TCAR Report

JACKSONVILLE TRANSPORTATION AUTHORITY

APPENDIX E

Vehicle/Operating System Requirements

ULTIMATE URBAN CIRCULATOR

1 VEHICLE REQUIREMENTS

Autonomous Vehicle (AV) technology is an emerging technology that is rapidly evolving. The AV y suppliers typically utilize smaller (when compared to the existing JTA Skyway vehicles), minibus style vehicles or pods with capacities ranging from 4-24 passengers; which, include a driverless operating system. In order to develop the vehicle design criteria, which would be used to procure the new AV technology vehicles, several design parameters must be defined. Those include:

- Capacity – Number of passengers each vehicle can carry
- Fleet size: Number of vehicles required to offer the expected level of service.
- Speed –Maximum speed at which vehicles will travel.
- Dimensions – Size of the vehicle considering existing infrastructure constraints and the various classes of AV's available in the industry.
- Maximum Grades – Considering existing Skyway guideway structure and planned future extensions as well as impacts to vehicle performance; i.e. how does a significant grade impact the battery performance and battery life?
- Safety Compliance – Safety requirements/standards that will be specified.
- Cyber Security
- Certification Requirement – Safety Certification process.
- Service Life – The expected service life of the AV Technology vehicles, and their components.
- Operating Range/Battery Charge –
    - The autonomy of a vehicle with a charged battery, i.e. How long can the vehicle operate on a single charge?
    - Battery charging infrastructure: charging stations, online charging, replacement batteries and charge individually, etc.
- Local Environmental Impact.:
    - Jacksonville's hot and humid environment will have an impact on passenger comfort and will impact the vehicle HVAC requirements and the performance impacts on the battery use and life.
    - Jacksonville's significant rain and wind events (hurricanes, tropical storms, etc) can affect the vehicle operating performance (traction, grade) and may impact the vehicle positioning, communications, and sensing (GPS, LIDAR, etc.) and therefore passenger safety

1.1 Capacity

For the U2C project, the Jacksonville Transportation Authority (JTA) plans to move forward based on the following 3 phases:

Near Term – In approximately 5 to 7 years, replace the existing Skyway with Autonomous Vehicle (AV) technology utilizing the existing guideway structure modified to accommodate AV Technology vehicles. Also includes the planned extension to Brooklyn.

Mid Term – In approximately 7 to 10 years, complete remaining planned extensions including potential river crossing with transitions to grade with dedicated lanes for AV. See Figure 1.1 depicting the existing alignment and planned extensions.

Long Term – In 10+ years, as AV technologies mature, open up the dedicated right of ways to allow mixed traffic at-grade with other AVs that are able to operate on the JTA AV communications infrastructure as well as incorporate more on demand based service to the system as artificial intelligence progresses..

Figure 1.1 – Skyway Map with Potential Extensions

For the initial phases, the plan would be to match the current operational capacity of the existing Skyway which typically operates two defined routes. The A-Route operates trains at 6-minute headways from the Convention Centre station to the Rosa Park station during peak hours of operation. The A-Route also serves Jefferson, Central and Hemming Park Stations. The D-Route operates trains at 6-minute headways, from Rosa Park Station to Kings Avenue, serving also Hemming Park, Central, San Marco and River Place Stations. Based on the capacity of the Skyway trains of 56 passengers per 2-car train, the system capacity is calculated to be approximately 560 passengers per hour per direction (pphpd) for each route and a total system capacity of 1,120 pphpd.

For the AV technology vehicles, the per car capacity ranges between 4 to 24 passengers. Refer to Table 1.1, which was developed based on data collected as part of an AV Industry Forum hosted by the JTA on May 23, 2017, and a Request for Information (RFI) sent out to the industry in early 2017. Based on a recent study/analysis that the JTA performed, the average speed of 14 MPH, and the 20 second station dwells, are utilized to derive system capacity.

Starting with the larger 24 passenger cars and using an average speed of 14 MPH and 20 second dwell times, approximately 12 vehicles operating at 3-minute headways (1.5-minute headways in the common section) between Rosa Parks and Central stations) are required to match the existing capacity of 1,120 pphpd.

For the smallest AV of 4 passengers per car, approximately 68 cars operating at 30 second headways and 20 second dwells are required. The feasibility of such scenario would have to be assessed further.

For the mid-size vehicles of 12-15 passengers per car, approximately 24 cars operating at 1.5-minute headways and 20 second dwells are required. When calculating fleet size, consideration must be given to battery life, autonomy, recharge time. and associated vehicle spares. The required fleet would be possibly 25-50% or more, greater than what is defined above as these are simply the number of vehicles required to match the capacity of the existing Skyway operation.

Vehicle Comparisons

Characteristics	Existing System	Autonomous Vehicle						
	Bombardier	Navya	2getthere	EasyMile		LocalMotors	RDM Group	Waymo
	UMIII VAL 2-Car Op	NAVYA ARMA DL4	GRT	EZ10, 1st Gen.	EZ10, 2nd Gen.	Olli	Pod-Zero (4-Seater)	Chrysler Pacifica Hybrid
Length (ft)	48	15.6	19.7	12.9	13.2	12.86	8.9	17
Width (ft)	7.0	6.9	6.9	6.6	6.6	6.73	4.6	6.7
Height (ft)	9.0	8.7	9.2	9.1	9.4*	8.2	6.6	5.8
Wheel base length (ft)	2.83	9.3	12.1	9.2	9.2	8.29	N/A	10.1
Ground Clearance (ft)	-	0.66	0.54	0.55	0.56	N/A	N/A	0.425
Floor height (ft)	4.2 (includes beam)	0.76	1.35	1.2	1.2	N/A	N/A	N/A
Unloaded Weight AW0 (lb/car)	26,100	5,291	7,720	4,400	4,695	3,300	1,323	6,300
Crush load Weight AW3 (lbs/car)	39,540	7,716	14,660	6,614	8,885	5,500	N/A	N/A
Charging Time	-	8 hr (90%, induction) / 4 hr (90%, plug)	10 min (30%→80% charge, induction)	5 hr	6 hr	4.5 hr	< 3 hr	N/A
Battery Charge Life	N/A	9 hr	30 min	14 hr	N/A	N/A	4-6 hr	N/A
Door Openings	One	One	Both	One	One	One	Both	One
Passenger Capacity	56 (2-car)	15	24	12	12	12	4	7
Maximum Speed (mph)	35	30	25	25	12	25	15	115**
Maximum Percent Grade (%)	8	12	10	15	8	N/A	N/A	N/A
Turning Radius (ft)	100	<14.75	25	16.5	16.4	N/A	N/A	N/A

Updated: 9/19/2017
Draft: For Planning Purpose Only.
Data retrieved from respective vehicle's website or literature unless otherwise specified.

Table 1.1 – Autonomous Vehicle Comparison

1.2 Speed

Table 1.1 was generated based on data collected from the Industry Forum and RFI responses noted above. Based on this data, the speeds of the AV cars ranged from 12 to 30 MPH as compared to the existing skyway monorail maximum speed of 35 MPH. The existing guideway structure includes some civil speed constraints through curves and at areas where vehicles would crossover from one lane to another. As mentioned above the average speed throughout the system considering acceleration, deceleration, civil speed constraints and distance between stations was calculated to be approximately 14 MPH which most AV technologies can meet.

1.3 Dimensions

The size of the AV technology vehicles is considerably smaller than that of the Skyway monorail 2-car consist. However, what is important as it relates to operating on the existing infrastructure, is the single car length, width and height as these dictate how it will fit on the guideway and navigate through curves and crossover locations. Another important consideration is the vehicle floor height as the existing monorail guide beam is planned to be removed. The AV technology vehicles will need to have an elevated running surface at stations to match the vehicle floor height with the existing station platform elevation. This is particularly important when considering ADA compliance requirements. The floor heights of the various AV cars range from 0.76 feet to 1.35 feet. Since the JTA is considering the possibility of having multiple AV suppliers operating on the U2C system, the design criteria for the vehicles will have to set the standard for vehicle floor height as measured from the running surface elevation to mitigate any potential issues with the station platforms, passenger access, etc. and insure compatibility and intra-operability between AV technologies.

1.4 Maximum Grade

The maximum grade on the skyway is 8% over the Acosta Bridge. All AV technology vehicles operate on battery power. Maintaining constant speed up a grade with a fully loaded vehicle will require increased power consumption which in turn impacts the time between battery charging. In addition, vehicle controls must support safe operation and braking on ascending and descending grades.

1.5 Safety Compliance

The U2C must comply with safety requirements established by the authorities having jurisdiction, i.e. NHTSA, FDOT and the City of Jacksonville. A discussion on safety Certification is included as an appendix. A summary of such discussion is included in section 1.5 to 1.7 of this report.

The National Highway Traffic Safety Administration (NHTSA) is responsible for establishing, maintaining and enforcing vehicle safety standards. The Federal Motor Vehicle Safety Standards (FMVSS) cover three aspects: crash avoidance, crashworthiness, and post-crash survivability. Miscellaneous standards are numbered above 500.

There are presently no complete set of safety standards specific to autonomous vehicles. The NHTSA has issued a voluntary guidance on automated driving systems in 2016 and an update in 2017.

1.5.1 Safety standards

There are a few safety standards applicable to autonomous vehicles. Based on a review by AV manufacturers, even some of the existing FMVSS standards will be required to be amended to be applicable to AVs. Below is a discussion of some of the existing or forthcoming safety standards.

ISO 26262- *Road Vehicles Functional Safety standard*, focuses on the functional safety of electrical and electronic (E/E) systems in vehicles. The scope is for series production passenger cars with maximum gross weight up to 3500 kg. Functional safety in accordance with ISO 26262 affects all systems containing electrical, electronic, or electromechanical components, i.e. systems from the fields of actuator and sensor technology as well as control electronics. Industrial systems are covered by IEC 61508, with additional specific standards applying to railroads, aircraft etc. ISO 26262 is the sector specific extension of IEC 61508 for the automotive industry.

ISO 26262 is not a certification standard and therefore contains no clauses regulating certifications or the scope thereof.

The NHTSA recently issued a notice of proposed rulemaking (NPRM) to establish a new Federal Motor Vehicle Safety Standard (FMVSS), No. 150, mandating vehicle-to-vehicle (V2V) communications for new light vehicles and to standardize the message and format of V2V transmissions. The proposed standard was issued for public comments in early 2017 and the comment period was closed in April 2017.

1.6 Cybersecurity

A group of international industry experts have come together to form the SAE International's cyber standards development committee. The aim of the committee has been to prioritize cybersecurity concerns and aggressively address these. After examining international research data, including government and industry collaboration, and privately funded industry consortia, the world's first Automotive Recommended Practice, SAE J3061 has been produced.

J3061™ recommends that a cybersecurity process be applied for all automotive systems that are responsible for functions that are ASIL (Automotive Safety Integrity Level) rated per ISO 26262, or that are responsible for functions associated with:

- Propulsion
- Braking
- Steering
- Security
- Safety

J3061™ also recommends that a cybersecurity process be applied for automotive systems that handle Personally Identifiable Information (PII).

1.7 Certification Requirement

House Bill H.R. 3388, also cited as the “Safely Ensuring Lives Future Deployment and Research In Vehicle Evolution (SELF DRIVE) Act”, was adopted on September 6, 2017. Based on review by legal scholars, the SELF DRIVE Act was passed out-of-concern for the patchwork of state laws that could hinder innovation but appears to leave a safety gap until NHTSA adopts a rule on safety assessments. The bill directs NHTSA to issue a final rule within two years that “requires the submission of safety assessment certifications regarding how safety is being addressed by each entity developing a highly automated vehicle or an automated driving system.” In the interim two years, the bill requires auto manufacturers to submit a safety assessment letter as contemplated by any NHTSA guidance in effect. However, the current 2017 NHTSA guidance does not appear to require such a certification letter.

1.8 Service Life

Although the AV Technology vehicles are significantly less costly than replacement of the Skyway monorail cars, consideration must be given to the AV technology’s design service life. Current APM specifications require a vehicle design service life of 25 years. Many APM vehicles have met and even exceeded these requirements through the years. AV technology vehicle suppliers appear to state that they can achieve a service life of up to 10 years before replacement.

1.8.1 Vehicle Cost

It is unknown at this time what an AV technology vehicle, that meets all the vehicle design criteria would cost. The JTAis currently testing several vehicles at the AV test track. The expected cost of Autonomous vehicles range from $250,000 to $1,000,000.However, it is likely that currently produced vehicles will not meet all of the U2C design requirements, and this may result in higher cost for each vehicle.

The per vehicle cost for an APM vehicle similar to the existing skyway vehicles is in the range of $2.5M to $3M.

1.9 Operating Range / Battery Charge

A key consideration for vehicle design criteria must include the battery range and charge time. This not only impacts system operation but also the size of the fleet required to support the 15-hours per day operation (6:00AM – 9:00PM). AV suppliers state that they can operate in a range from 6 to 14 hours per day before requiring a full recharge. This range varies widely depending on several factors including vehicle size, weight, speed, guideway grades, HVAC, onboard lighting, communications, etc. Battery recharge time is another key consideration for design criteria development. The average battery recharge time from fully discharged to fully charged is in the range of 3 to 8 hours. It should be noted that the battery technology and associated discharge and recharge time and processes are constantly evolving and improving. Consideration must also be given to the battery design service life for AV technology. Replacement of the batteries over the design service life of a vehicle can become a significant cost to the Owner and must be considered as part of the life cycle cost of a vehicle.

1.10 **Local Environmental Impacts**

Jacksonville's maritime climate requires unique environmental considerations for the AV vehicles. The temperatures can range from sub freezing to over 100° F with humidity levels reaching 100% during the summer months. As passenger comfort is a key consideration, the AV vehicle must be able to maintain a comfortable environment. The HVAC system will be a drain on the vehicle battery and could impact the battery life and re-charge times. This must be taken into consideration.

In addition to the temperature and humidity, Jacksonville can experience periods of heavy wind and rains especially with tropical storms and hurricanes. The AV vehicles will be required to safely maintain communication (GPS, LIDAR, etc.) and operation (traction, traction on grade, etc.) during these periods.

2 **OPERATING SYSTEM REQUIREMENTS**

In order to replace the existing Skyway with a fully functional and integrated Autonomous Vehicle (AV) technology system, multiple subsystems would be required as part of the overall system architecture. These subsystems include:

- Autonomous Vehicles
- Supervisory Control System
- Communications
- Power Distribution/Charging Stations

2.1 **Autonomous Vehicles**

Based on the information gathered from the JTA Industry Forum and the RFI, the vehicles are typically outfitted with a series of cameras, lenses, and sensors located around the vehicle to characterize the surrounding environment and sense the location of the vehicle in proximity to obstacles. The cameras/sensors, are combined with a mapping system (Lidar) and/or GPS, and in some cases wayside magnets embedded along the alignment, to travel along their route. Information is managed through proprietary onboard operating systems that control the vehicle speed, acceleration/deceleration profiles, steering, direction, station stops, braking and safety functions such as collision avoidance between vehicles and with end of track buffers.

2.2 **Supervisory Control System**

Although the AV Technology vehicles can operate automatically and safely along a defined route, the overall AV system architecture must include a supervisory control system that monitors and controls certain aspects of the AVs (See Figure 2.1). This includes route setting for each vehicle, vehicle health monitoring, which includes alarms such as low battery, flat tire, vehicle stopped or misaligned at a station, motor failure or overload, smoke or fire onboard and all other alarms required to ensure reliable, flexible, functional and safe operations of the vehicles. The supervisory control system is typically located in a central control facility. For the new U2C AV system the plan would be to replace/upgrade the existing Skyway central control room equipment and workstation monitors, etc. with new. Current Automated Transit Systems deployed in several locations around the world typically include supervisory control systems that are well developed and could be readily adapted to the AV Technology. Supervisory Control Systems would also provide monitoring and controls for other system equipment such as opening and closing power circuit breakers, status of circuit breakers, monitoring access to critical wayside equipment rooms, etc.

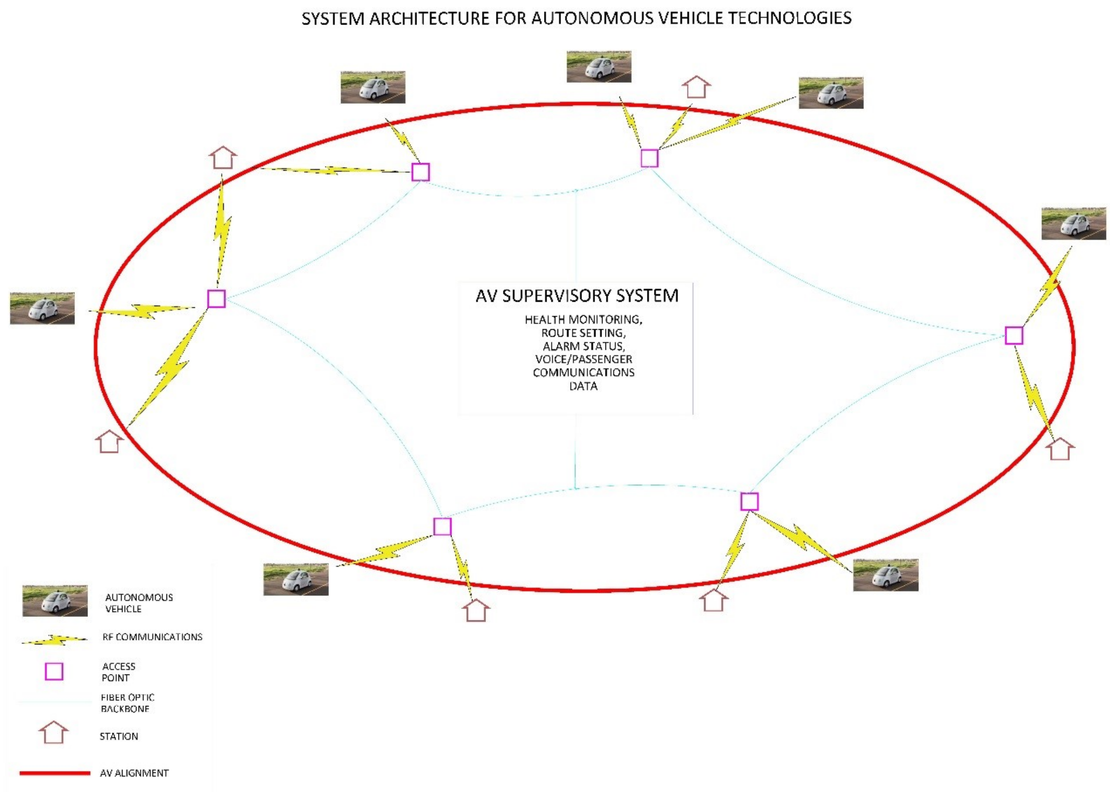

Figure 2.1 – AV Technology Supervisory System Architecture

A second AV Technology system requirement will be the physical infrastructure necessary for all communications to occur. What cybersecurity measures will be implemented to avoid malicious interference? Will the AV communication use a public 4G or 5G wireless network or a proprietary system that is dedicated and secured similar to the existing Skyway system? To address some of the cybersecurity concerns, the JTA is considering utilizing their own communications network and protocols for the AVs operating in the U2C environment. Figure 2.2 shows the JTA Communications Network Concept.

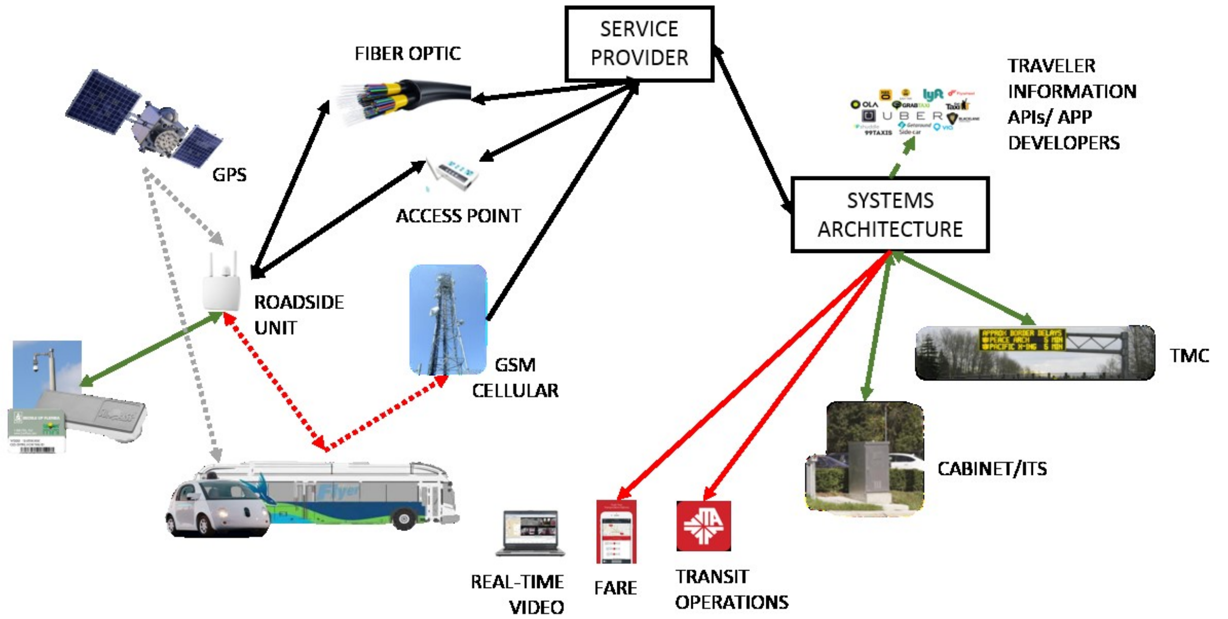

Figure 2.2 - JTA Communications Network Concept

2.3 Communications

The AV technology vehicles will need to include the ability to communicate vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) including both voice and data, Refer to Figure 2.2. V2V communications would be used so that each AV knows other nearby AV's location, direction, routes and speed, and use such information for its own operational parameters. V2I communication is used to allow the vehicle to communicate with the supervisory system including the supervisory functions described above, as well as vehicle to station communications for triggers related to platform Public Announcements (PA) and dynamic signage. V2I can also be used for voice communications from onboard passengers to the Supervisory Control Operator or other designated person to manage potential emergencies or other passenger related necessary communication.

2.4 Power Distribution / Charging Stations

As previously mentioned, AV's are powered with onboard batteries that provide necessary power for propulsion motors, onboard HVAC, lighting, communications equipment, door motors/controls and onboard vehicle operational control and monitoring equipment. These onboard batteries have a finite charge life ranging from 4 to 14, hours as identified in Table 1.1 and are required to be recharged when their charge has been depleted. Recharge times can vary from 3 to 8 hours. As such, charging stations must be considered and provided, to allow for the most efficient use of their charging time. Depending on how the charging stations are located and configured throughout the system, and how long they can hold a single charge, additional AVs can be deployed into service while the AVs are removed from service for charging, to maintain the desired/required capacity at the given time of day. A key consideration for vehicle charging stations is the existing Skyway power infrastructure that utilizes 480V, 3-phase power, distributed along the alignment from several substations. One option would be to provide a possible pocket track at strategic locations to allow for efficient dispatching of newly charged AVs and removal and charging of AVs with low battery charge. Another option is to have the charging station centrally located at or near the AV maintenance facility. Other considerations would include online dynamic charging perhaps at stations while the vehicles dwell or some method of inductive charging while the vehicles operate along their routes. As the battery technologies continue to evolve, better solutions may become available in time