driver brake activation and stopping distance is additionally reduced once the driver initiates braking due to the BAS algorithm.

The system targets rear-end collisions scenarios such as approaching a sudden stop in the flow of traffic and when the preceding vehicle brakes suddenly.

Rollover Mitigation

The load and high center of gravity of military vehicles increases the overall risk of rollover events. Rollover Mitigation monitors the vehicle behavior through the sensors in the Electronic Stability Control system and intervenes when a roll over event is predicted. Rollover Mitigation stabilizes the vehicle by braking individual wheels and reduces the driving torque, the resultant is a reduction in the lateral forces generated at the road surface. This system is effective at preventing vehicle rollover events; it can keep all wheels on the road surface.

Blind Spot Warning

Blind Spot Warning systems warns the driver of a potential collision with vehicles in the blind spot of the vehicle during a lane change using short range radar or ultra sonic sensors. If a vehicle is detected in blind spot area the driver will be informed that a lane change maneuver cannot be completed safely. The driver can be informed via various warning strategies. For example, an optical warning and an audible warning indicating that a lane change maneuver is not warranted. The customer benefits from the blind spot system by offering an increased comfort and safety in lane change events. This system can be used in conjunction with Lane Keep System as explained below.

Lane Departure Warning System (LDWS)

LDWS is a system that warns the driver when the vehicle threatens to unintentionally leave the lane it's travelling in. When the driver uses the turn indicator, the system assumes that the lane change is intentional. In such a case, no warning occurs. LDWS is available in several versions: one that only provides an audible warning, and one that provides a brief haptic warning via steering or brake input and/or emits a warning vibration in the driver's seat. The driver can activate or deactivate the system in multiple ways through the steering controls or via the instrument cluster bank.

Depending on the system implemented, various baseline components are needed to support the LDW System. These components can include but are not limited to Electronic Stability Control Systems; Adaptive Cruise Control using long and short range radars, cameras, and/or Light Detection and Ranging (LIDAR) sensors; high speed electrical architecture; advanced Human Machine Interfaces using lamps, audible alerts, messages and buttons to interface with the system and relay information to the driver.

The customer benefits from the LDW system by gaining support in lateral vehicle guidance to increase comfort and safety. The target scenario for LDWS is unintentional lane departures.

Lane Keep System (LKS)

LKS is a system that supports the driver and intervenes when the vehicle threatens to unintentionally leave the lane it's travelling in. When the driver uses the turn indicator, the system assumes that the lane change is intentional. In such a case, no intervention occurs. LKS is available in several versions: it can provide a brief input or increased turning resistance via steering or brake input. The LKS system will also warning the driver as defined in the LDWS section noted above. The driver can activate or deactivate the system in multiple ways through the steering controls or via the instrument cluster bank.

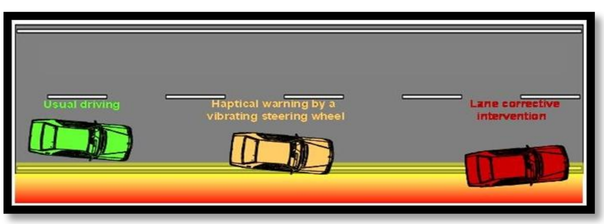

Figure 9: LDWS warns the driver if he unintentionally drifts out of his intended lane

Depending on the system implemented by the OEM, various baseline components are needed to support the Lane Keep System as noted in the LDWS section above. The customer benefits from the system in lateral vehicle guidance which increases comfort and safety. The target scenario is unintentional lane departures.

Occupant Protection Technology

Using inputs from the Collision Mitigation system, once an accident is determined eminent, the Occupant Protection Technology prepares occupants and the vehicle for the impact. In additional to the Collision Mitigation System, the system is able to trigger electric seat belt pretensioners for the passengers; autonomously closes windows and sunroof when an accident is likely (automatic- up feature required); move the seat position into a more favorable impact-ready position (power/memory seat required); and last, should the accident be avoided, the vehicle systems returns to normal driver control. The customer benefits from the overall reduction in occupant displacement and load in frontal impacts.

Advanced Headlight Systems

Using inputs from the forward looking vision sensor(s), the Advanced Headlight System feature automatically controls low/high beam transitions according to ambient light, weather and traffic conditions. Additionally, Advanced Headlight System can be used in to control the curvature of the beam. In a curve, the system will modify the trajectory of the beams to follow the curve for increased vision.

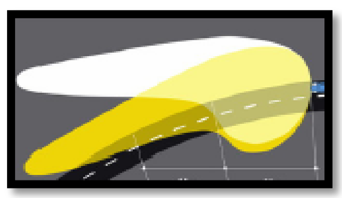

Figure 10: Headlights adjust with road curvature

MBtech PURCHASING & COST BENEFITS:

An optimized development model requires the rapid identification and sourcing of capable supply partners for any system and resultant vehicle. MBtech leverages its knowledge and experience with the world's best automotive suppliers to establish cost effective collaboration models. This drives efficient and cost effective sourcing processes resulting in technological advantages at a cost competitive price point. We consistently employ tested processes to ensure our technical and financial objectives are met. This is done by leading the core sourcing processes which include: builds and production RFQ and source selections; Establishing commodity strategies; Leading all core purchasing efforts which include - coordination of non disclosure agreements, RFQ, quote analysis, supplier technical capability analysis; and source selection for each subsystem; providing detailed purchasing reporting coordination, including development of weekly reporting statistics for key activities; Leading all supplier event coordination.

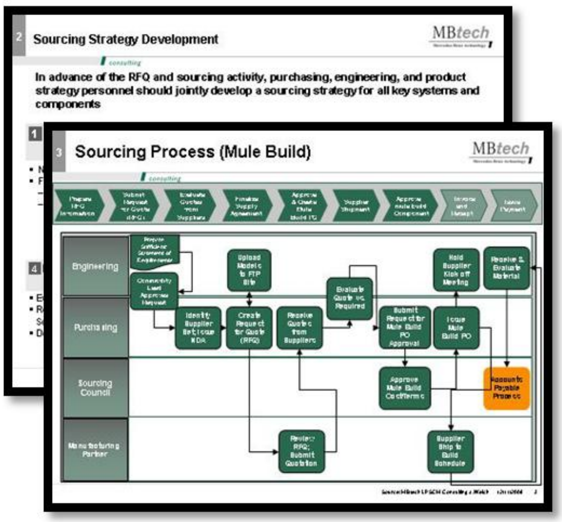

Figure 11: MBtech purchasing processes and strategies result in cost effective collaboration models

Common use and bundling strategies of forward-looking sensors by Driver Assistance Systems like Adaptive Cruise Control, and active safety systems such as Collision Mitigation System and Brake Assist drive sensor synergy. This results in a robust system while minimizing the cost drivers. Last, give the economic environment in the automotive arena, MBtech is a global leader in cost and waste management. Thus, each new system development task has equal goals of world class engineering and optimized cost structures. MBtech must exceed our end customers' expectations technically while delivering the system at a price point that is extremely competitive.

DRIVING ARCHITECTURES

Robotic Convoy requires the ability to provide safe autonomous robot navigation in dynamic urban environments containing objects and a mixture of other vehicles and pedestrians which includes detecting other moving vehicles in the environment, vision-based detection of lane geometry and lane marking types, and decision logic for safe rules-of-the-road driving (e.g., Interjection of non-convoy vehicles, intersection precedence and gap acceptance for lane changes and turns at intersections). The RC driving architecture must also detect and recognizes traffic signs through advanced machine learning algorithms. This will be a growth area for future RC improvements.

Driving architecture will provide the sensor interfaces for vision, radar, INS & GPS, it will be able to compute & predict dynamic obstacles, classify objects, localize the vehicle state including position, velocity and turn rate in the lane, detect roads of various forms and markings it will compute and direct routes driving behaviors and motion plans and provide the vehicle interface, user interface and health monitor. The DA will compute the drivable area including checking for blind spot clearance, understanding the depth of field of obstacles.

Safety of crew, equipment and non-combatants is a primary concern for robotic convoy and other active safety capabilities so automated safety responses are enhanced by SAIC's Combat Causal Reasoning (CCR) program, which includes technology for detecting people in the vicinity of a moving robot by LADAR.

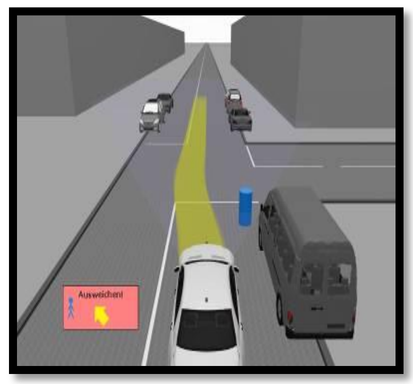

Figure 12: Situation awareness and path projection

CCR also addresses occluded humans and vehicles, traversable obstacles and also has the ability to distinguish warm vehicles.

CCR's ANS reasons about the underlying goals of human activities and selects and executes the appropriate behaviors. In order for an autonomous UMS to be truly effective in real-life tactical situations, the UMS must be capable of operating cooperatively with, or in proximity to, human beings, or human-occupied vehicles. In order to operate in this way the UMS must be able to recognize human activities in the context of root causes and select appropriate behaviors.

A platform-specific Vehicle Control Unit (VCU) system uses an SAE-AS4 JAUS interface handling messages such as Wrench and GPOS and modules including Primitive Driver, Global Pose Sensor, and Vehicle Speed Sensor.

HUMAN ROBOT INTERFACE (HRI)

HRI requirement for including:

1) share information with the common operating picture displays,
2) transition seamlessly between autonomous and operator-assisted mobility, and
3) assist driver/indirect driver in manned mode.

Current capability of the RCTA-developed HRI include:

1) RSTA data display,
2) teleoperation,
3) mapping and planning display,
4) multiple Unmanned Convoy vehicle control, and
5) reports and messages display.

Sensors for Robotic Convoy application must include 360 deg sensors for intermingling and merging of traffic. GPS/IMU are critical to the steering commands for convoy operation. An EO/IR camera will be most effective for sign detection/recognition.

The robotic convoy must have the ability to sense, detect and track primary and secondary roads. RC must understand and adapt to the Rules-of-the-road. LADAR and radar will map static terrain elevation/obstacle detection. The LADAR and radar must also detect and track moving vehicles and animals (2- and 4-legged) in vicinity of the robot.

Static and dynamic obstacle avoidance will be Context-dependent. Terrain analysis is required for off-road RC operation. Dynamic route replanning is required as the battlefield traffic or threat situations change.

C2 & NETWORK MANAGEMENT

Information Management and Networking (IMN) manages the network between the Human Robot Interface and Autonomous Driving Architecture, particularly if there are multiple vehicles or multiple

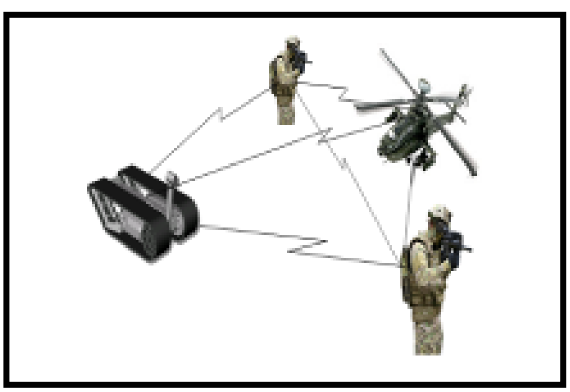

Figure 13: SAIC IMN & C2ORE provides efficient and collaborative network connections for unmanned systems.

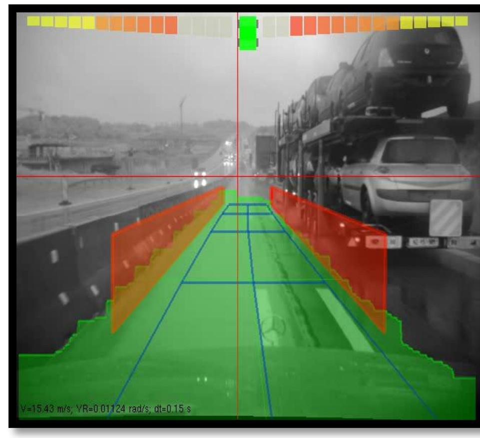

Figure 14: MBtech provides expertise in System Integration of Driver Assistance Systems

controllers, or when network nodes are near the edge of network connectivity. IMN prioritizes delivery of messages, reduces message sizes, reduces the number of non-data packets and manages the connection to SOSCOE, ensuring that command information gets to the robot and that important situational awareness is delivered to the HRI. IMN is transparent to the HRI application; it abstracts the physical radio connection to any IP radio.

IMN increase the effectiveness of tactical networks to ensure Warfighters get the information they need when they need it. Developed by NSRDEC and SAIC, IMN is government owned, and is specifically designed to address the issues of ad-hoc tactical wireless networks.

IMN transmits highly compressed images across the network as binary data, reducing transmission size; in support of interoperability, messages are converted back to the common JPEG format before the message is received by the application; Images can optionally be converted to grayscale or resized to fit the needs of the recipients and the network

IMN traffic shaping manages network traffic as the network load approaches and reaches saturation. Messages will be transmitted based upon the quality of service (QoS) and control mechanism.

IMN provides a tactical message filter that helps units gain SA of elements outside of their network and prevents a resource constrained network from being overwhelmed with all of the data available from the Tactical Operations Center (TOC).

IMN prevents congestion by using an advanced traffic shaping algorithm and prioritizes egress network traffic so that the important data get through before lower priority data; smoothes network flows to prevent bursts and network failures by queuing transmissions when needed; drops unnecessary messages before they enter the network and restricts low priority messages from consuming too much bandwidth.

GROWTH

Robotic Convoy and Active Safety Tecnologies can be enhanced by the addition of advanced techniques in various systemic approaches. Forward thinking and planning will need to consider the integration of Unmanned Aerial Vehicle (UAV) mission collaboration, auto park capabilities, human recognition and situation awareness techniques. The Robotic Convoy must have growth designed into its architecture and be based on open hardware and software standards to facilitate enhancement upgrades.

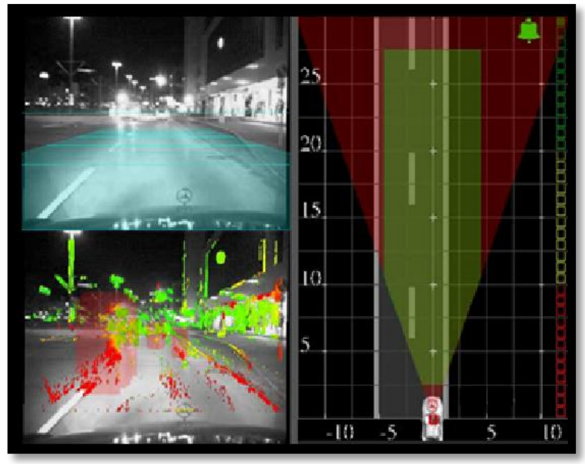

Figure 15: MBtech provides expertise in development and validation automotive technologies

CONCLUSION

Maximizing the use of COTS will enable the Army to produce, field and support Robotic Convoy and Active Safety technologies over the long-term. These technologies include Electronic Stability Control, Rollover Mitigation, Lane Departure Warning, Keeping Assist, Brake Assist, Occupant Protection Technology, Adaptive Cruise Control, Collision Mitigation, Occupant Protection Technology, Vehicle to Vehicle Communication (Vii) and Automated Highway Capabilities into the tactical and combat vehicle fleets. The MBtech/SAIC approach builds on the cost effectiveness of the automotive supply base while simultaneously assures the reliability of mass produced and widely tested automotive components and subsystems. The approach discussed here leverages advanced robotics techniques developed for DoD by SAIC while leveraging C2, HRI and safe operations projects ongoing at SAIC. The approach will also leverage MRAP field integration and support techniques and lessons learned throught the fielding of over 10,000 MRAP vehicles.

The Army has identified an operational need for a Robotic Convoy capability for its tactical vehicle fleets. The Department of Defense, must identify an approach with supporting technology and supply base to procure and support a Robotic Convoy solution at the lowest cost possible. While cost is a key driver, the selected system approach must be proven and robust. An effective approach is to integrate and adapt the advanced automotive technologies, components and suppliers currently delivering advanced safety technologies into the automotive market. These advanced automotive technologies merged with DoD robotics enhancements in tactical behaviors, autonomous driving, command & control and unmanned systems collaboration will advance the operational utility of robotic convoy application in manned and unmanned modes.

The cost effective integration of the automotive and defense technologies are key to fleet acquisition, integration, support and capability growth. MBtech will bring its automotive-proven techniques and system integration experience in Driver Assistant Systems, Vehicle to Vehicle Communication (Vii) and Automated Highway Capabilities. MBtech has the additional know-how to aid the driver: Night Vision, Adaptive Headlight System and Distracted Driver Support.

SAIC will compliment the MBtech capabilities with the integration of advanced tactical behaviors, autonomous driving, integration of robotic communications into the tactical communication network, compatibility with the JAUS/AS-4 architectures and optional integration of unmanned systems collaboration both ground and air, field integration and support.

The approach discussed in the paper by the MBtech/SAIC team will be based on proven technologies, affordable from an established automotive supply base, proven awareness of military vehicle integration requirements & subsystems and an established field support capability built upon MRAP experiences.

Our partnership is your success!

MBtech

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