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Moving Technology Forward by Putting Robots to Work on Military Installations: Autonomous Warrior Transport On-base (AWTO)

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ABSTRACT

The Autonomous Warrior Transport On-base (AWTO) pilot project is an Applied Robotics for Installations and Base Operations (ARIBO) project that addresses the real-world needs of the Warrior Transition Battalion at Fort Bragg. Soldiers in this battalion, some of whom have mobility difficulties, often require transportation assistance from the barracks to the Womack Army Medical Center. TARDEC and Robotic Research are utilizing robotic technology to provide an unmanned transport system equipped with a reservation/reminder system for these soldiers and caretakers. As a result, we are combining operational value and experimentation, creating a practical-to-tactical strategy that leverages existing autonomy R&D programs to build on increasingly complex operational scenarios.

1 INTRODUCTION

The purpose of this paper is provide an overview of the Applied Robotics for Installation and Base Operations (ARIBO) program concept and to detail one of the currently ongoing ARIBO pilot projects, Autonomous Warrior Transport On-base (AWTO). There are two active pilot projects: One at Ft. Bragg, NC (AWTO) where autonomy-enabled vehicles are set to begin autonomously transporting passengers in November 2016; the other is at the Stanford Linear Accelerator (SLAC) where a repurposed small robot will be used to monitor the accelerator tunnels for maintenance issues.

ARIBO continues to evolve as a living laboratory concept. We are working with POCs at our pilot sites as well as with other installations - namely Ft. Leonard Wood and West Point – to quantify the value of robotic systems in the installation-oriented application of autonomous technologies that are also being developed for warfighting application. We also continue to work with the Department of Transportation and a number of universities toward defining non-DOD funding projects based on the framework laid out under ARIBO. The goal is to produce “co-evolutionary” technical and social-behavioral value through a cycle of data collection, reliability analysis, and technical & behavioral improvement.

1.1 ARIBO strategic objectives:

1. *Socialize users and non-users with automated systems*
2. *Identify operational issues and help with development of mitigation strategies to increase use of automated systems*
3. *Generate empirical data (e.g. performance, reliability, maintenance, etc.)*

1.2 High-Level Focus Areas and Applications

It is widely acknowledged that technology can improve the efficiency and safety of vehicles on roadways. Both technical and operational refinement are needed to fully understand the most advantageous and cost-effective applications that will accelerate the widespread adoption of autonomy-enabled systems [1]. In an effort to understand how both users and non-users interact with autonomous vehicles, the ARIBO AWTO is investigating a personal mobility use case in a campus-like setting which involves free-flowing traffic, intersections, parking lots, pedestrians, and bicyclists.

The technical issues being explored and refined include: system reliability, efficiency, and safety; vehicle-to-vehicle and vehicle-to-infrastructure (V2X) communications; data security; human-machine interfaces (HMI); and vehicle obstacle avoidance, navigation, mapping, and fault tolerance. Operational and acceptance data are expected to inform decisions involving policy & infrastructure modifications. Understanding of these issues and the factors that affect them will also reduce the cost of future development of automated systems as environments and behaviors become more accommodating over time.

1.3 Potential for impact

In the ARIBO AWTO pilot project users interact with the technology(ies) on a regular basis as they go about their daily routines. They are afforded the opportunity to identify areas for improvement and suggest new uses through in-person and online feedback tools while they become more comfortable with the technology. Throughout this agile feedback loop, valuable data are collected documenting operational, maintenance, and reliability factors which, in turn, improve the veracity of the business case and help target future system improvements and other use cases or applications. Users come to understand the technology, its capabilities, its potential and developers come to understand the real uses and required tweaks to the systems, the real costs, and the real benefits.

The Army manages over 66,000 non-tactical vehicles (NTVs) at a cost of over $400M per year. Over 15,000 of these are passenger vehicles (low-speed electric vehicles (LSEV) and sub-compact through mid-size vehicles). The Army also manages over 2,200 buses [2]. There are many use cases across the various vehicle types including pool vehicles signed out for daily use which represent savings opportunities through on-demand systems. One shared automated vehicle has the potential to replace 4-6 personally-owned vehicles [3]. While we do not think this reduction would apply to all of the Army's NTVs, the potential is great and data produced from this project will help refine this estimate and identify the best areas for potential savings.

2 Autonomous Warrior Transport On-base (AWTO)

The ARIBO AWTO project is different from typical technology demonstration projects where vehicles are built to requirements, demonstrated a handful of times, and then mothballed. The AWTO research project is intended to build knowledge around how automated vehicles perform in real-world environments and understand more about how they impact the real-world system. AWTO is addressing the real-world needs of the Warrior Transition Battalion (WTB) at Fort Bragg. The soldiers in this battalion, some of whom have mobility difficulties, often require transportation assistance from the barracks to the Womack Army Medical Center (WAMC). Prototype automated vehicles are deployed to transport soldiers from the WTB barracks to the WAMC in order to improve and learn more about the reliability of the automated system and understand the impact of automated vehicles on operations and the transportation system.

TARDEC and Robotic Research are utilizing robotic technology to provide an unmanned transport system and reservation/reminder system for these soldiers and caretakers. Soldier, caretakers, researchers, etc.; referred to as either participants or users request on-demand transport via their personal mobile phone, or public kiosk. In turn, the reservation system will send reminders of transportation appointments through application notifications and SMS. The latter is particularly important for AWTO, because some passengers may be affected with traumatic brain injuries, which can affect memory recall. Discussed in detail later in this paper, AWTO uses a multi-phase approach to gradually build trust and establish safety and reliability metrics for the system.

2.1 AWTO System Technology

The AWTO system is comprised of prototype robotic platforms, reservation and scheduling tools, users, and the environment. The platforms and res/schd tools will evolve as the project advances through several development and operational phases. These anticipated evolutionary enhancements such as interface layouts, maximum vehicle speed, and additional sensors; will result from years of phased testing and experimentation. Prior to and synchronously, improvements are developed and integrated to improve the base autonomy system performance and reliability based on day-to-day operational use and wear and tear. Results from experimentation may point to necessary environmental changes for allowing the system to function as intended (e.g. signage aiding the robotic platform's ability to negotiate intersections). Uncontrolled intersections present one of the most challenging situations for autonomous vehicles due to uncontrollable factors in the environment, namely non-users such as pedestrians and human-operated vehicles.

Selecting a Platform

The AWTO Robotic Platform is a modified Cushman Shuttle6 electric golf car. This platform was chosen for a variety of reasons but most importantly cost and the ability to procure them using the GSA schedule. All modifications made were designed to minimize changes to manual operation; therefore, it drives almost identically to electric golf cars used throughout the county. There are two current models; Figure 2a shows the base model, and Figure 2b shows the wheelchair accessible model. Participants will have the ability to request which model is needed for their transport.

(a)

(b)

Figure 2: (a) Base AWTO platform, and (b) wheelchair accessible version

AWTO Autonomy Applique

The Autonomy Applique includes all of the hardware and software necessary to run the Shuttle 6 platform in autonomous (unmanned) mode. The applique has two main components: the By-wire Kit (B-Kit), and the Autonomy Kit (A-Kit). The B-Kit hardware and software provide drive-by-wire and emergency stop safety (E-Stop) system. The drive-by-wire includes the actuators and software to control steering, throttle, and brakes. The A-Kit contains the perception sensors and computational hardware that runs the high level software providing the 'intelligence' for the robotic vehicle, including sensing, obstacle detection, prediction, and planning. All of the modifications that would impact manual operations reside within the B-Kit**.**

Shuttle6 User Interfaces

During the development of the AWTO autonomous Shuttles, specific user interfaces were developed allowing riders to physically interact with the vehicle. These developed interfaces increase safety while onboard the vehicle as well as during ingress and egress. These interfaces include the E-Stop buttons, vehicle pause/resume buttons, and the vehicle audio system.

The E-Stop system is designed as a fail-safe mechanism that once engaged guarantees the vehicle comes to a stop and will not move when in Robot Control mode (Figure 3). The safety operator E-Stop button is located on the front seat riser between where the operator and potential passenger might sit. This button is accessible to the operator while he/she is wearing a seatbelt. There are also four additional E-stop buttons that are located on the four corners of the vehicle allowing users the capability to stop the vehicle in case of an emergency when the vehicle does not have a safety operator onboard.

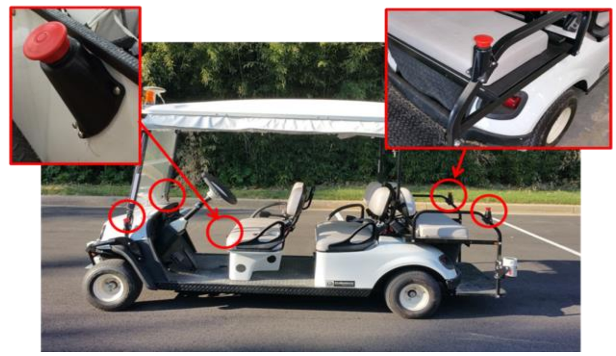


Figure 3. E-Stop system locations for safety operator and riders.

Five pause/resume buttons were installed throughout the vehicle (Figure 4), two at each end of the first two passenger rows and a single button at the rear center. Before disembarking, the vehicle will request that a passenger pushes the resume button before they disembark. This same button can be used to pause the vehicle, which will slowly bring the vehicle to a stop. To support safety, a speech-based feedback system is integrated with the E-Stop and pause/resume buttons.

Figure 4. Pause/Resume buttons are located throughout the vehicle

A female voice instructs riders when the vehicle is E-Stopped or Paused, as well as instructs riders when it is safe to get off or board the vehicle. When the vehicle is ready to resume autonomous movement, it first tells the user if there are any obstructions (object on front left, object to the right). Once the obstruction is clear, it tells the user to push the resume button. Knowing what the vehicle is doing will help riders respond in appropriate ways (e.g., boarding or disembarking the vehicle at appropriate times) and assist in the user trust calibration process [4].

Shuttle6 Operator Interfaces

During developmental testing and in the beginning phases of experimentation, a safety operator will be onboard the vehicle. To aid the safety operator, there is a tablet-based operator control unit (OCU) located onboard the vehicle. The OCU was designed to provide diagnostic information (Figure 5) about the status of the vehicle and feedback about the current and planned behaviors of the vehicle.

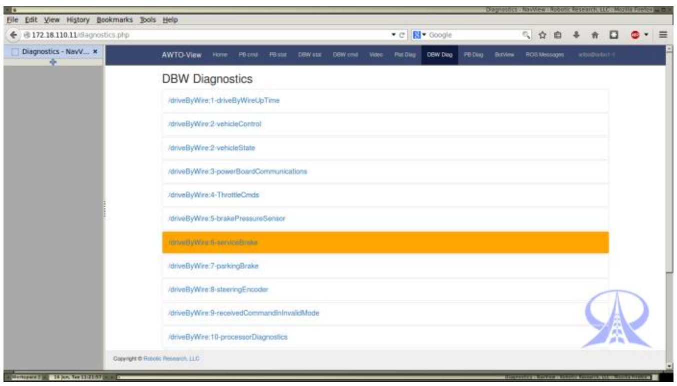


Figure 5. Diagnostic display example

The OCU also displays the vehicle's status display (Figure 6 & 7). Since this information is not always needed by the safety operator, it can be minimized when not in use. This provides the safety operator the ability to focus more attention on the status display allowing for appropriate information filtering [5]. Due to the large amount of available diagnostic information only trained personnel may drive the vehicle as a safety operator.

The vehicle status display provides an overhead satellite map that marks the location and direction of the vehicle [7], [6]. Figure 6 depicts this map, marking the vehicle location, route network, planned trajectory, and vehicle status.

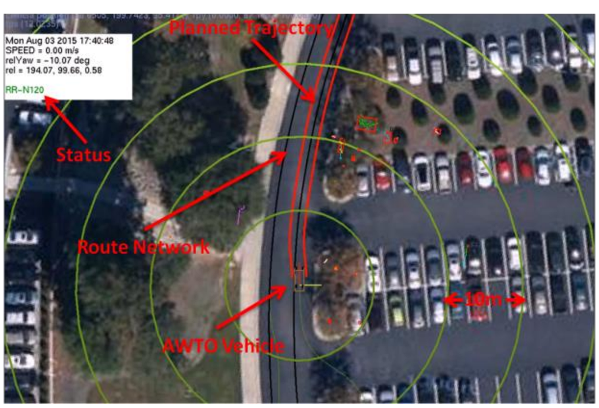


Figure 6. Vehicle status display example

The vehicle has two modes: Human Mode and Robot Mode. The mode is selected using a momentary toggle switch. A pull-to-unlock toggle lever prevents accidental switching of modes and LED lamps indicate when the system is under "Human" or "Robot" control. An LED also indicates when the E-Stop is engaged and the A/B-kit is powered. In Figure 6, the vehicle was driven in Human Mode to this point and has just been set to Robot Mode. Since the vehicle is still paused, the planned trajectory is shown in red, meaning the vehicle has a valid route, but is commanded to stop. The future trajectory of the vehicle is marked by the left and right boundaries of the vehicle footprint. This is useful to determine if the vehicle will have enough room to maneuver past an obstacle. In addition, the status box (upper left of the figure) includes the Inertial-Based navigation unit (RR-N120) status line to indicate when the navigation unit has calibrated itself and is ready to run. It is colored in green when ready and red when not. In the future, additional key component readiness status will be included in the status box. The display also provides a planned path, and icons marking planned robot behaviors, such as stop locations, as well as areas of risk or potential obstacles (Figure. 7).

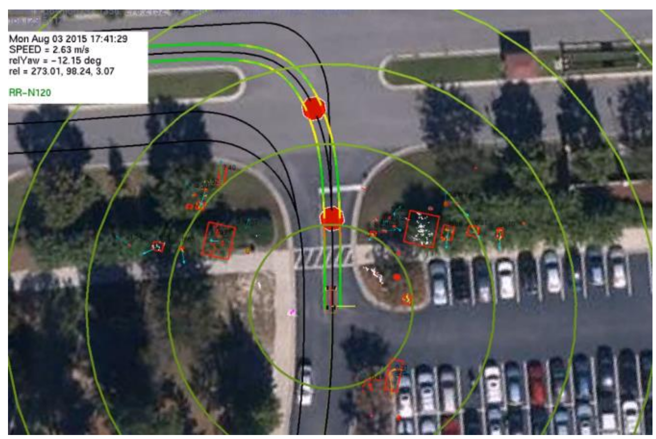


Figure 7. On the vehicle status display, the location where the vehicle stops are marked by the Stop Sign shapes (red octagons). The locations of the stop signs are where the Rear Axle of the vehicle still stop. In addition the red squares identify potential obstacles identified by the sensor system.

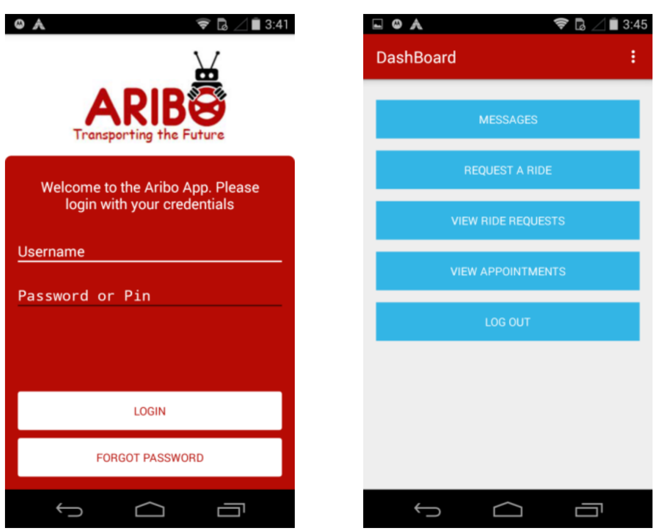
Reservation and Scheduling System

The design and development of the rider Reservation and Reminder Application was a combined effort between Robotic Research and University of Texas at Arlington Research Institute (UTARI). The reservation component of the application was designed around three main components: as-needed, reservation-based, and optimized ride-sharing transportation services. The reminder system was designed to send mobile application notifications, emails, or SMS messages to the rider to remind them of their appointment. The purpose of the reminders is twofold: to reduce missed medical appointments and minimize vehicle idle time during high-demand periods.

Specific customizations were made to accommodate riders' needs. In order to make this system available to the maximum number of potential riders, an Android application was developed. The application was designed to run on both mobile platforms as well as a publically available secure kiosk (Figure 8). The 3-in-1 kiosk allows for maximum flexibility for site installation and is ADA compliant to accommodate wheel chair users.

Figure 8. The application is designed to run on both mobile platforms as well as a publically available kiosk.

The initial application design took into account some user interface design guidelines to address potential challenges. The first challenge was scalability issues between developing a display for use on a mobile device and a larger tablet interface. The second challenge was to develop an application that can be easily used by individuals with a range of technological acuity or skill, and mental and physical capabilities due to injury (see Figure 9).



(a) (b)

Figure 9. Login screen to the reservation application on the Android device (a) and main menu of the application (b).

A key consideration in the design of this user interface was to reduce stress and cognitive load in order to maximize acceptance and ease-of-use of the system for a wide range of users. In order to reduce cognitive load, similar items were placed in close spatial proximity taking into account symmetry, unity, and cohesion of items [5], [8]. Design also included traditional windows-type interaction [9] in order to link the new application to similar, known systems. The number of items per page, spacing between items, and reduction of "dead space" or non-functioning buttons [6] were considerations in the design of the system since people perceive aesthetic and functional designs as easier to use [9].

2.2 Phased Approach to Deployment

ARIBO/ATWO's phased approach plans for incrementally increasing automated technologies over time, building trust and acceptance while ensuring safety and reliability. From phase to phase this approach encourages system adjustments and policy refinement by identifying operational shortcomings. Examples would be augmenting or adding signage to aid the system or integrating a new sensor. Furthermore this approach maximizes system runtime while allowing for technical improvements and facilitates subsequent phase Test Procedures and Scenario Development.

The AWTO Program consists of three evaluation phases preceded by an initial development phase. Each of the phases and their associated risk analysis have been identified and associated mitigation plans continually evolve. Each phase caries forward the risks of the previous phase in addition to new ones identified with increasing automation.

In the first phase, the test-vehicles (herein referred to as the Shuttle) are controlled by human operators. Passengers can familiarize themselves with the system and mobile applications while data and statistics are collected on the vehicle for evaluation. The follow-on phases will gradually introduce more and more autonomous capabilities until the human operator is removed completely. By establishing baseline practical capabilities early on in a real-world environment, the Army can clearly measure the cost-benefit of transitioning to fully-autonomous vehicles and begin assessing potential impact for other on-base applications. Lessons learned and component improvements may also transition to more complex tactical environments.

This technical evaluation will be continually monitored by the AWTO engineering team. Shuttles have been operated by engineers from the development team in the actual operating environment since August 2015, continually tuning the technology to the conditions. The Shuttle will be remotely monitored in real time at the duty desk at WTB for the duration of the Program. Because distances involved in this Program are short (about 1/2 mile) the Shuttle will never be more than about 200 meters from either WTB or WAMC so humans can respond quickly in the event of an emergency.

Phase I

Phase I is the chauffeured phase where a trained human driver operates the Shuttle while passengers are aboard. Because the use of OEM components on the Shuttle control systems was maximized, there is essentially no difference between driving this Shuttle and a GSA-purchased electric golf car. Sensors and the autonomy system run in the background collecting data (but not controlling the Shuttle with a passenger aboard). Data from the driver and the robot is compared and - after engineers and leadership are confident in the performance - the Program moves to Phase II.

Phase II

Phase II, the driver becomes a safety operator. The robot is now controlling the Shuttle and the safety operator is ready to take control in the event of an emergency.

Phase III

Phase III removes the human safety operator; the shuttle is operating completely autonomously. Phase III will not occur until leadership is confident that the data collected shows the Shuttle to be safe and reliable.

2.3 Evaluating the System

As stated in the introduction, ARIBO/AWTO has three strategic objectives. The first objective is to *Socialize users and non-users* with the AWTO system encouraging “trust and confidence” in autonomous technology. The second is to *identify operational issues and develop mitigation strategies* in order to offset technical risk through operational system enhancements and policy adjustments. The final strategic objective is to *generate empirical data* (e.g. performance, reliability, maintenance, etc.), specifically for maintenance, reliability, operational and user effectiveness, and modeling and simulation for business case analysis.

In conjunction with Robotic Research and TARDEC, Nexus EMC developed an Evaluation Plan to quantify the performance of this groundbreaking technology and novel approach to system testing and acceptance. Executing the Evaluation Plan will quantify progress toward these strategic objectives.

Evaluation Plan

The Evaluation Plan will evaluate automated vehicle technologies and document their performance and capabilities. The plan provides the framework to define and capture system performance measures, contains detailed site and vehicle characterizations, and outlines user needs though discussion and surveys. Site characterization includes detailed route classification and is essential in understanding the operational environment. Characterizing attributes such as site population, traffic patterns, road attributes, and extreme temperatures and weather conditions as well as characterizing vehicle information such as specifications, performance, and capabilities are also documented. The plan describes the operational parameters based on the system components and outlines the evaluations necessary to determine system performance during each phase. Ideally, this will allow the rapid duplication of ARIBO/AWTO at other locations or in other use cases with similar attributes.

Performance Measures

Well-defined performance measures based on thorough understanding of the system technologies and their application are critical to ensure the system is optimally executing intended functions. The following performance measure are captured in the evaluation plan.

Baseline Performance and Safety Measures (Phase I/II) - The measurement of safety performance requires a look at not only the baseline (pre Phase I) safeguards and features, but also a look at the improvements made at the end of each phase based on operational analysis. Measurements of safety related impacts to users and equipment should provide feedback mechanisms facilitating user acceptance.

Socialization and Acceptance Performance Measures (Phase I/II/III) - Rate of which our Reservation Application and vehicles are used and other related measures provide quantitative means to assess how well the system is accepted and ultimately used. Increasing user awareness and training them to use the system increases familiarization and helps to manage expectations. The system as designed provides mechanisms for feedback to assist in continued engagement of the users.

Operational and Effectiveness Performance Measures (Phase II/III) - Comparing the use of AWTO transportation options to existing manned options will provide the basis for measuring operational and effectiveness performance. Examining how well the AWTO system performs in comparison to today’s technologies will highlight the benefits of the system and provide context for the cost of expanded applications. Continued refinement of these performance measures through Phases II and III.

Sustainment Performance Measures (Phase II/III) - System costs are most significant after fielding a newly developed capability. Operational, maintenance and sustainment costs will be collected and critically analyzed during Phases II and III. These measures will reflect actual costs and time for equipment, repair, and software updates as well as down time and mission capable status. Additionally, we will capture costs associated with personnel recruitment, training, and certification.

2.4 Shuttle Operations Data Collection

To evaluate performance characteristics of the Shuttles, data will be collected driving the route in both human and robot mode. The evaluation will initially operate with two Shuttles operated in human mode (i.e. operated by drivers with autonomy running in the background). This is "Phase I." Depending on passenger demand, shuttles may alternate duty cycles, that is to say, one Shuttle may be assigned to operate autonomously (robot) with a human safety operator and no passengers. The other Shuttle will be driven by a human and operated as a typical shuttle with passengers. Data will be captured by both Shuttles while operational. During Phase I, passengers will only ride on the human driven Shuttle. During Phases II and III, after data is collected and analyzed and confidence in the autonomous capabilities is gained, passengers will ride in the robot-driven Shuttle.

During Phase I, if passenger demand allows, the duty cycle will be as follows:

- Alternate each day which Shuttle leads and follows. For the entire day, the same Shuttle will either lead or follow. Alternate the order of the Shuttle daily. For example, the Shuttle which led on Monday will follow on Tuesday.
- Alternate for each route which Shuttle is controlled by the robot or human. For example during the first route run, the lead Shuttle will be driven by a human and the follow- Shuttle will be driven by the robot. During the second route-run, the lead Shuttle will be driven by the robot and the follow- Shuttle will be driven by the human.
- For the duration of the study, one Shuttle will operate in robot-mode and one with a driver. During later phases, participants will ride on both Shuttles.
- Continue to drive the route throughout the day even if there are no participants to pick-up or drop off.

This approach captures a lot of data quickly. Assuming that the route loop can be driven by both Shuttles 14 times per day (with and without users) 5 days per week, 140 route loops will be driven weekly: 70 human and 70 robot. Over a fifteen (15) week period, data for approximately 2,000 routes loops will be collected: 1,000 human driven and 1,000 robot driven. This data will provide the foundation for evaluating the performance of the Shuttle's autonomous capability. Additional data collection will be needed to improve confidence in the Shuttle's performance capability.

Table 1 below illustrates the minimal number of recommended route loops to capture:

Phase	Loops / Week	Weeks	Total Loops
Phase 1	140	15	2,100
Phase 2 & 3	140	40	5,600
Phase 2 & 3 Optimal	140	80	11,200

Table 1: Evaluation Loops by Phase

Reliability Data

During operations logbooks will be kept to collect reliability-related data. This data includes the amount of time shuttles are taken out of service for repair or maintenance, the reason they are taken out of service, and the amount of time a shuttle is out of service.

Route Zones

The shuttle will transport participants over a roughly one-mile, round-trip route. The full test route has been divided into five (5) *route zones.* Route zones divide and subdivide the route between WTB and WAMC into discreet sections that allow events to captured and analyzed in a manner that allows data to be generalized to similar environments such as navigating an intersection or operation in a parking area.

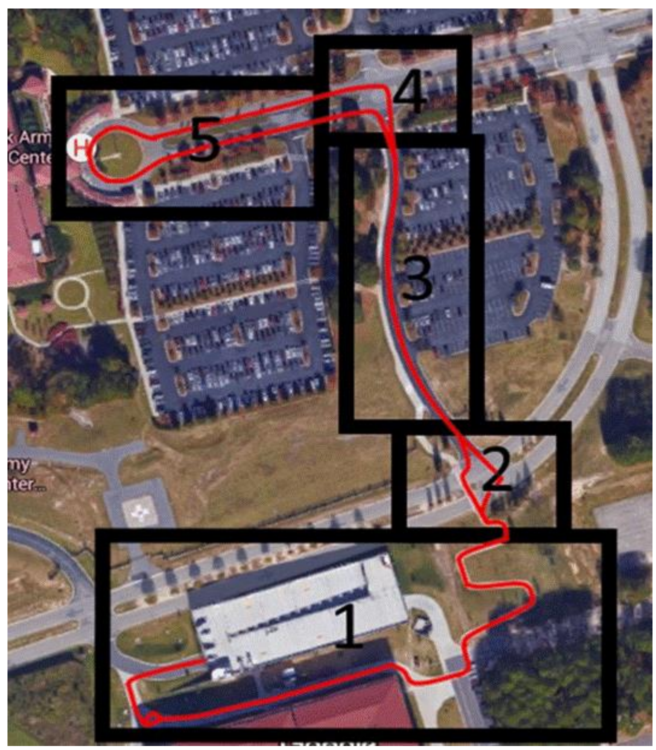


Figure 10: Shuttle Total Route and 5 sub Zones

Route Segments

Each of the route zones are further sub-divided into route segments that focus on a series targeted operational conditions. Each route segment has specific metrics which can be evaluated.

Route Metrics

A route metric is a defined scenario to flag for comparison. For example, data will be captured that assesses the Shuttle response to pedestrians crossing the street in its planned path. Where possible, route metrics have been identified that can be captured in multiple route segments. This will strengthen the overall performance analysis by increasing the sample size of specific situations, with a variety of influential variables. These variables can then be evaluated to determine shuttle performance in the presence of those variables and compare it to driver (human) performance. For highly complex situations, we will re-run real data sets in simulation while changing certain variables such as distance to pedestrians. This allows larger ranges of data to be run and analyzed more frequently, leading to a greater overall number of test cases.

2.5 User Evaluation Data Collection

It is important to capture data from drivers and riders (users) in tandem with shuttle operations data to ensure accurate interpretation of the holistic data-sets. Ride-related data will be collected through surveys that are completed after each route. This information will be used to better describe route-specific circumstances and help interpret performance results. Additionally, survey data will inform technology acceptance and comfort level changes over the period of performance. For example, participants may initially dislike riding on the Shuttle; however, as their comfort level increases, they may prefer it over the, traditionally-driven shuttle. In this case, participants may miss more appointments initially until their comfort level reaches a threshold. With this knowledge in hand, expectations can be adjusted to define and account for the initial 'acceptance' period. The technology, interface, or processes can be modified to improve the acceptance and comfort of users through a range of options (e.g. a modified drive cycle).

It will also be important to capture self-reported data from drivers and safety operators (DSO) to evaluate the system from their perspective as a user group. For example, some safety operators may be more likely to take control of the Shuttle in situations even if intervention is not needed [4]. As their confidence in the robot driver increases, they may become less likely to intervene.

Capturing subjective data from the onset is vital in defining the boundaries for various levels of acceptance at various points throughout the project. Understanding user evaluations and identifying levels of acceptance will provide additional context for the objective data collected through the vehicle sensors and autonomy kit. Without this initial subjective information and being able to tie it to shuttle operations data, it will be more difficult to interpret and normalize the results.

Drivers' User Survey: After most routes, the driver answers predefined questions (with appropriate space for comments) about the route. The survey is completed for both Shuttles regardless of the driving mode (human and robot).

Riders' User Survey: Riders are asked to answer a survey about the ride during phase 1 with more probing questions in Phase II (robot mode). This will be important to document rider expectations. For example, is it acceptable if the human and robot perform the same or is more expected of one than the other? Is it expected that the robot will drive more conservatively? Will riders' expect the robot to drive better than the human? What does "better" mean to users? And what levels of robot performance are needed to meet the same comfort level as a Driver-operated shuttle? Separate user evaluations will include questions that assess the impact of the reservation and scheduling tool.

2.6 Human to Robot Comparison

AWTO is leveraging technology being developed by another Pilot Project, ARIBO Black Box Recorder (ABBR). The ARIBO Black Box Recorder system provides a comprehensive suite, hardware and software, for studying the safety of an autonomous system. The system is designed for comparing two autonomous systems, or for comparing a human driver to an autonomous system using a comprehensive set of autonomous event detections that exploit our knowledge of AWTO autonomous mobility software.

The ABBR data recorders log the human driver's input (acceleration, steering, paths) and the robotic controller data (sensor data, obstacle detections, planned paths). This data is used by a safety reviewer to compare human performance with the likely performance of the robot. Multiple interfaces exists allowing the safety reviewer to change what is being recorded and when. Recording all data at full rate not only quickly fills the removable disks, but also saves large amounts of data that is unhelpful in assessing the safety of the robotic system. Using the software suite, the safety operator will be able to specify lower rates for various conditions. A queue structure allows logging full rate data before, during, and after certain trigger events (such as if the human driver pushed a "record" button, or the various automatic triggers). The safety reviewer can use software wizards to select and adjust the automatic triggers. These wizards are widgets that allow the safety reviewer to set up the conditions under which the automatic event detection will happen. The automatic triggers are simple, and can be computed in real time, such as geolocation and differences in speed. Other triggers are more complicated, and would be run on recorded data to help the safety reviewer eliminate false anomalies. ABBR provides an interface on or off the shuttle allowing the human driver to enter trip reports. It also allows cataloging results over many runs.

ABBR is critical for evaluating the performance for the autonomous shuttle to the human driver. By utilizing the ABBR on real-time and collected data, driving patterns and scenarios will be analyzed enabling the comparison of human to robot driving modalities.

Data examples:

- Distance to stationary objects: average, median, maximum, minimum distance the vehicle comes to stationary objects such as cars in the WAMC circle.

- Pedestrian Reaction: average, median, maximum, minimum distance at which the vehicle initiates a response.

- Intersection Entrance: average, median, maximum, minimum distance and estimated time to intersect of oncoming traffic that the Shuttle enters the intersection.

- Critical Path Selection: Does the Shuttle enter a designated clear area if an obstacle in the distance will force it to stop in an un-safe location such as while crossing a road?

- Frequency and circumstances when a human took control of a vehicle that was in robot mode. Account for driver comfort level.

- Additional parameters will be identified during Phase I. As data accumulates, patterns will emerge that will warrant deeper investigation of performance variance.

2.7 Where We are Today

The design and initial implementation phase was completed in August 2015 with on-site adjustments through April 2016. In preparation for Phase I evaluations, system characterization tests have been conducted at Fort Bragg, which have provided many insights into various challenges regarding the deployment of a long-term pilot project. These challenges include the Human-Robot interface, cost-benefit tradeoffs, sensor processing, data analysis, and autonomous fleet command/control and management.

An IRB exemption was granted in February, 2016 giving the final go-ahead to begin Phase I operations. Under Phase I, shuttle operations commenced enabling riders to use the service. In May 2016 AWTO began Phase I which is currently ongoing. Riders are completing surveys linked through the reservation app that contain questions related to the riders' perceptions of vehicle trustworthiness and acceptability of the autonomy-enabled capabilities of the vehicle. There are also questions specific to the design of the vehicle that will increase comfort usability of the system. The three AWTO phases of operation will be conducted from May, 2016 until December, 2017.

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