



Lincoln Multimodal Technology Vision

A guide for the future of mobility

Lincoln, Nebraska USA

February
2018

created with
assistance from:



created for
use by:



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Disclaimer: This document is not intended to dictate design or operations of an autonomous vehicle provider, supplier or vendor. HDR does not certify or warranty the pilot study design or operations. HDR is providing a planning level document that contains possible operational scenarios for decision makers to formulate final design and operational plans. All vendors, suppliers and/or operators shall review and determine the appropriate requirements of the pilot vehicles and systems to meet the operational requirements for the safe and proper operations of the vehicle.



V

Vision

- What is this project all about?
- What do we hope to achieve?
- How will riders use this service?
- Where will it serve?

What is this project all about?

The City of Lincoln is on the move. Understanding the direction and anticipating how new transportation technologies can be utilized, the City is embarking on one of the largest deployments of autonomous microtransit vehicles into a mixed traffic environment anywhere in the United States. This is an exciting time, with many emerging technologies that are poised to increase mobility options for individuals around the world, and Lincoln will establish itself as a community at the forefront of using those technologies for the good of its people.

This project will use a relatively new form of transportation, the autonomous microshuttle. Several companies are developing these vehicles and systems, with dozens of deployments in the United States and many more throughout the world.

This will be a demand-responsive system, meaning the shuttles will only operate and make stops if there is a direct request from a rider through a smartphone app or kiosk. Shuttles will travel in open traffic on Lincoln's public roadways along a predefined route, making pick-ups and drop-offs at predefined stops at a user's request. Vehicles typically can carry from 8-16 passengers, and travel at

average speeds from 15-20 miles per hour. This initial pilot is intended to last two years, with an operational deployment date by fall of 2018 pending funding. When deployed, this will be one of the largest single deployment of mixed-traffic microshuttles in the country.

What do we hope to achieve?

As this project is developed and is eventually kicked off, it is critical to keep focus on the goals of the project. In short, a goal is a desired outcome expressed in simple terms. The overall goals of the project include:

- Safely and efficiently move people between major destinations and landmarks within Downtown Lincoln
- Test an on-demand autonomous service along a fixed route
- Highlight innovative transportation in Lincoln



Figure 0.1 An example of an autonomous microshuttle
Image source: HDR

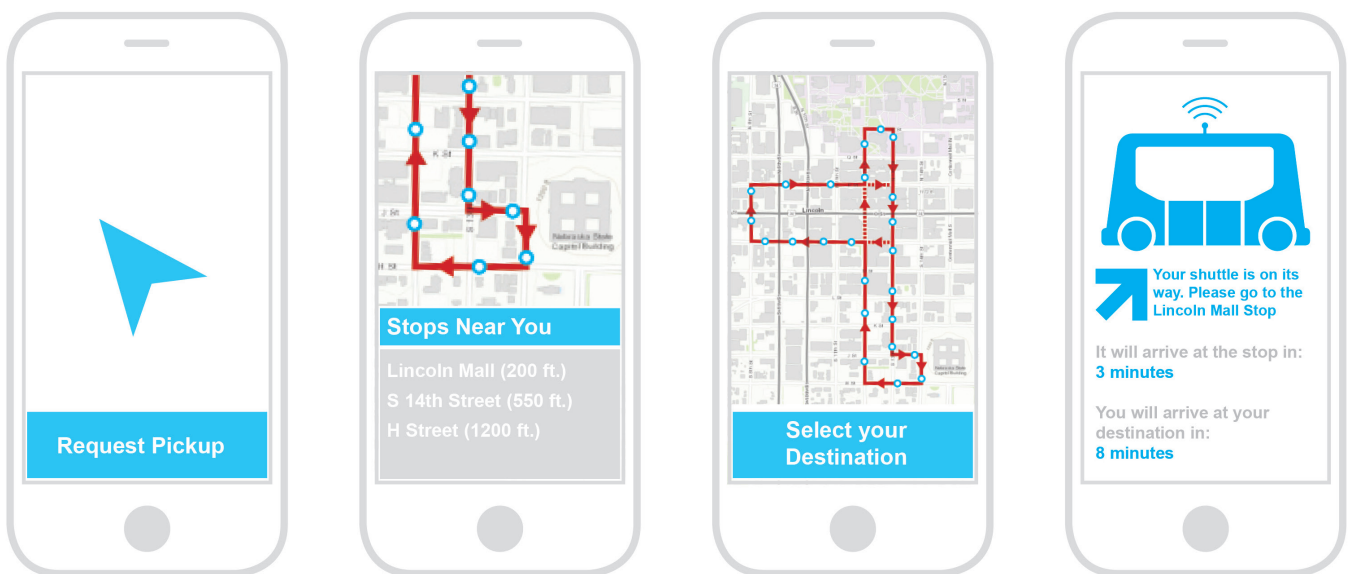


Figure 0.2 User experience in requesting a shuttle from the smartphone app
Image source: HDR

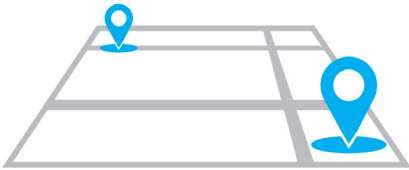
How will riders use the service?

The process for riding the shuttle should be easy and straightforward. Users already familiar with ridesharing apps will be able to quickly use the new app, while new users should find it easy to learn.



Start the app

Similar to current ridesharing services, the app will use GPS to identify the user's location and calculate which route stop is closest to his or her location.



Rider selects their pickup and drop-off location and confirms with a mobile app payment

Users will confirm their pick-up location and identify their drop-off location among one of the predetermined stops along the route. They will confirm the trip through a mobile application payment system built into the app.



Rider goes to the nearest pickup location

The app will tell the user how much time they have to get to the pick-up location once the ride is requested. The AV's management software will deploy vehicles based on demand, and calculate which vehicle will be best able to serve the users in the system at any given time



Rider boards the shuttle

Once the shuttle arrives at the predetermined pick-up location, the rider can board and begin their trip. The shuttle may pick up other passengers and will calculate if one of the shortcut routes will be used.



Rider arrive at their destination

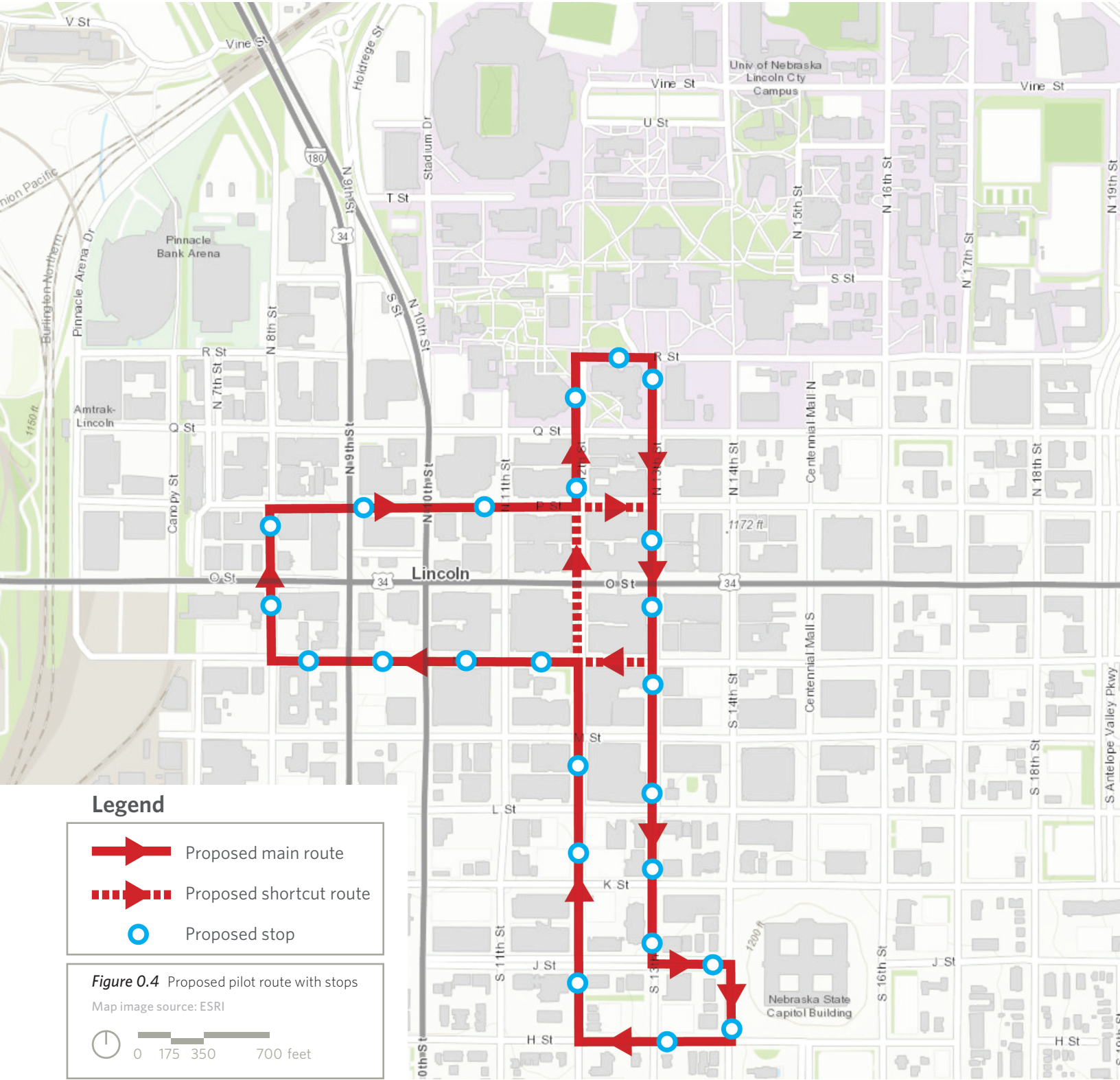
The shuttle will make stops that are requested for either pick-up or drop-off locations. Once a rider reaches their destination, the doors open and they exit the vehicle.

Figure 0.3 Overview of user experience in shuttle operation

Image source: HDR

Where will it serve?

The proposed route is intended to serve the highest concentrations of people and attractions in Downtown. It is intended to be easy to use, easy to understand, and provide enough stops to be easily accessible.



01

Introduction

- Project overview
- A call to act
- Project goals and outcomes
- Transit ridership increases
- The rise of autonomous vehicles

Project overview

This document represents a vision for how the City of Lincoln, Nebraska will establish itself as a nationwide leader in the implementation of autonomous vehicle technology, and how that technology will be used in a real-world deployment to support Lincoln's existing transit service. Upon implementation, this will be one of the largest mixed-traffic deployment of autonomous microshuttles in the United States, solidifying Lincoln's reputation as a community that is forward thinking and helping to lead the country into an exciting future.

This Vision is intended to lay the groundwork and outline how the initial deployment should be conducted. While it can't answer every question, it will provide a benchmark for how the system should operate, where it will be deployed, and how it is intended to serve the Lincoln community.

A call to act

The City of Lincoln is on the move. The City is home to a growing and thriving community; recognized nationally as a premier American city of businesses, entrepreneurs, young people, retirees, and families. Lincoln has added 140,287 new residents since 1958 and in that same amount of time, the City has grown from 25.54 square miles to 92.74 square miles; a 265% increase. To successfully support Lincoln's continued growth and prosperity, the City must establish a strategic mindset that is aimed at continual improvement of vital infrastructure and services coupled with a sustainable and responsible approach to the management of public resources. As growth continues, so too does its impact on the community. Continued growth will result in more pressure on the existing system, and an increasing need for infrastructure that will bring additional maintenance and operational costs.

The City wants to offer additional mobility options for the community by leading an early expansion and adoption of a downtown transit system that will facilitate the movement of people between major destinations such as the State Capital, the University of Nebraska, and the Haymarket District. Recognizing that technology will have the ability to improve upon traditional transit systems, the City is proposing to create the largest, full-service autonomous microtransit deployment in the United States. This transit service will provide on-demand service on a fixed route, and may one day lessen the need for personal vehicles within Downtown Lincoln.

Project goals and outcomes

As this project is developed and is eventually kicked off, it is critical to keep focus on the goals of the project. In short, a goal is a desired outcome expressed in simple terms. The overall goals of the project include:

- Safely and efficiently move people between major destinations and landmarks within Downtown Lincoln
- Test an on-demand autonomous service along a fixed route
- Highlight innovative transportation in Lincoln

Transit ridership increases

In April of 2016, StarTran released the final report of its Transit Development Plan that outlined the state of Lincoln’s existing transit service, areas likely to see an increase in ridership, and a number of short and long term recommendations to improve system service and usability.

As outlined in the study, transit ridership has experienced a steady increase in annual ridership of 26% from 1.7 million to 2.2 million from 2010 to 2014. As the City continues to grow, likely so too will ridership. The City and StarTran are looking to improve service while planning for the future, and this pilot deployment is the first step.

The rise of autonomous and connected vehicles

Autonomous vehicles (AV) utilize technology to monitor the driving environment and perform driving functions independent of human interaction. There are several technologies that support these functions (see figure 1.1):

- Radar sensors monitor the position of nearby vehicles.
- Light Detection and Ranging (LIDAR) sensors detect lane markings and road edges.
- Video cameras interpret traffic signals and road signs and detect pedestrians, nearby vehicles, and other objects.
- A global positioning system (GPS) places the vehicle accurately within a map.
- An on-board computer analyzes the above inputs and controls steering, acceleration, and braking.

Autonomous vehicle technology exists on a spectrum, with Level 0 representing vehicles lacking any autonomous functions and Level 5 including fully autonomous vehicles capable of driving in any scenario. Many vehicles currently available for sale have autonomous functions ranging from radar cruise control and automated emergency braking (Level 1) to more advanced self-driving capabilities like Tesla’s AutoPilot system (Level 3). Autonomous microtransit shuttles represent Level 4 autonomy because they do not require driver fall-back capabilities, yet they cannot operate in all conditions. Level 5 autonomy adds this full operating range and is in the research and development phase.

Connected vehicles (CV) consists of point-to-point dedicated short-range communication (DSRC) message exchanges including vehicle-to-vehicle communication that allows enabled vehicles to communicate with each other; vehicle-to-infrastructure communication that allows vehicles to communicate with surrounding infrastructure; and, vehicle-to-all communication that enables the interaction of vehicles and any capable communication device in the immediate vicinity. The potential applications allowed by connected vehicle technology are considerable in number and include safety, environmental, mobility, road weather, and smart roadside families of applications.

Dynamic transit/mobility-on-demand is a hybrid model combining the benefits of both ride-sharing and traditional transit. Rather than using traditional fixed routes, these services links riders to transit service on an on-demand basis. Often dynamic transit will utilize a central dispatching software that optimizes service while minimizing the distance each traveler has to traverse to reach a “pop-up” transit stop.



Figure 1.1 Navya sensor platform
Image source: curbsideclassic.com

02

Context

- Downtown overview
- Downtown landmarks and activity nodes

Downtown overview

Downtown is the cultural, political, and educational center of the Lincoln community. It is home to the Nebraska State Capitol, the University of Nebraska's main campus, the County Seat, and the City's administrative offices. Downtown Lincoln has a mixture of density without large amounts of traffic, creating a district that is perfect for testing an autonomous microtransit system.

The Downtown is bounded generally by Salt Creek and the railroad corridor to the north and west, and by Antelope Creek to the east. The development pattern transitions from commercial / office / institutional into almost completely residential by G Street to the south. The employment density map (Figure 2.1) demonstrates the extent of high-density employment locations within Downtown. The final route should serve this built-in user base as a source of stable ridership.

A number of opportunities exist that can take advantage of highly visible areas, districts with a built-in platform of users, and areas that have a large number of attractions (see Figure 2.2).

Haymarket District

The Haymarket District is a hub of nightlife and development activity, serving residents, students, visitors, and downtown workers. A number of development and

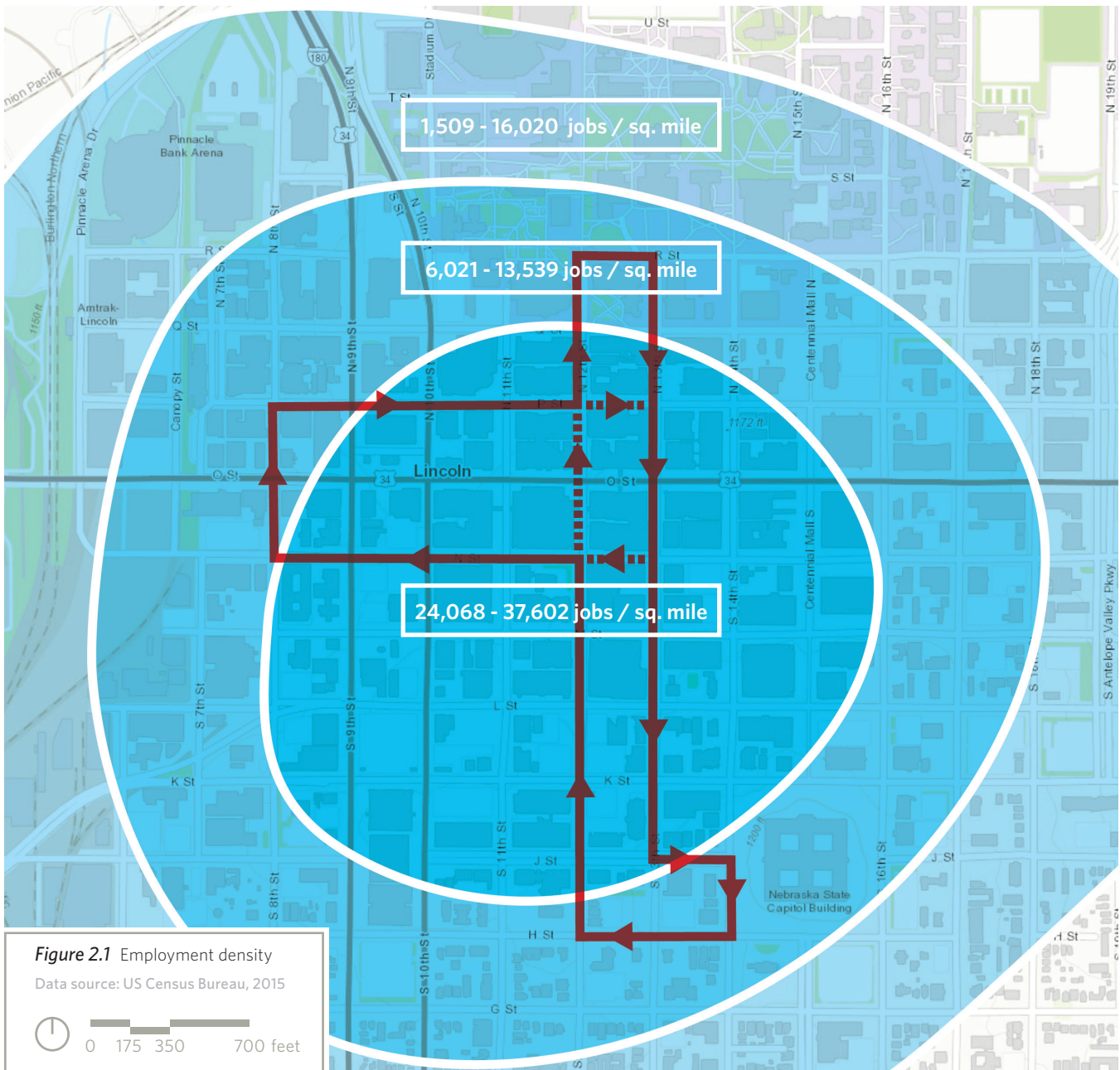


Figure 2.1 Employment density
Data source: US Census Bureau, 2015

0 175 350 700 feet

redevelopment projects have occurred within the District, offering an opportunity to highlight the progress Lincoln has made in the past several years. Specifically, the Haymarket has a high concentration of attractions that bring visitors and residents downtown, including:

- Hotels
- Parking Structures
- Restaurants
- Nightlife

The proposed route travels through the heart of the Haymarket District, coming within two blocks of three

parking structures and three hotels, within a block of the Pinnacle Bank Arena, and cutting through the heart of the entertainment and restaurant section located along 8th Street. Additionally, the route is within one block of the new development along Canopy Street (see Figure 2.3).

South Haymarket District

The South Haymarket District is prime for redevelopment, with a new plan in place to help guide future growth in the area. Already, several new projects such as the 8N Lofts and the Latitude Building have been constructed in or near the District, which would be served by the proposed AV shuttle route.

University of Nebraska

With a high concentration of students and employees, all navigating within campus by either walking or cycle, the University provides a great opportunity to tap into a population of potential riders. The proposed route, while not operating within campus, will be able to transport students and employees from campus to various areas around the Downtown, including areas likely for student housing.

Lincoln Mall

In terms of visibility, the Lincoln Mall is a great opportunity to showcase driverless technology. Book-ended by the County and City offices to the west, the State Capitol to the east, and a number of institutional and organizational uses to the north and south, the corridor is the center for civic activity in the Downtown. Additionally, the State Capitol building is one of the most architecturally significant landmarks in the State, giving visitors a chance to experience the technology as they visit the State's capital.

O-Street Corridor

The O-Street Corridor is the primary east/west roadway through Downtown Lincoln, connecting to areas both east and west of Downtown. A significant amount of density is oriented along the corridor, supporting a mixture of retail, entertainment, office, and residential users. While the corridor itself may be difficult for the current generation of autonomous shuttles to navigate, the current route is proposed to be located within a short walk to this important corridor.

Downtown landmarks and activity nodes

Parking Structures (Public and Private)

A number of public and private parking structures are located throughout Downtown, with many public structures clustered on the western edge of the Haymarket District, and private structures located more centrally to the District (see Figure 2.3). Autonomous shuttles would be a benefit to maximizing the utility of parking structures, as they could help balance the demand for parking throughout the Downtown, perhaps giving access to underutilized parking areas.

Hotels

Hotel guests offer a built-in base of users who are more likely to be without cars, and who are more likely to eat out and travel to employment centers. Most hotels in Downtown Lincoln are clustered in the Haymarket District (see Figure 2.3), which further reinforces the importance of connecting to the area.

Cultural Amenities (Theaters & Museums)

A cluster of museums and theaters is located just south of the University (see Figure 2.3). This cultural hub is an excellent place to showcase autonomous technology, and to better connect visitors of these institutions to other areas of interests throughout the Downtown, including parking structures.

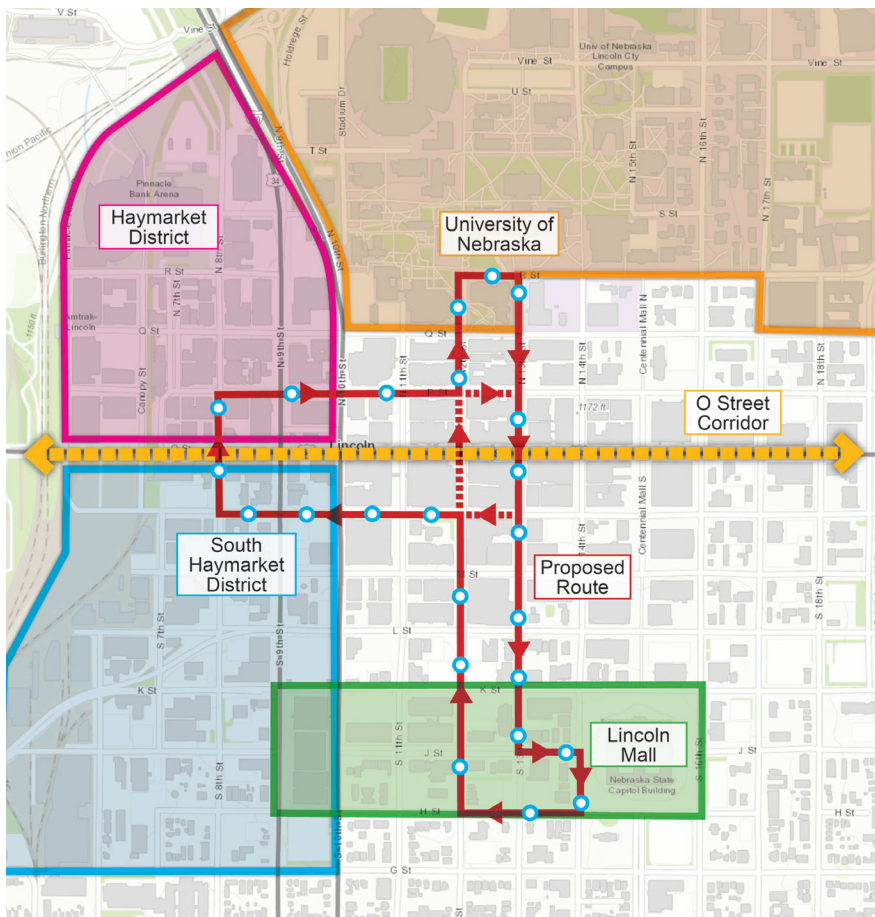


Figure 2.2 Downtown destination districts

Map image source: ESRI

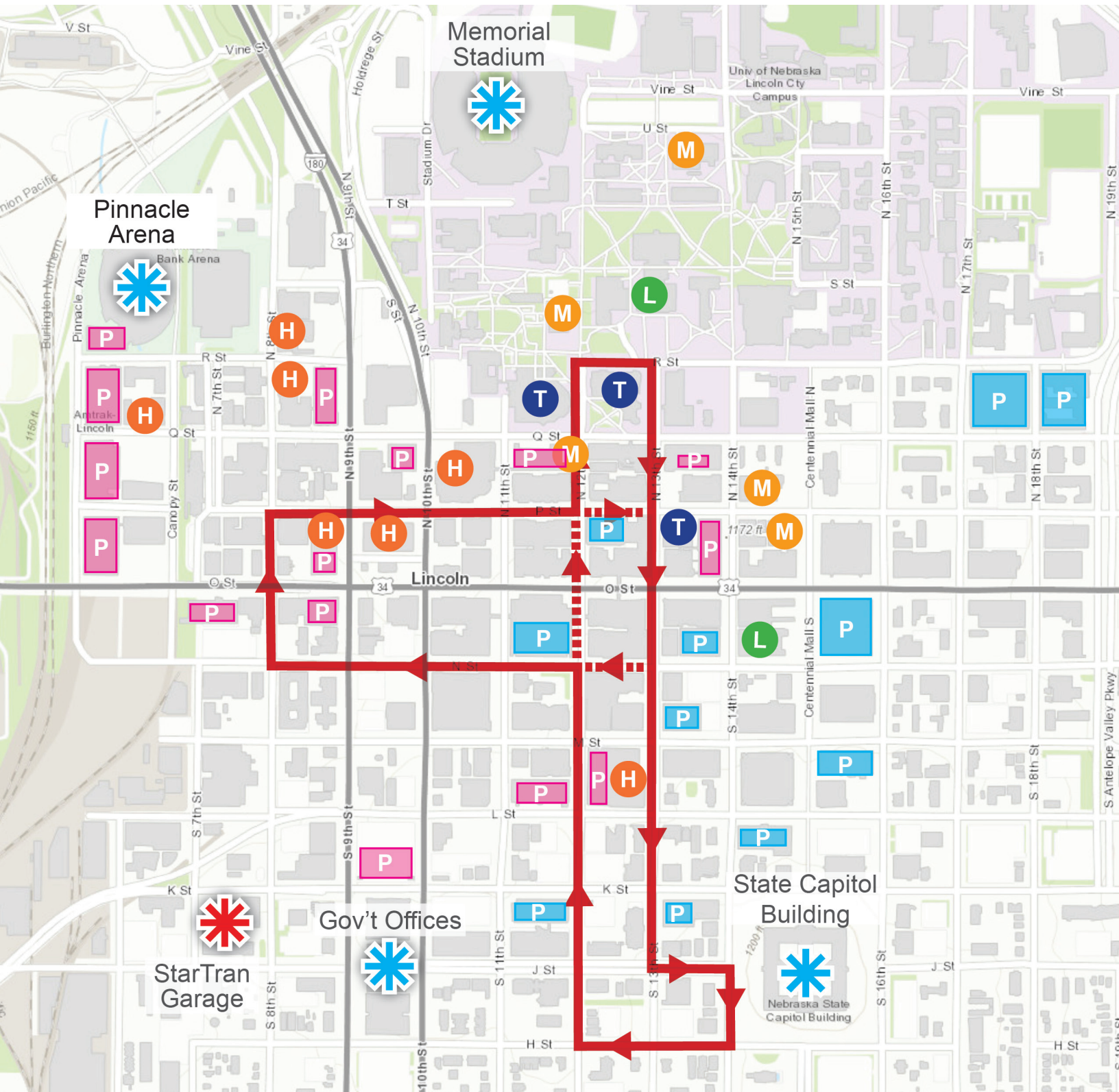


Figure 2.3 Proposed pilot route with stops

Map image source: ESRI



Legend

- | | | | | | |
|---|----------------|---|-------------------|---|---------|
|  | Main route |  | Public garage |  | Hotel |
|  | Shortcut route |  | Private garage |  | Museum |
|  | Stop |  | Point of interest |  | Theater |
| | |  | Library | | |

03

Concept

- Vehicles
- How will riders use the service?
- Smartphone app
- Route
- Static Signage
- Stops
- Infrastructure Components

Vehicles

AV technology offers a number of potential applications for transit vehicles, from microshuttle vehicles to full-size buses. A number of manufacturers are marketing low-speed 8-16 passenger autonomous shuttle vehicles. At present these vehicles operate primarily in dedicated lanes, though some models are capable of mixed traffic operation.

AV microshuttle vehicles offer a number of potential benefits, including flexibility in the range of applications:

- Circulator routes
- Replacements for short, existing transit lines with low ridership
- First and last mile connections for high capacity transit lines
- Demand responsive, flexible routing services within a predefined zone.

Beyond their flexibility, there are a number of important factors to consider in making the decision to utilize AV microshuttles. Agency operating costs are generally lower than traditional transit vehicles, while user costs are lower than transportation network company (TNC)

services. Lower operating costs come from a number of factors:

- Reduced labor costs
- Battery electric charging and propulsion
- Accident avoidance capabilities

Additionally, many vendors offer all-inclusive purchase and leasing options that include vehicle and route set-up, remote monitoring, ongoing software updates, maintenance, and a user-facing interface. This enables public agencies to deploy cutting edge technology while minimizing their exposure to risk.

However, there remain a number of limitations for AV microshuttle deployments. Vehicles typically operate at speeds lower than 30 miles per hour, and seating capacity is limited compared to traditional buses. Microshuttles are thus not well suited to replace high capacity, long distance, or high speed transit routes. Routes must be carefully inventoried prior to operation, further limiting the maximum distance of a route. Vehicles can typically operate for 8-12 hours on a single charge, however this is greatly diminished in hot and cold weather when climate control is necessary.

Manufacturers have varying levels of readiness for operating in mixed traffic environments, and today’s vehicles may default to a state of caution that is at times prohibitive (such as left turns or merging into traffic). One way to overcome some of these limitations is by deploying infrastructure-based assistive technologies.

Beyond microshuttle technology, other manufacturers are developing full-size transit vehicles at varying levels of automation. For example, Daimler is developing the fully autonomous Mercedes-Benz Future Bus prototype as part of the City Pilot demonstration. On the other end of the spectrum, vendors such as Mobileye are developing after-market solutions to add low level autonomous features such as pedestrian detection and collision avoidance that can be added to existing transit vehicles. It is likely that full size autonomous transit vehicles will not be ready for permanent deployment for many years, and will initially be deployed in dedicated lane applications such as bus rapid transit.



Figure 3.1 Navya autonomous microshuttle

Image source: Michaël Gounon



Figure 3.2 EasyMile autonomous microshuttle

Image source: City of San Sebastian - CityMobil2



Figure 3.3 Local Motors autonomous microshuttle

Image source: Local Motors

How will riders use the service?

The process for riding the shuttle should be easy and straightforward. Users already familiar with ridesharing apps will be able to quickly use the new app, while new users should find it easy to learn (see Figure 3.4)

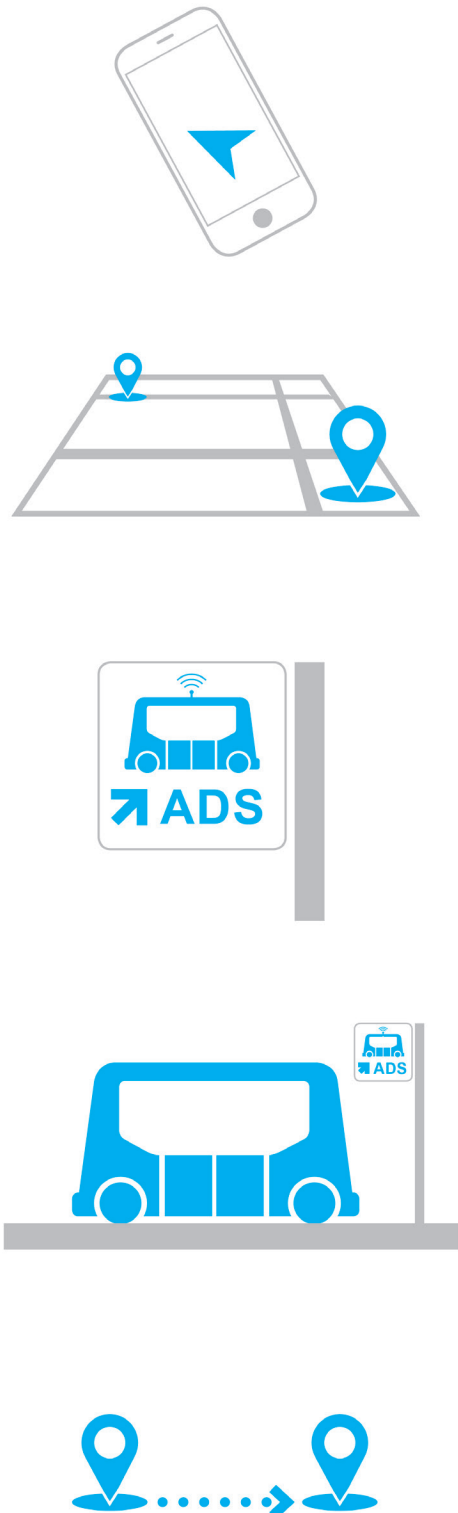


Figure 3.4 Overview of user experience in shuttle operation

Image source: HDR

Start the app

Similar to current ridesharing services, the app will use GPS to identify the user's location and calculate which route stop is closest to his or her location.

Rider selects their pickup and drop-off location and confirms with a mobile app payment

Users will confirm their pick-up location and identify their drop-off location among one of the predetermined stops along the route. They will confirm the trip through a mobile application payment system built into the app.

Rider goes to the nearest pickup location

The app will tell the user how much time they have to get to the pick-up location once the ride is requested. The AV's management software will deploy vehicles based on demand, and calculate which vehicle will be best able to serve the users in the system at any given time.

Rider boards the shuttle

Once the shuttle arrives at the predetermined pick-up location, the rider can board and begin their trip. The shuttle may pick up other passengers and will calculate if one of the shortcut routes will be used.

Rider arrive at their destination

The shuttle will make stops that are requested for either pick-up or drop-off locations. Once a rider reaches their destination, the doors open and they exit the vehicle.

Smartphone app

The app should be available for iOS and Android users. The following sequence of events describes the user's interaction with the smartphone application while requesting a ride (Figure 3.5).

1. Once the user starts the app, it will use the phone's GPS location services to determine where the rider is located.

The app will determine the closest stops to the user's location.

2. The user will choose which stop he or she intends to board the shuttle.
3. The user will identify which stop along the route they intend as their destination.
4. Once a ride is requested from the user, the app will contact the shuttle management system, which will identify which vehicle has the ability to provide the shortest travel time from the time of request to the time of drop-off (the closest shuttle may not be the fastest if the user could potentially use a shortcut, but another user needs the full route). The system will deploy the vehicle it determines as the best option to pick up the rider.

The system will calculate the estimated pickup time for the rider at the stop specified.

The vehicle arrives at the stop and picks up the rider. It will take a shortcut if needed, and will drop off the rider at the selected stop, making other stops as requested by other riders.

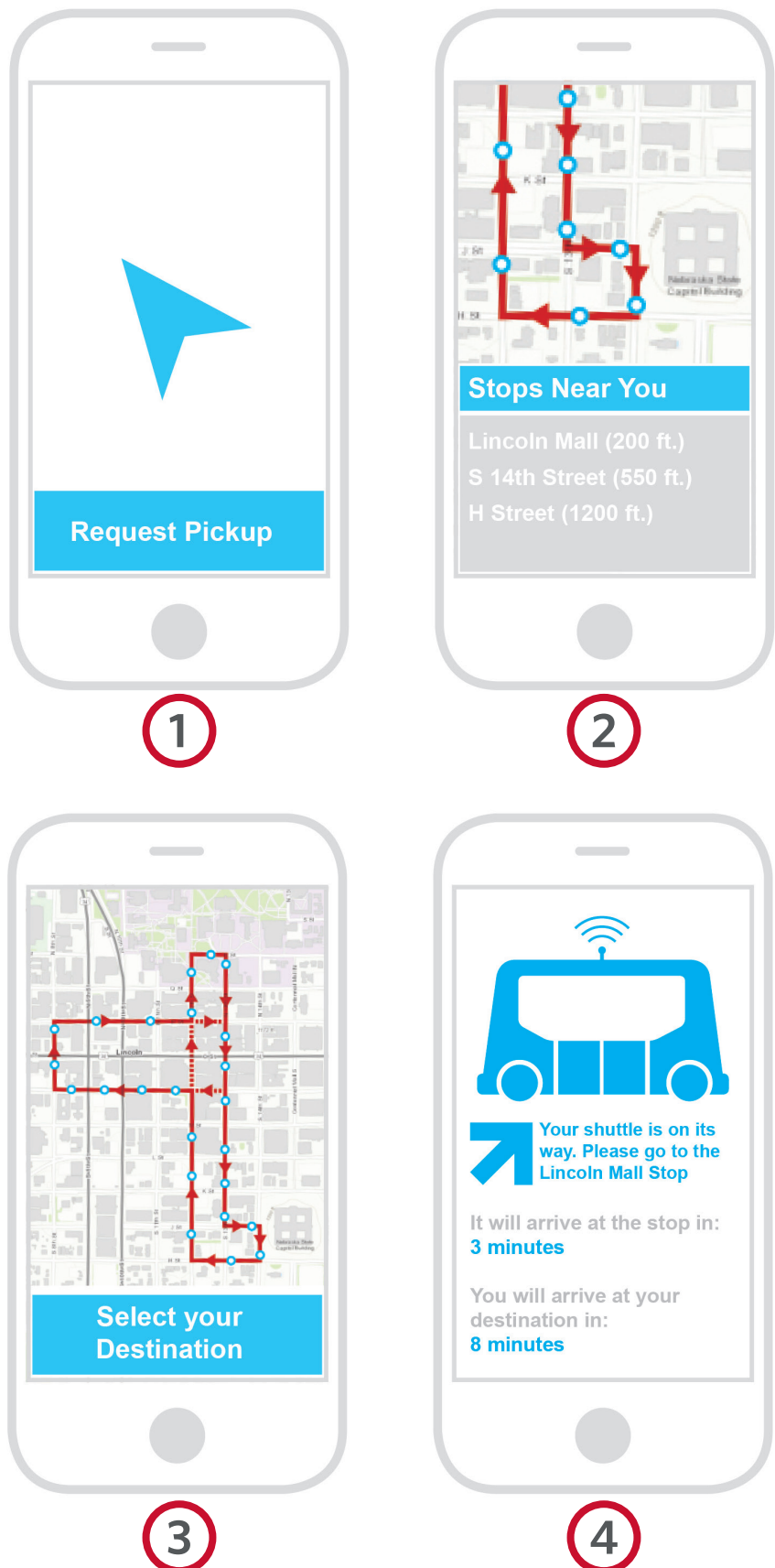


Figure 3.5 User experience in requesting a shuttle from the smartphone app

Image source: HDR

Route

How the route was identified

Broadly speaking, the route is intended to move people throughout highly frequented areas within the Downtown District. Of critical importance is to connect to identifiable landmarks and districts that have a high level of residents, employees, and visitors, giving opportunity to expose the Lincoln community to the new transportation technology.

Two sets of considerations were developed to guide the identification and selection of the route options and final route. Service-oriented considerations outline, in simple terms, what the route should achieve and how it should serve riders and the Lincoln community. Functional-route considerations describe on-the-ground constraints that the current generation of autonomous transit vehicles would have operating within Lincoln.

Service-oriented considerations

A series of service-oriented considerations were identified to guide development of the initial route. These objectives were developed to maximize the impact of the autonomous transit deployment, and allow the City and StarTran to test the viability of autonomous microshuttles as a component of Lincoln's transit system. The following considerations guided the development and selection of the route:

Maximize exposure and visibility within Downtown

Autonomous transportation is coming. This pilot is an opportunity to highlight the benefits of the technology, while allowing riders an opportunity to get comfortable with using the new technology.

Keep the route simple and easy to understand

Users should be able to quickly understand the major destinations and the overall direction and form of the route.

Add another layer of transit service not currently being offered in Downtown

The route should offer something new in addition to the existing transit service. Duplication of existing service and routes should be avoided.

Serve well-developed areas with high concentrations of residents, employees, students, and visitors

Transit is able to offer its highest level of efficiency when it serves high density areas. To keep a high number of riders using the autonomous shuttles, the route should serve areas where high numbers of people already exist or are likely to visit.

Highlight new projects and progress in Lincoln

The City of Lincoln has experienced the completion of a number of new private development projects in addition to a new public streetscape and improvements to public spaces throughout areas in Downtown. The route is an opportunity to highlight the continuing progress in Lincoln.

Attract new transit riders

Lincoln is a City that is highly dependent on individually-owned automobiles. New transit options are an opportunity to get the City's residents familiarized with transit in a new way. Autonomous vehicles are coming, and their presence may attract new segments of transit riders in addition to current riders. The proposed route should offer an opportunity to appeal to a wide variety of people.

Functional route considerations

At this point in time, autonomous vehicle technology has a number of constraints in operation. The technology is rapidly improving, but this pilot has to operate within its current capabilities. Additionally, this is an opportunity to test the applicability of autonomous transit while avoiding costly changes to the existing infrastructure that would not otherwise be needed, and to utilize the existing context or conditions as much as possible. The following functional considerations were used in determining the proposed route:

Road directness / Complexity

In short, the simpler the driving situation, the easier it will be for the vehicle. The route should avoid busy roads, unnecessary turns, and use streets that have the least amount of obstacles, lane changes, or complicated traffic patterns.

◦ **Low traffic volumes**

High volume, high speed roadways can be problematic for the current generation of AV shuttles, as they have substantially more traffic to navigate alongside.

- **One-way streets preferred**
One direction of traffic flow is easier for a vehicle to navigate than two. One-way streets will also have a greater likelihood of being multi-lane, without being high volume (see Figure 3.6).
- **Signalized intersections preferred**
Signal controlled intersections allow for a predictable flow of traffic. Some versions of AV transit may require the addition of DSRC (Dedicated Short Range Communications) radio units to communicate the phasing of the signal to the vehicle.

- **Primary roadways preferred**
Where possible, primary roadways should be prioritized for routes ahead of secondary roadways. These will generally have a higher degree of development and density, more existing stops, and larger right-of-way width.

At least two traffic lanes

Two traffic lanes in the same direction will allow the AV shuttle to operate at lower speeds without causing issues for regular traffic, allowing faster traffic to pass the vehicle. Additionally, it provides the option for the shuttle to pick-up and drop-off in a traffic lane if necessary.

The proposed route uses a number of one-way streets, all with at least two traffic lanes that will allow regular traffic to pass the slower-moving shuttle.

Utilize existing bus stops and turnouts where possible

To reduce the need for site improvements, existing stops and turnouts should be utilized where possible. In areas without existing stops or turnouts, parallel parking, head-in parking, and loading zones may be considered. The City would need to prohibit parking in strategic areas to allow for an unobstructed pick-up and drop-off zone where parking exists now.

Minimize the number of turns

The less turns, the simpler the route. Additionally, left turns, even if signalized, can be difficult for the current generation of autonomous vehicles.

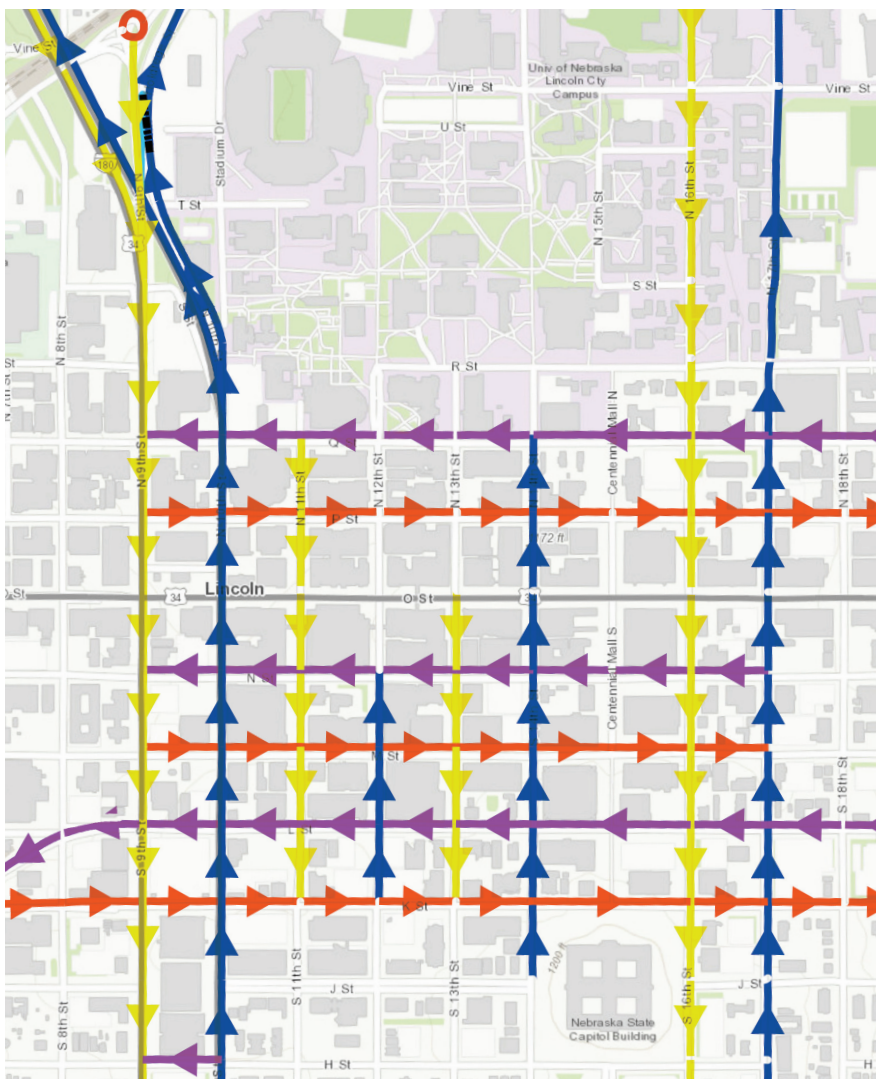

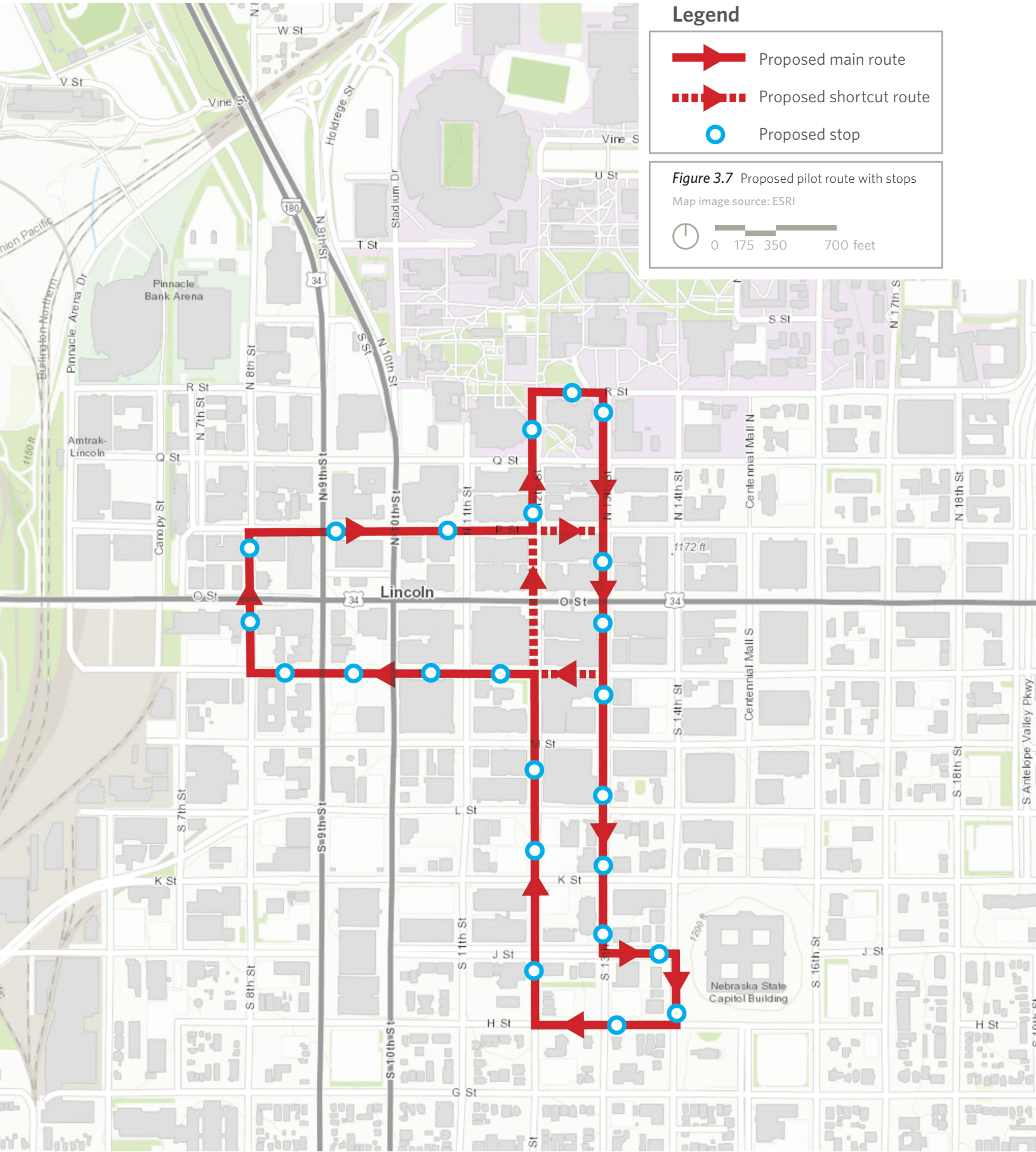


Figure 3.6 Street Direction
Map image source: ESRI
0 175 350 700 feet

Legend
 Existing one-way street direction



Legend




-  Proposed main route
-  Proposed shortcut route
-  Proposed stop

Figure 3.7 Proposed pilot route with stops

Map image source: ESRI



Route Description

The draft route proposal (Figure 3.7) was created by balancing service considerations with functional considerations to create a realistic, operable route that serves the Lincoln community in the most effective manner. The route proposed operates on different streets and in the opposite direction from the existing Downtown Circulator.

Starting near the University at the intersection of 13th Street and R Street, shuttles will:

- Head south eight blocks on 13th Street until they reach the Lincoln Mall.
- Left turn to head east for one block on the Lincoln Mall;
- Right turn to head south one block on 14th Street;
- Right turn to head west two blocks on H Street;
- Right turn to head north five blocks on 12th Street;
- Left turn to head west four blocks on N Street;
- Right turn to head north two blocks on 8th;
- Right turn to head east four blocks on P Street;
- Left turn to head north two blocks on 12th Street;
- Right turn to head east one block.

Overall, the vehicles will travel roughly 2.2 miles on the main portion of the route. The route includes three shortcut that can greatly shorten the distance of the trip by effectively skipping one of the three legs if there are no riders to pick up or drop off. Because the vehicles are intended to be demand-responsive, it is difficult to estimate the average wait time for a vehicle. Assuming a worst case scenario where all vehicles are clustered in one area, none take a shortcut, and they average 10 mph over the full 2.6 mile route, a rider would wait a maximum of 15.5 minutes for the next available ride. That time comes down significantly when the bypasses shortcuts are included and the shuttles are spaced more evenly throughout the route.

This route takes planned road closures, such as the farmer’s market, into consideration. As an option to better serve the parking areas to the western edge of the Haymarket District, a future route extension could be added up Canopy Street on days with no planned closures.

Static Signage

New static signage should be installed at every potential stop along the route. Signage should clearly identify the area as a stop for the autonomous service, and have instructions on where to download the app. Additionally, signage can identify the route and available stops throughout Downtown.

A schematic of a potential sign is shown in Figure 3.8, which can use existing signage poles where available.

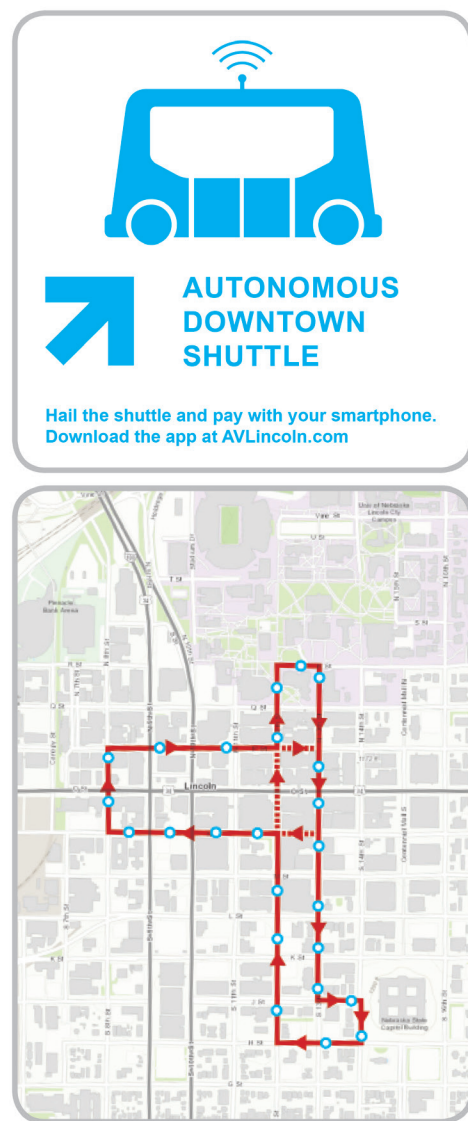


Figure 3.8 Static signage example

Image source: HDR

Stops

The stops indicated on the map above make the best use of the existing conditions of the street and sidewalk. The intent is to require as little change to the existing infrastructure as possible, while providing riders with ample opportunity to use the service. The map of the route in Figure 3.13 shows the stops color-coded based on the type of location : existing loading area, transit stop, parking area, or traffic lane.

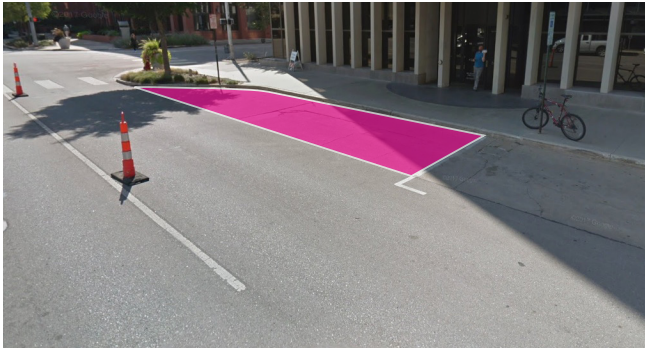


Figure 3.9 Loading area / turn-out example
Image source: Google Maps



Figure 3.10 Transit stop example
Image source: Google Maps

Loading Area / Turn-Out (4 stops)

Areas with existing loading areas or turn-outs are an opportunity to use the existing roadway and curb configuration as pick-up and drop-off locations for the autonomous microshuttles. Each zone has different regulations, so there may be times of the day where a pick-up or drop-off is not allowable or feasible. In those instances, the app will not include that stop as an option.

Transit Stop (6 stops)

Where existing, transit stops already used by the StarTran system should be utilized. Several exist along the proposed route and provide an excellent opportunity to transfer to and from existing bus lines, and to use the facilities already constructed.



Figure 3.11 Traffic lane stop example
Image source: Google Maps

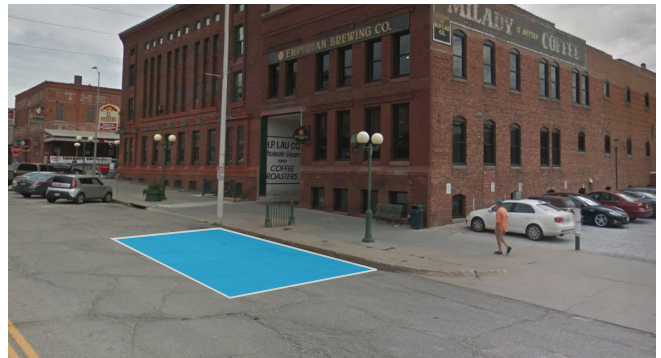


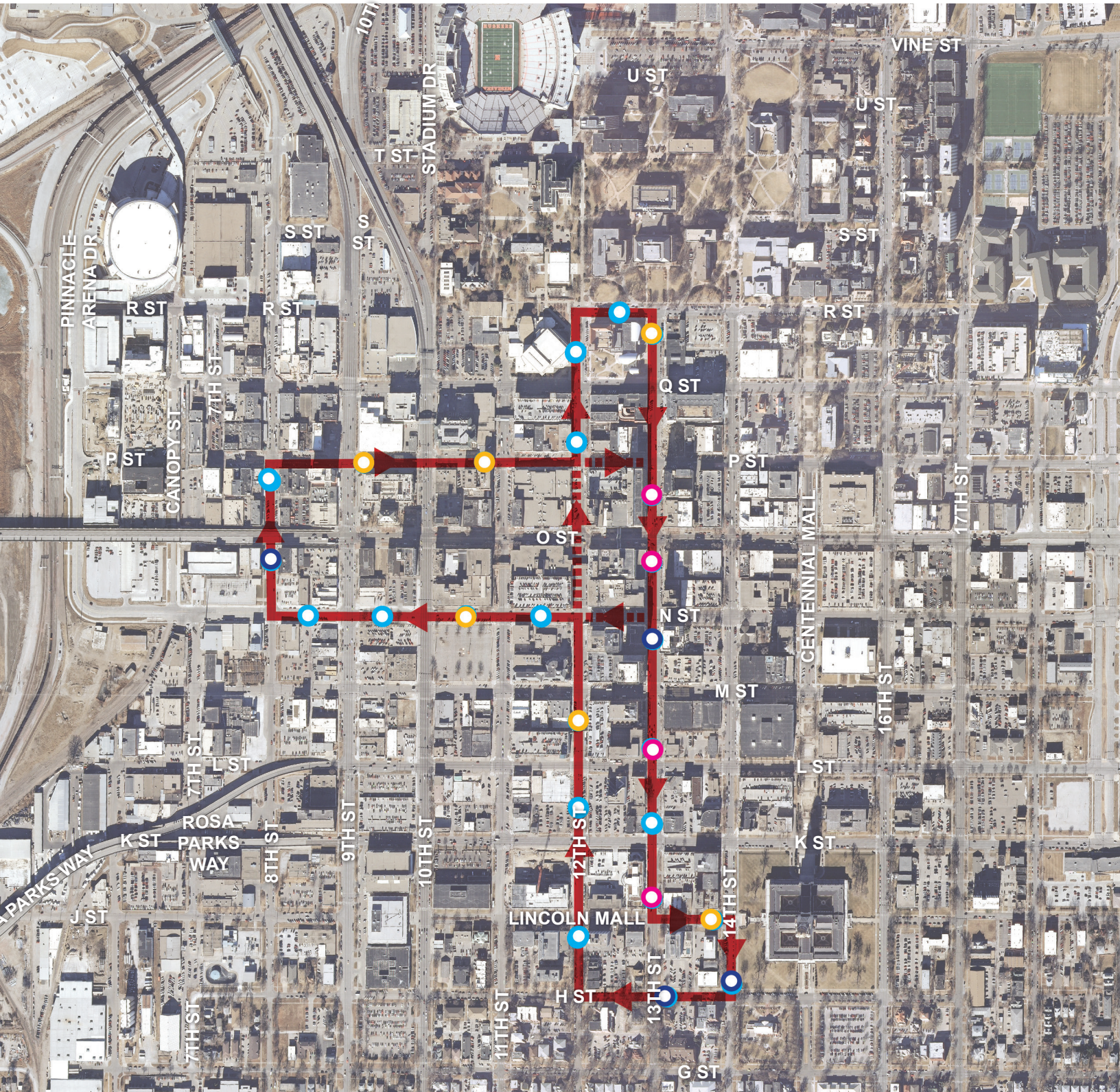
Figure 3.12 Parking area stop example
Image source: Google Maps

Traffic Lane (4 stops)

Some areas in Downtown have a curb that meets the street without on-street parking present. These areas are proposed for stops within traffic lanes in situations where passing lanes exist, and where traffic is slow.


Parking Area (10 stops)







Removing parking to provide for a microshuttle stop should be a last option. Several areas provide no other opportunity to incorporate a stop, so parking must be considered. In general, less parking will be affected if parallel spots, rather than head-in angled spots are used. Only one stop proposed on the map uses angled head-in spots.



Legend

Figure 3.13 Proposed pilot route with stops
 Map image source: ESRI



- | | | | | | |
|---|----------------|---|-------------------|---|-------------------|
|  | Main route |  | Loading area stop |  | Traffic lane stop |
|  | Shortcut route |  | Transit stop |  | Parking area stop |

Infrastructure Components

Signalized Intersections

One of the key considerations for AV microshuttles to be able to safely operate is appropriate treatment of intersections. At signalized intersections, signal phase and timing data (SPaT) must be transmitted to vehicles to increase situational awareness. While there are a number of ways to do this, the preferred method among microshuttle manufacturers is to utilize dedicated short range communications (DSRC) radio units.

DSRC forms the backbone of connected vehicle technology, which consists of point-to-point wireless communication between and among vehicles and infrastructure, including the following:

- Vehicle-to-vehicle (V2V) communication that allows vehicles to communicate with each other;
- Vehicle-to-infrastructure (V2I) communication that allows vehicles to communicate with surrounding infrastructure; and,
- Vehicle-to-all (V2X) communication that enables the interaction of vehicles and any capable communication device in the immediate vicinity.

The DSRC radios are the radio processors and associated firmware that is responsible for queuing, broadcasting and receiving connected vehicle messages. This sub-system component will also be responsible for broadcasting V2I and V2V messages from the OBEs and receiving V2I and V2V messages from RSEs and other OBEs, respectively. A second responsibility of this sub-system component is to ensure the authenticity of received messages and to process and provide the necessary encryption and authentication to messages received and transmitted.

Each autonomous vehicle will be equipped with a DSRC unit. In addition, the installation of roadside DSRC radios is recommended for all signalized intersections. The DSRC radio will be the mechanism by which traffic signal phasing and timing is shared with the vehicles. The signalized vehicles along the route are found in the following locations:

- S. 13th St. & K St.
- S. 13th St. & L St.
- S. 13th St. & M St.
- S. 13th St. & N St.
- S. 13th St. & E. O St.
- N. 13th St. & P St.
- N. 13th St. & Q St.
- N. 12th St. & Q St.
- N. 12th St. & P St.
- N. 11th St. & P St.
- N. 10th St. & P St.
- N. 9th St. & P St.
- S. 9th St. & N St.
- S. 10th St. & N St.
- S. 11th St. & N St.
- S. 12th St. & N St.
- S. 12th St. & M St.
- S. 12th St. & L St.
- S. 12th St. & K St.

Placement of DSRC radios inside signal cabinets, with antennae placed on nearby poles or mast arms, represents a very effective way to transmit SPaT data due to the extremely low latency of DSRC technology. Further it establishes a backbone for future connected vehicle applications as adoption rates increase with time.

Unsignalized Intersections

AVs are able to detect stop signs and appropriately determine when they have the right of way. However, a potential challenge exists at two-way stops where opposing traffic has the right of way. Current AVs are programmed to be highly cautious and may experience difficulty pulling into traffic in this scenario. The installation of four-way stops is recommended at all intersections where two-way stop signs give opposing traffic the right of way.

These intersections include:

- S. 13th St. & Lincoln Mall
- S. 12th St. & H St.
- S. 13th St. & H St.

Transit Stops

Infrastructure at transit stops is expected to be minimal, and will include static signage and, in some cases, pavement marking. Transit stops should be placed approximately every other block, as well as at key destinations such as the Nebraska Statehouse, University of Nebraska, and at locations that generate a lot of pedestrian traffic such as hotels, parking garages, and existing StarTran hubs. While the geography of the route will be fixed, including three proposed short-cuts, vehicles will deploy and stop dynamically according to the requested origin and destinations of passengers.

Existing transit StarTran stops will require new static signage to indicate the presence of an AV microshuttle stop. Where no transit service currently exists, stops will vary depending on whether curbside access is available. When available, static signage to indicate stops, as well as any necessary curbside parking and stopping restrictions, will be required. If curbside access is not available, transit stops should be placed where there is existing parallel parking. Pavement marking will be used to indicate the presence of a transit stop, along with static signage to indicate the presence of a stop as well as the new parking restriction.

Assistive Technologies and Reference Markers

One challenge that AVs encounter is the need to place themselves accurately within their environments. Assistive infrastructure technologies can help AVs overcome this barrier. On corridors with tall buildings on one or both sides of the streets, an urban canyon effect can disrupt or distort signals from the Global Positioning System (GPS). Placement of GPS signal repeaters on traffic signals or streetlights can mitigate this problem. Additionally, static signage with reference marker symbols can be placed at the roadside to help the vehicles place themselves accurately within their

Charging and Maintenance Facilities

The autonomous vehicles will be fully electric and will require a routine charging schedule. Charging should occur at a nearby facility that allows easy access to the route. Additional services such as cleaning and vehicle inspections and servicing will also be completed at this facility. The vehicles will be housed in the maintenance facility when not in service. The ability to comfortably accommodate all of the autonomous vehicles when needed and the availability of sufficient power for charging stations should be considered during the facility selection process.

04

User Scenarios

- Initiation of Service
- Statehouse user requests ride to Haymarket District
- Vehicle takes a shortcut
- Vehicle is full
- Vehicle serves multiple passengers at once
- Vehicle is involved in a traffic incident
- Route is blocked

Overview

A series of user scenarios were developed to reflect potential situations that will occur during the operation of the autonomous transit vehicles in downtown Lincoln.

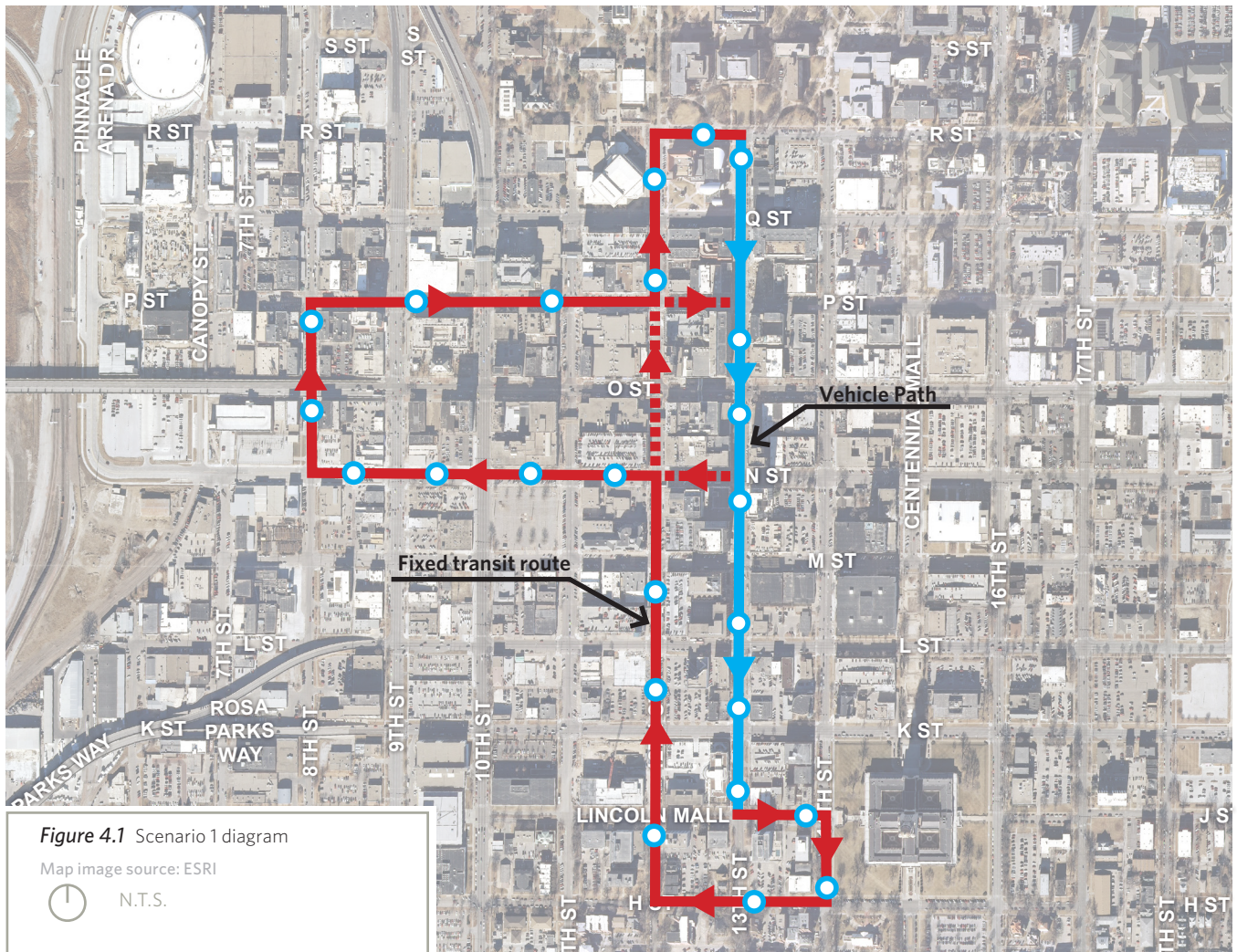
These scenarios focus on general vehicle operations, the integration of the mobile application with transit vehicle operations, and the rider experience. This section addresses 7 scenarios that are expected to occur during the proposed transit vehicle operations. Each scenario may include a diagram followed by a sequence of events that occur during the scenario.

Scenario 1:

Initiation of service

Series of events for Scenario 1

1. The vehicle initiates service at the charging and storage facility.
2. The vehicle's on-board technology components are initiated and complete their first scan of the day.
3. The vehicle departs from the charging and storage facility and travels to the intersection of N. 13th St. and R St. to begin operating along the fixed route.
4. The vehicle notifies the TMC that it has initiated service.
5. The TMC activates the ability for a passenger to request rides from the vehicle through the mobile application.
6. The vehicle drives to or remains at a predetermined staging area to await a passenger request.

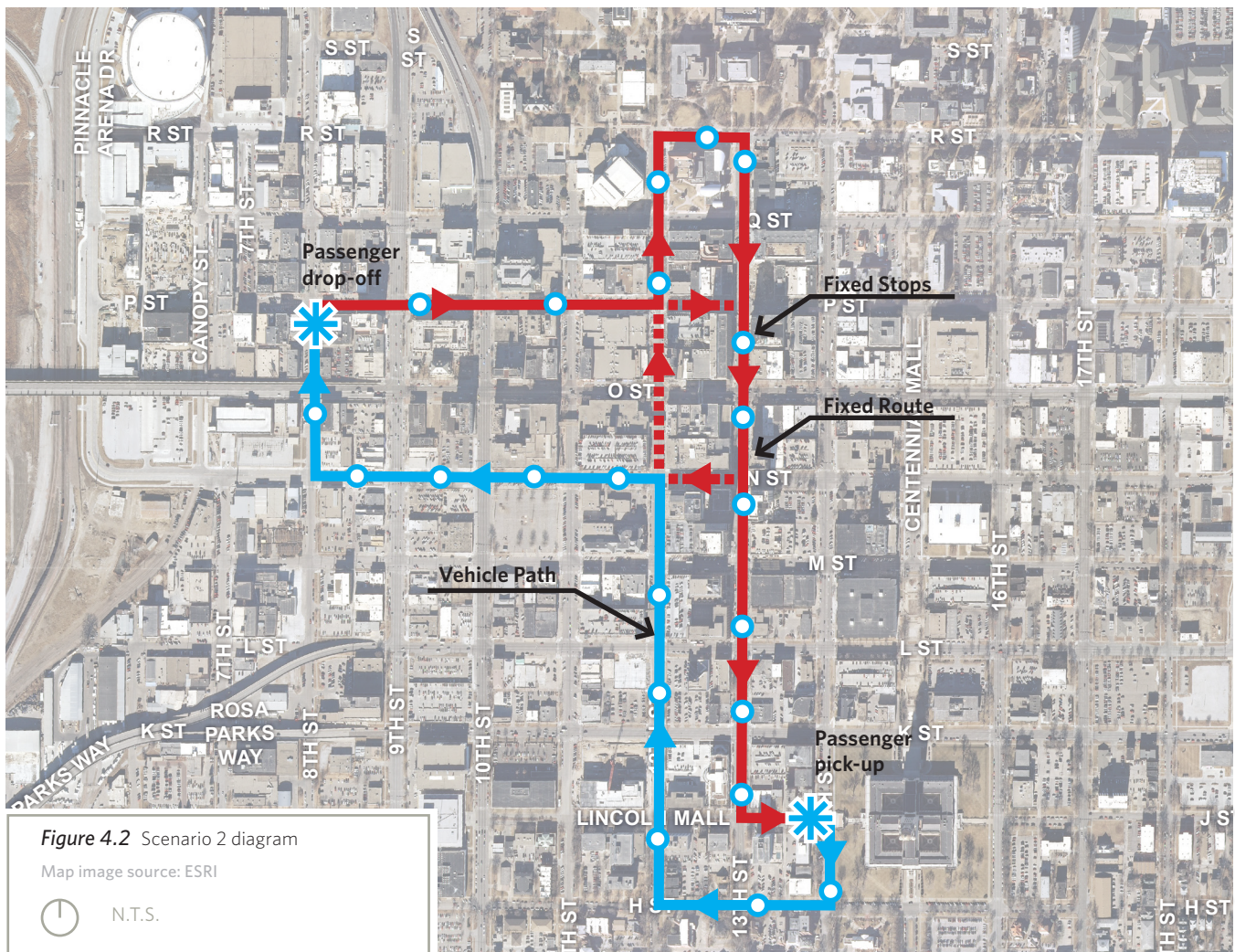


Scenario 2:

Statehouse user requests ride to the Haymarket District

Series of Events for Scenario 2

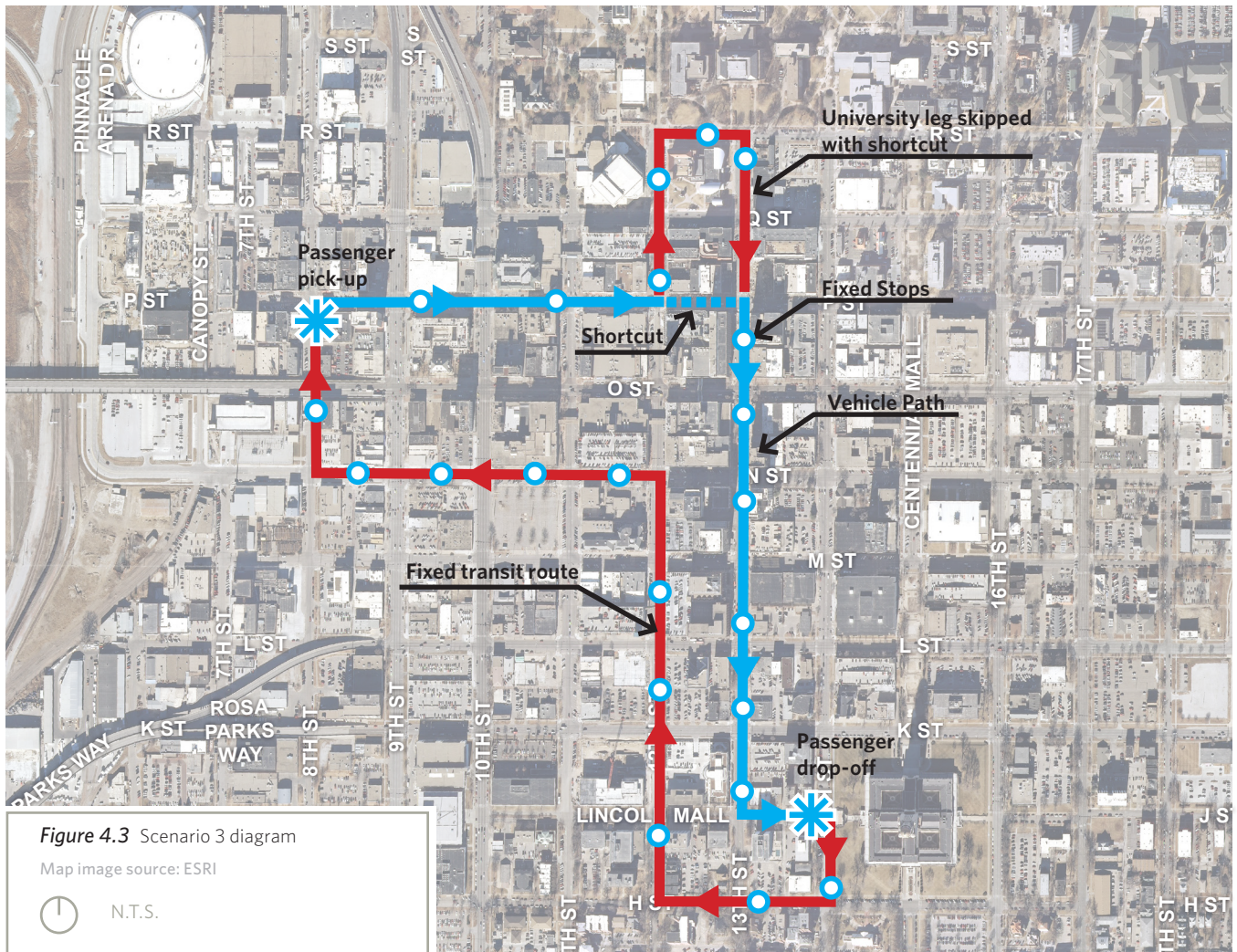
1. The user opens the mobile transit application.
2. The user requests a ride from the Statehouse to the Haymarket District.
3. The app requests that a vehicle be dispatched to pick up a passenger at the Statehouse.
4. The TMC determines which available vehicle is able to provide the shortest route for the rider and dispatches the vehicle to the Statehouse.
5. The vehicle arrives at the Statehouse and the passenger that requested the ride through the mobile application boards the vehicle.
6. The vehicle continues normal operations along the fixed route.
7. The passenger that requested a ride to the Haymarket District alights from the vehicle when it approaches the transit stop at the intersection of N. 8th St. and Q St.



Scenario 3: Vehicle takes a shortcut

Series of Events for Scenario 3

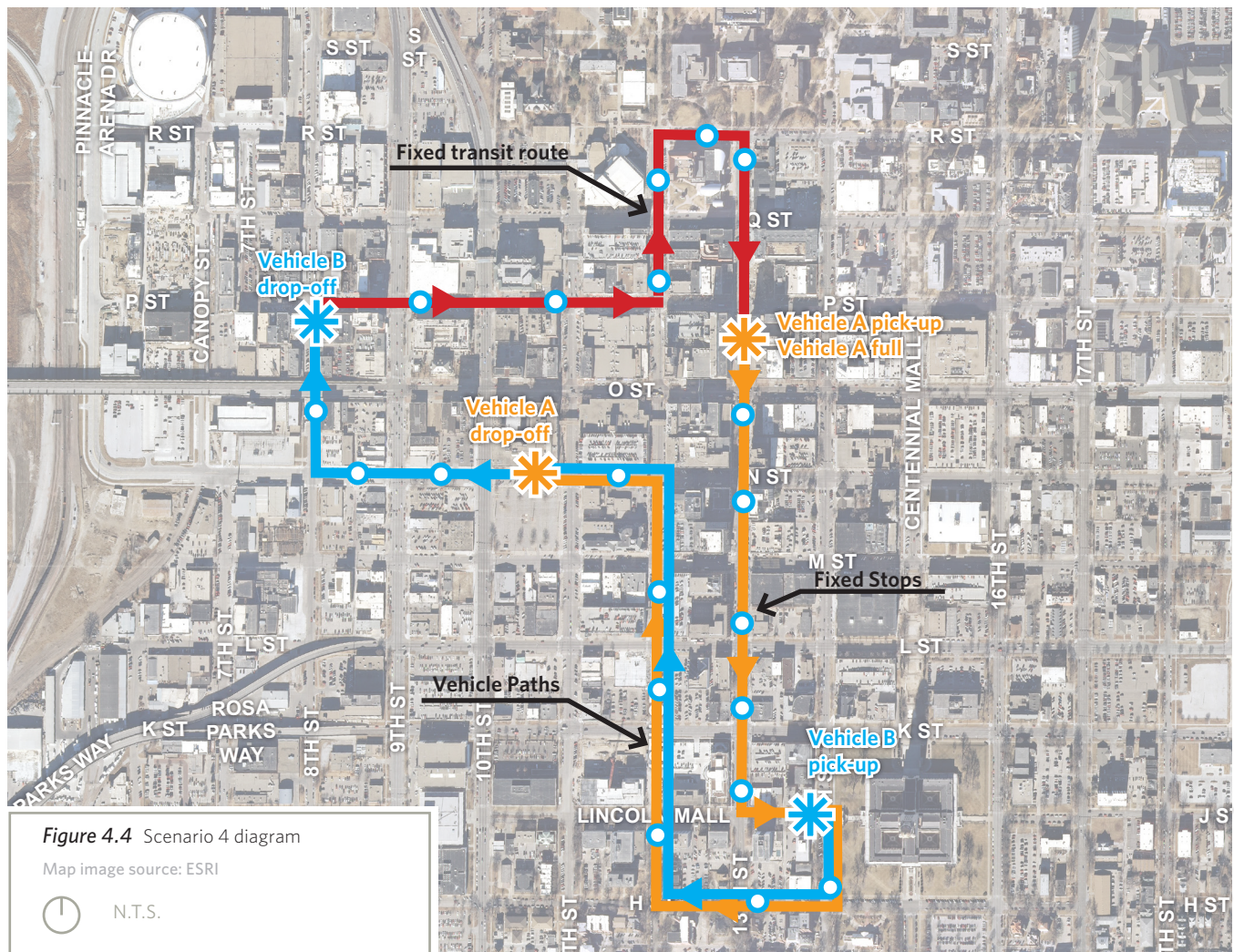
1. The autonomous vehicle is traveling along the route, headed East on P St. (West of N. 12th St. St.) with a passenger that is headed to the Statehouse.
2. The TMC determines that there is no need pick-up or drop-off needed at the University of Nebraska-Lincoln transit stops.
3. The TMC instructs the vehicle to bypass the portion of the fixed route that travels to the campus of the University of Nebraska-Lincoln.
4. When the vehicle reaches the intersection of P St. and N. 12th St., it continues straight through the intersection instead of turning left on N. 12th St. as it would on the fixed transit route.
5. The vehicle continues along the route until it stops at the transit stop near the Statehouse.
6. The passenger gets off of the vehicle.
7. The vehicle continues to service the fixed route as usual until another demand-responsive situation arises.



Scenario 4: Vehicle is full

Series of Events for Scenario 4

1. The autonomous vehicle is traveling on the fixed route approaching the Statehouse.
2. A passenger requests a pick-up at the transit station near the Statehouse, hoping to board the next vehicle that arrives.
3. A vehicle headed towards the Statehouse determines that it has reached maximum capacity and cannot accept any more passengers.
4. The vehicle approaches the transit stop near the Statehouse.
5. No passengers on board the vehicle signal that they would like to get off at the transit station.
6. The vehicle determines that it cannot stop to pick-up the waiting passenger at the Statehouse.
7. The vehicle alerts the TMC that it was unable to service the passenger waiting at the Statehouse.
8. The TMC contacts the next available vehicle with a request to pick up the passenger at the Statehouse.
9. The TMC alerts the waiting passenger that the vehicle is full, and indicates a new vehicle has been dispatched.
10. The next available vehicle is dispatched to the Statehouse.
11. The vehicle arrives at the Statehouse and the passenger that requested the ride through the mobile application boards the vehicle.
12. The vehicle continues normal operations along the fixed route.



Scenario 5: The vehicle serves multiple passengers at once

Series of Events for Scenario 5

1. The autonomous vehicle is traveling along the fixed route, waiting to be dispatched to a passenger pick-up location.
2. Passenger A uses the mobile application to request a ride from the transit station in the Haymarket District to the University of Nebraska-Lincoln campus.
3. The app requests that a vehicle be dispatched to pick up a passenger at the Haymarket District.
4. The autonomous vehicle is dispatched to the Haymarket District.
5. The vehicle arrives at the transit station in the Haymarket District and the passenger that requested the ride through the mobile application (Passenger A) boards the vehicle.
6. The autonomous vehicle continues along the route.
7. Passenger B uses the mobile application to request a ride from the transit station near the Great Plains Art Museum to the Statehouse.
8. The app requests that a vehicle be dispatched to pick up a passenger at the Haymarket District.
9. The vehicle traveling from the Haymarket District is determined to be the closest available vehicle and is assigned to pick up Passenger B.
10. The vehicle arrives at the transit station near the Great Plains Art Museum and Passenger B boards the vehicle.
11. The vehicle continues along the fixed route.
12. The vehicle stops at a transit station adjacent to the University of Nebraska-Lincoln campus.
13. Passenger A gets off of the vehicle.
14. The vehicle continues along the route.
15. The vehicle stops at the transit station near the Statehouse.
16. Passenger B gets off of the vehicle.
17. The vehicle continues to travel along the fixed route until it is dispatched to pick up a passenger.



Scenario 6:

Vehicle is involved in a traffic incident

Series of Events for Scenario 6

1. The autonomous vehicle is traveling along the fixed route, servicing passengers as rides are requested through the mobile application.
2. The vehicle hits an obstruction.
3. The vehicle stops.
4. The Traffic Management Center is notified that the vehicle has been involved in an incident.
5. The TMC dispatches a local public service representative for the City of Lincoln to the scene of the incident.
6. The representative arrives at the scene and discovers that the vehicle has hit an obstruction along the route.
7. The City representative determines the appropriate course of action based on the obstruction that the vehicle hit and the severity of the collision.
8. If the collision is determined to be serious, the representative escorts the passengers off of the vehicle and notifies the TMC and the City of Lincoln that additional help will be required to resolve the issue. If the collision is not considered to be serious, the representative notifies the TMC and City of Lincoln that the vehicle has been involved in a minor incident and the issue can be resolved quickly.
9. If the vehicle requires maintenance, it is taken back to the storage, maintenance, and charging facility.
10. Once the issue has been resolved, the vehicle continues normal operations along the fixed route.

Scenario 7:

The route is blocked

Series of Events for Scenario 7

1. The autonomous vehicle is traveling along the fixed route, servicing passengers as rides are requested through the mobile application.
2. The vehicle approaches a stationary object, such as a delivery vehicle, that is obstructing the route.
3. The vehicle stops before reaching the object.
4. The vehicle notifies the vendor TMC that there is an obstruction on the route and that the vehicle has stopped.
5. The vendor TMC checks the exterior camera to determine the nature of the obstruction.
6. If the vendor TMC determines there is enough clearance to safely pass the obstruction, they will instruct the on-board operator to manually drive the vehicle around the obstacle.
7. If an on-board operator is not present, the vendor TMC will remotely operate the vehicle around the obstruction, or direct the vehicle to pass the obstruction.
8. The vehicle performs a safe passing movement and continues along the fixed route.



05

Policy and Legislative Environment

- Overview
- Modifications to Nebraska State Law
- Meeting Federal Motor Vehicle Standards

Overview

Several existing State and Federal regulations must be modified or waived in order to operate the proposed autonomous transit service in Lincoln. These regulations relate to the physical operation of the vehicle on public roadways, the driver's interaction with the vehicle operations, licensing requirements, and various definitions.

Modification to Nebraska State Law

State responsibilities related to motor vehicles generally include licensing drivers, registering vehicles, and enacting and enforcing traffic laws and regulations. A complete scan of existing Nebraska legislation was done in order to identify conflicts with autonomous vehicle operations. The Nebraska State laws that will potentially need to be modified or waived in order to implement the autonomous transit vision described in this document are identified in Table 5.1.

Table 5.1 Nebraska State Law Modifications

Nebraska Law	Related Text
60-3, 100	"A license decal shall be issued with the license plate as provided in subdivision (ii) of this subdivision and shall be displayed on the driver's side of the windshield."
60-4, 122	"(1) Except as otherwise provided in subsections (2), (3), and (8) of this section, no original or renewal operator's license shall be issued to any person until such person has demonstrated his or her ability to operate a motor vehicle safely as provided in section 60-4,114."
60-462.01	"For purposes of the Motor Vehicle Operator's License Act, the following federal regulations are adopted as Nebraska law as they existed on January 1, 2017: The parts, subparts, and sections of Title 49 of the Code of Federal Regulations, as referenced in the Motor Vehicle Operator's License Act."
60-474	"Operator's or driver's license shall mean any license or permit to operate a motor vehicle issued under the laws of this state"
60-476	"Operator or driver shall mean any person who drives a motor vehicle"
60-484	"(1) Except as otherwise provided in the Motor Vehicle Operator's License Act, no resident of the State of Nebraska shall operate a motor vehicle upon the alleys or highways of this state until the person has obtained an operator's license for that purpose."
60-489	"Except for a farm permit issued under section 60-4,126, the operator's license shall at all times be carried by the licensee when operating a motor vehicle on the highways of this state and shall be presented by the licensee for examination, or he or she shall present proof of ownership of the same, upon demand by any officer, employee, or agent of the Nebraska State Patrol or police or peace officer recognized as such by the laws of this state..."
60-6, 125	"(1) When a red lens is illuminated with rapid intermittent flashes, drivers of vehicles shall stop at a clearly marked stop line or shall stop, if there is no such line, before entering the crosswalk on the near side of the intersection or, if there is no crosswalk, at the point nearest the intersecting roadway where the driver has a view of approaching traffic on the intersecting roadway"
60-6, 136	"(1)(a) He or she approaches the crest of a grade or is upon a curve in the highway where the driver's view is obstructed within such distance as to create a hazard in the event another vehicle might approach from the opposite direction"
60-6, 148	"(2) ...at the point nearest the intersecting roadway where the driver has a view of approaching traffic on the intersecting roadway before entering the intersection. (3) ... at the point nearest the intersecting roadway where the driver has a view of approaching traffic on the intersecting roadway."
60-6, 168	"No person having control or charge of a motor vehicle shall allow such vehicle to stand unattended on a highway without first: (1) Stopping the motor of such vehicle; (2) except for vehicles equipped with motor starters that may be actuated without a key, locking the ignition and removing the key from the ignition; (3) effectively setting the brakes thereon; and (4) when standing upon any roadway, turning the front wheels of such vehicle to the curb or side of such roadway."

60-6, 173	<p>"(1) ...shall stop such vehicle not more than fifty feet nor less than fifteen feet from the nearest rail or railroad and while stopped shall listen and look in both directions along the track for an approaching train. The driver shall not proceed until precaution has been taken to ascertain that the course is clear.</p> <p>(2) (b) At an abandoned or exempted grade crossing which is clearly marked as such by or with the consent of competent authority when such markings can be read from the driver's position"</p>
60-6, 179	<p>"(1) No person shall drive a motor vehicle when it is so loaded, or when there is in the front seat such a number of persons, exceeding three, as to obstruct the view of the driver to the front or sides of the vehicle or to interfere with the driver's control over the driving mechanism of such vehicle.</p> <p>(2) No passenger in a vehicle shall ride in such a position as to interfere with the driver's view ahead or to the sides or to interfere with the driver's control over the driving mechanism of such vehicle."</p>
60-6, 179.02	"(2) Except as otherwise provided in subsection (3) of this section, no person shall use a handheld wireless communication device to read a written communication, manually type a written communication, or send a written communication while operating a motor vehicle which is in motion."
60-6, 254	"Operator; view to rear required"
60-6, 255	"(2) It shall be unlawful for any person to drive any vehicle upon a highway with any sign, poster, or other nontransparent material upon the front windshield, side wing vents, or side or rear windows of such motor vehicle other than a certificate or other paper required to be so displayed by law. The front windshield, side wing vents, and side or rear windows may have a visor or other shade device which is easily moved aside or removable, is normally used by a motor vehicle operator during daylight hours, and does not impair the driver's field of vision."
60-6, 257	"(1)(a) If the windows in such motor vehicle are tinted so that the driver's clear view through the windshield or side or rear windows is reduced or the ability to see into the motor vehicle is substantially impaired"
60-6, 265	<p>"(1) Occupant protection system means a system utilizing a lap belt, a shoulder belt, or any combination of belts installed in a motor vehicle which (a) restrains drivers and passengers...</p> <p>(2) Three-point safety belt system means a system utilizing a combination of a lap belt and a shoulder belt installed in a motor vehicle which restrains drivers and passengers."</p>
60-6, 270	"No driver shall operate a motor vehicle... unless the driver and each front-seat occupant in the vehicle are wearing occupant protection systems"
60-6, 287	"It shall be unlawful to operate upon any public highway in this state a motor vehicle which is equipped with or in which is located a television set so placed that the viewing screen is visible to the driver while operating such vehicle."
60-6, 303	"Any peace officer or carrier enforcement officer having reason to believe that the weight of a vehicle and load is unlawful is authorized to require the driver to stop and submit to a weighing of the vehicle and load..."
60-642	"Operator or driver shall mean any person who operates, drives, or is in actual physical control of a vehicle."

60-683	"(4) When in uniform, to require the driver of a vehicle to stop and exhibit his or her operator's license and registration certificate issued for the vehicle"
60-696	<p>"(1) Except as provided in subsection (2) of this section, the driver of any vehicle involved in an accident upon a public highway, private road, or private drive, resulting in damage to property, shall (a) immediately stop such vehicle at the scene of such accident...</p> <p>(2) The driver of any vehicle involved in an accident upon a public highway, private road, or private drive, resulting in damage to an unattended vehicle or property"</p>
60-697	"(1) The driver of any vehicle involved in an accident upon either a public highway, private road, or private drive, resulting in injury or death to any person, shall (a) immediately stop such vehicle at the scene of such accident and ascertain the identity of all persons involved, (b) give his or her name and address and the license number of the vehicle and exhibit his or her operator's license to the person struck or the occupants of any vehicle collided"

Meeting Federal Motor Vehicle Safety Standards

Like all vehicles that operate on public roads, the microtransit vehicles are required to meet the Federal Motor Vehicle Safety Standards (FMVSS). The FMVSS are "U.S. federal regulations specifying design, construction, performance, and durability requirements for motor vehicles and regulated Automobile safety-related components, systems, and design features." The FMVSS contains a significant number of provisions that all motor vehicles must meet; particularly those involving crash-worthy and is supplemented for transit vehicles by a host of other regulations regarding persons with disabilities as identified in the American's with Disabilities Act (ADA) and codified in 49 CFR Part 38, Subpart G.

With few exceptions, all transit vehicles must comply with the FMVSS Numbers: 101-106; 108; 111; 113;116; 119-121; 124; 205; 217; 302; and 303. Additional standards regarding safety for the transit driver also must be met provided there is an on-board driver. Several small transit vehicles deployed within the U.S. operate a speeds less than 25 mph and have a gross vehicle weight less than 3,000 pounds. These vehicles fall under the FMVSS Low-Speed Vehicle definition and are generally exempted from many of the FMVSS regulations.

The 8-16 passenger autonomous microtransit vehicles currently offered in the market today operate within the speed parameters of a Low-Speed Vehicle, but have almost twice the allowable weight. Therefore, these vehicles need to meet FMVSS regulations like any other transit vehicle. Due to the relative newness of these vehicles and this technology in general, understanding the safety implications of low-speed vehicles at twice the GVW in the context of a highly autonomous system has not been sufficiently researched. In the meantime, NHTSA has been granting exceptions, on a case-by-case basis, for autonomous microtransit vehicles. Both Easymile and Navya have received such exemptions and a similar exemption would be expected for the Lincoln Pilot.

06

Schedule and Cost

- Schedule
- Business models
- Cost

Schedule

The ultimate goal is to have a functional autonomous shuttle system open to riders by mid to late fall, 2018. The schedule as outlined below summarizes the major milestones and their optimal timeline for completion:

- **Vendor engagement**
Begin in early 2018
- **Waiver from Federal Motor Vehicle Safety Standards**
from NHTSA
February, 2018
- **Exemption from Nebraska regulations and creation of AV Proving Ground**
March, 2018
- **Vehicle vendor(s) selected and vehicle's procured**
Summer, 2018
- **Pilot Testing**
Late Summer / Fall, 2018
- **Full Operations**
Mid-Late Fall, 2018

Business Models Overview

There are several potential business models that could be used to fund the pilot project including a fully City funded pilot, a pilot funded by obtaining research grant funding, or funding the pilot through a public-private partnership(s). Funding options could also be used in combination as well.

City Funded

Given the relatively new nature of the technology and the objectives of the pilot project, it may be challenging for the pilot to be fully funded through fare revenue collection and/or commercialization of advertising space on the vehicles and/or stops given the short duration of the project and the unknown ridership and market penetration. One important component of the pilot will be to test how a larger deployment of shuttles could be partially supported with a reliable revenue stream. A fare-supported model would charge users of the shuttle service on either a per-month or a per-ride basis, giving passengers the flexibility adapt their payment option to their use of the shuttle. Frequent users of the service might opt for a monthly fee, while infrequent users would be better suited for a per-ride fee. The City will need to balance the fee to be low enough to attract users, but high enough to generate revenue to offset some cost of operation. A business model that partners with other organizations or businesses could offer additional ways to generate steady revenue. Heavy users may want a dedicated stop along the route to give better access to off-site parking, or connect to high concentrations of parking and amenities. Additionally, revenue can be generated by selling the exterior of the vehicles with “wraps”, in a similar fashion to what is typically done for buses.

Research Grants

As an alternative to the city self-funding the pilot, there are a number of research and other grant opportunities that may provide funding. Funding transit technology such as autonomous vehicles is generally an allowable component to many Federal transportation funding grants.

Partnering Opportunities

Finally, there is the potential for the City to partner with other public-private entities to establish a microtransit autonomous vehicle proving ground in Lincoln that could attract private investment. For example, in 2017 the U.S. DOT designated 10 Autonomous Vehicle Proving Grounds across the country as locations where testing and research by both public and private entities could be performed. Several of these proving grounds have kick-started their activities through the use of a public-private partnership. For example, as part of the Texas Alliance, the City of Arlington, Texas is establishing a microtransit service within the city limits through a partnership with Chariot, a private transportation provider. The City of Lincoln could engage various industries to utilize the vehicles as a proving ground to test, in a real-world environment, emerging technologies such as those associated with electric battery utilization and charging, emergence of 5th Generation (5G) cellular technology, and new advances in pedestrian and vehicle safety systems.



Figure 6.1 Bus wrap example

Image source: Sounder Bruce <https://flic.kr/p/sc3NLD>

Cost

Three primary options are available for the acquisition of autonomous microshuttles, and include outright purchase, contract with a service provider, or a lease. These options are briefly described, along with the estimated cost of each option, not including roadside infrastructure.

Purchase vehicle directly

The option that offers the most control for the City is to purchase the vehicles outright. Vendors have provided estimates on the cost of an individual vehicle at approximately \$350,000 and a yearly operating cost of approximately \$47,000 per year. The operating cost covers the supervision, fleet management, system licensing, and ongoing maintenance. Insurance would not be part of the cost.

Contract with a service provider

A number of microshuttle deployments within the United States and Europe have been managed by transit management / fleet management companies. This option offers the most turn-key solution to the City, who would contract directly with the management company to manage all aspects of the pilot deployment. Companies such as FirstGroup, TransDev, and Keolis have all managed deployments of both EasyMile and Navya shuttles. These companies would own the vehicles, provide maintenance, insurance, and operations of the pilot, in addition to any employees needed.

Preliminary quotes of the service provider option are estimated around \$725,000 per year for a four-vehicle deployment, and one full-time employee. This option assumes that “shuttle ambassadors” are provided by the City or one of its partners. This option would cover the cost of maintenance, insurance, overall management of the fleet, and coordination of any transit deployment apps that would be needed.

Lease through lease agreement

Vehicle vendors are in the process of solidifying options for turn-key lease agreements that would cover the cost of the microshuttle, maintenance, insurance, and the cost of the “back end” operations. This option would not include any employees, and the City would be responsible for

coordination of any apps and transit payment modules. This option offers a good amount of flexibility and an upfront cost that is likely lower than the other two options, but does leave some effort for the City in terms of staffing and management.

Cost Estimate

The most appropriate option for Lincoln will ultimately depend on the duration of the pilot, how much effort the City is willing to cover in-house, and how the technology progresses. As the technology becomes more widespread, and as more companies enter the market, there may be fluctuation in prices that make owning vehicles a less desirable option.

For the purpose of this project and this cost estimate, the lease option has been used as the basis for vehicle cost. Based on preliminary discussions with vendors, an estimate of \$140,000 per vehicle per year has been used as the assumed lease price. This yearly price includes the cost of liability and collision insurance for the vehicle.

The estimated costs associated with a 2-year deployment of autonomous microshuttles in Lincoln are shown in Table 6.1. This preliminary cost estimate includes the infrastructure components such as DSRC radios, GPS repeaters, signing, pavement marking, charging facility upgrades, and installation of equipment. In addition, ongoing costs associated with the lease and insurance of four vehicles as well as annual maintenance of vehicles and equipment were estimated.

Total preliminary cost is estimated at approximately 1.39 million dollars, although a conservative approach may be appropriate for budgeting purposes, with an upper range of approximately 2 million dollars.

As the project moves forward and more details regarding the vehicle requirements and specific transit stop locations are determined, this cost estimate must be updated to reflect the most current quantity and unit cost approximations.

Table 6.1 Preliminary cost estimate - Lease Agreement

Item	UOM	Unit Cost (\$)	Quantity	Total Cost (\$)
Initial costs				161,385
DSRC radio	Each	1,400	19	26,600
DSRC radio installation and labor	Each	5,000	19	95,000
GPS repeater	Each	300	10	3,000
GPS repeater installation and labor	Each	2,000	10	20,000
Signs (stop signs, transit signs, parking signs, reference markers)	SF	20	490	9,800
Installation of signs	SF	6.50	490	3,185
Pavement markings	LF	0.50	2600	1,300
Upgraded electric for charging facility	LS	2,500	1	2,500
Ongoing costs (2 years)				1,225,500
Vehicle lease, maintenance, and support from vendor	Each / year	140,000	8	1,120,000
DSRC radio annual maintenance	Each / year	2,250	38	85,500
GPS repeater annual maintenance	Each / year	1,000	20	20,000
Total preliminary cost estimate				1,386,885

07

System Functional Requirements

- Overview
- System Functional Requirements Table

Overview

The following table (Table 7.1) presents a set of common vehicle specifications that might be used in procurement. Individual AV manufacturers may have potential requirements and/or capabilities that go beyond those described in this chapter and throughout this document. As such these specifications may evolve over time as the City of Lincoln moves towards a larger implementation of the concept. Lincoln will soon be in the process of engaging with firms and vendors to discuss the pilot project. These efforts may result in the City learning new information that will impact the specifications.

Table 7.1 System Functional Requirements

Spec. Number	Requirement Priority	Requirement Statement
Physical Requirements		
PHY_001	Mandatory	The vehicle shall be no wider than 8 feet.
PHY_002	Mandatory	The vehicle shall be no longer than 25 feet.
PHY_003	Valued	If provisioned for standing passengers, the vehicle shall have an interior height for standing passengers of at least 7 feet.
PHY_004	Mandatory	The vehicle shall have a ground clearance of at least 10 inches while in motion.
PHY_005	Mandatory	The vehicle shall have a mechanism for City of Lincoln staff to re-fuel the vehicle.
Operational Requirements		
OP_001	Mandatory	The vehicle shall be able to be legally operated on public streets. <i>Note: Some vehicles may only be legal for operations when in dedicated lanes.</i>
OP_002	Mandatory	The vehicle shall be able to operate in mixed traffic general purpose travel lanes.
OP_003	Mandatory	The vehicle shall be able to operate within a 10' lane.
OP_004	Mandatory	The vehicle shall be capable of ascertaining right of way at intersections.
OP_005	Mandatory	The operational speed of the vehicle shall be at least 12 mph and no more than 35 mph at grade.
OP_006	Mandatory	The vehicle shall be capable of being operated in an autonomous fashion. <i>Note: The term "Autonomous" conveys the intent for the vehicle to be able to be operated without an on-board or remote operator. Normal driving functions such as (a) stopping, (acceleration/deceleration), traveling to the next station, and (c) detecting and reacting to potential hazards in the vehicle path are included in this definition.</i>
OP_007	Mandatory	The vehicle shall be capable of operating on a fixed route.
OP_008	Mandatory	The vehicle shall be capable of operating on a dynamic schedule based on rider demand.
OP_009	Mandatory	The vehicle shall be capable of utilizing pre-defined short cuts based on rider demand.
OP_010	Mandatory	The vehicle shall be capable of receiving ride requests via smart phone application.
OP_011	Valued	A full complement of passengers should be able to embark/disembark from the vehicle within 20 seconds upon the vehicle coming to a complete stop.
OP_012	Mandatory	The vehicle shall be capable of operating continuously for a minimum of five hours without refueling. <i>Note: This requirement includes those conditions where climate controls are required.</i>
OP_013	Mandatory	The vehicle shall be able to be refueled overnight. <i>Note: Overnight is defined as a continuous period of inactivity of 8-10 hours.</i>

OP_014	Mandatory	The vehicle shall be capable of being manually operated for maintenance or emergency purposes. <i>Note: Examples of maintenance operations include positioning the vehicle for refueling, changing tires, fixing minor structural damage, etc. Examples of emergency purposes would include navigation around an unexpected obstacle encountered.</i>
OP_015	Mandatory	The vehicle shall be capable of disembarking passengers in the event of an emergency. <i>Note: For example, if there is a system failure within the vehicle, a medical emergency among passengers, etc.</i>
OP_016	Valued	The vehicle shall be capable of being locked. <i>Note: Locked refers to the ability of securing the vehicle to prevent unwanted entry and operation of the vehicle.</i>
OP_017	Valued	The vehicle shall be equipped with an emergency stop capability that can be activated by passengers.
OP_018	Mandatory	The vehicle shall provide to City of Lincoln real-time location information at a frequency of at least once per minute (60 seconds). <i>Note: Location information is expected to consist of Latitude, Longitude, Timestamp, Heading, and Speed.</i>
OP_019	Mandatory	The vehicle shall capture and notify City of Lincoln of a traffic issue/ incident within 60 seconds of occurrence.
OP_020	Valued	The vehicle shall be able to count and report to City of Lincoln daily the number of passengers transported.
OP_021	Valued	The vehicle shall have the ability to monitor in real-time the conditions within the vehicle's cabin. <i>Note: Visual monitoring would be preferred.</i>
OP_022	Valued	The vehicle shall be able to provide visual monitoring of the conditions external to the vehicle.
Passenger Comfort and Safety Requirements		
PC_001	Mandatory	The vehicle shall be capable of simultaneously transporting a minimum of 10 able-bodied persons.
PC_002	Mandatory	The vehicle shall be able to simultaneously accommodate at least one person in a wheelchair and at least six (6) other able-bodied persons.
PC_003	Valued	The vehicle shall have a mechanism enabling the entry and exit of the vehicle by a person in a wheelchair without requiring infrastructure-based equipment or ramps.
PC_004	Mandatory	The vehicle shall have provisions for a minimum of three persons to simultaneously travel in a seated position.
PC_005	Valued	The vehicle shall include provisions to secure occupied wheelchairs during transportation movements.
PC_006	Valued	The vehicle shall be capable of transporting a motorized scooter.
PC_007	Valued	The vehicle shall be equipped with seat-belts or other safety devices such as air-bags for the protection of occupants in vehicle crashes.
PC_008	Mandatory	The vehicle shall be equipped with climate control equipment capable of maintaining an interior cabin temperature of between 68 - 72 degrees Fahrenheit during transportation operations when the outdoor air temperature is between 20-90 degrees Fahrenheit.

08

Outcomes, Other Considerations, Next Steps

- Outcomes
- Other considerations
- Next steps

Outcomes

At its core, an autonomous shuttle is a new technology, one that will continue to grow in sophistication and adoption as the technology becomes more mature. This pilot is an opportunity for the City of Lincoln to establish itself as an early adopter, and an early leader in the deployment of this technology. The City and its partners can use this pilot as a way to gauge a number of useful insights related to the technology, including:

- Public acceptance of autonomous technology
- Test the viability of microtransit as a component of a transit system
- Test the viability of demand-responsive transportation as a way to reinforce transit
- Better trip data from users
- Understand how emerging autonomous technologies work and can be deployed in a real-life setting

This pilot is the first step in what could be a larger deployment of autonomous technology that serves the needs of the traveling public. Looking into the future, there may be additional phases that address last-mile issues with bus transit, or ways to deploy short-trip transit within the denser areas of Lincoln.

As mobility providers such as Uber, Waymo, Lyft, Ford, and GM are rapidly developing autonomous technology, the reduction in cost and increase in safety and reliability may be a challenge for transit. These services will likely be significantly less expensive than traditional car ownership, and may present real competition for transit. It's imperative that transit remain the backbone of Lincoln's transportation, providing access in an equitable manner to the City's population. It's likely that to stay competitive, transit will have to begin to utilize the same technologies and efficiencies that make the mobility providers an appealing option to the traveling public.

Other Considerations

Every new technology brings disruption in some form or another. One major point of contention with autonomous technology is the threat to jobs. It is not, and should not be the intent of this pilot to displace any jobs within the city. This pilot will add another layer of mobility within the downtown district, adding more options and perhaps appealing to a broader range of people. The deployment of the microtransit vehicles has the potential to employ several additional people to perform maintenance and supervision of the vehicles, in addition to acting as "ambassadors" to introduce the technology to the public.

Next Steps

This document is intended to guide the City of Lincoln in near-term planning as it moves towards implementing its multi-modal vision. The following steps should be taken in the immediate term to make the autonomous downtown shuttle a reality:

- Continue to engage the University of Nebraska, Downtown Lincoln Association, the Lincoln Chamber of Commerce, and internal stakeholders to encourage ongoing coordination in project implementation.
- Utilize ongoing dialogue with AV vendors to refine vehicle specifications and solicit proposals for vehicle leases.
- Perform analysis of existing intersections to finalize where new traffic control devices, if any, are needed.
- Identify where dedicated short range communications (DSRC) technology is needed at signalized intersections, and engage with AV microshuttle vendors to determine their requirements of DSRC infrastructure.
- Determine where vehicles can be stored and charged at night, and whether the chosen site meets electrical requirements for vehicle charging.
- Engage contractors for the installation/alterations of required DSRC, signage, pavement striping.
- Perform a preliminary hazard analysis (PHA), operations hazards analysis (OHA), and threat and vulnerability analysis (TVA) using the guidance set forth by the Federation Transit Administration in the Hazard Analysis Guidelines for Transit Projects.
- Develop and deliver training programs for City of Lincoln staff, first responders, and other participants in the day-to-day and emergency operations of the autonomous downtown shuttle.
- Develop and refine performance metrics with stakeholders and vendors to ensure the right data is captured to demonstrate project success.
- Identify opportunities for future route options and connection points to existing transit stops, parking, and points of interest.
- Verify pilot project is in conformance with applicable requirements of the FTA, NHTSA, ADA, and State and Local governing bodies.

Disclaimer: This document is not intended to dictate design or operations of an autonomous vehicle provider, supplier or vendor. HDR does not certify or warranty the pilot study design or operations. HDR is providing a planning level document that contains possible operational scenarios for decision makers to formulate final design and operational plans. All vendors, suppliers and/or operators shall review and determine the appropriate requirements of the pilot vehicles and systems to meet the operational requirements for the safe and proper operations of the vehicle.



Appendix

- Microtransit deployments
- Vehicle options
- Infrastructure and operational considerations
- Business models
- Technology considerations

Microtransit Deployments

There are a number of ongoing and planned autonomous microshuttle deployments in the United States and around the world. The locations of the U.S. deployments are shown in Figure A.1 and Table A.1. The weather conditions, roadway configurations, intended ridership, and time-lines of the deployments vary greatly.

The Contra Costa Transportation Authority launched an autonomous microshuttle service to serve employees in a large office park in San Ramon, CA. The service is currently only open to select employees that have agreed to provide feedback on their experiences¹. The Minnesota Department of Transportation is testing an autonomous shuttle on a closed course at their MnROAD testing facility in Monticello, MN. The deployment aims to analyze the operation of the vehicle in a variety of winter weather conditions². Jacksonville, FL and Arlington, TX have ongoing microshuttle deployments with routes that currently operate on closed routes and are generally planned to be open to the public during events and

¹ <http://www.govtech.com/fs/Driverless-Shuttle-Program-Kicks-Off-in-California-to-Tackle-First-MileLast-Mile-Mobility-Obstacle.html>

² <http://www.dot.state.mn.us/autonomous/bus/>

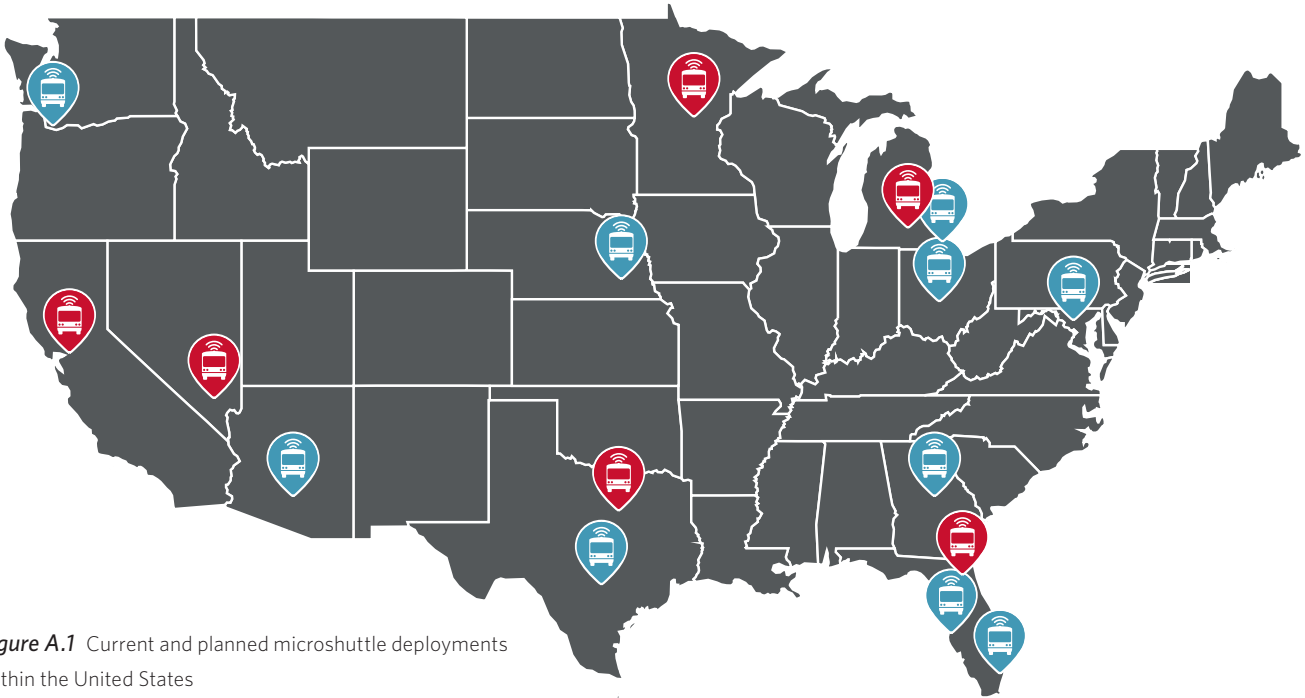


Figure A.1 Current and planned microshuttle deployments within the United States

pre-planned functions³⁴. A deployment in Las Vegas that was open to the public created controversy when it was involved in an incident during its inaugural day of operation. While the collision was minor and did not result in any injuries, the event was analyzed closely and it was determined that the autonomous shuttle was not at fault⁵.

The ongoing microshuttle deployments are providing agencies, researchers, and other interested parties with a number of lessons learned. Public acceptance of autonomous vehicles has increased as successful testing has been completed and more communities are given a chance to experience the emerging technology first-hand. Data quantifying measures such as ridership and miles traveled is being collected throughout the projects. Once the deployments are complete, this information will be extremely valuable in shaping future autonomous shuttle operations.

Table A.1 Microshuttle Deployments

	City	Shuttle	Mixed-Traffic
Current Deployments	Las Vegas, NV	Navya	Yes
	San Ramon, CA	EasyMile	Partial
	Jacksonville, FL	EasyMile	No
	Monticello, MN	EasyMile	No
	Arlington, TX	EasyMile	No
	Ann Arbor, MI	Navya	Yes
Planned Deployments	Lincoln, NE		Yes
	Phoenix, AZ		
	Austin, TX		
	Tampa, FL		Yes
	Miami, FL		
	Baltimore, MD		
	Columbus, OH		Yes
	Detroit, MI		

³ <http://www.arlington-tx.gov/news/2017/11/02/schedule-free-ride-milo-arlingtons-autonomous-shuttle-month/>

⁴ <http://jacksonville.com/news/metro/2017-12-19/jta-opens-test-track-future-self-driving-transit-shuttles>

⁵ <https://www.forbes.com/sites/jimgorzelay/2017/11/08/las-vegas-lets-it-ride-with-self-driving-shuttle-service/#213a3e17748f>

Vehicle Options

Overview

The proposed Lincoln deployment presents a number of challenges for the current offering of autonomous vehicle platforms. The size of the deployment, the complexities of a mixed-traffic scenario, and the challenges of production have led to a narrowing of two capable

platforms, each with its own strengths in relation to the Lincoln deployment. Both Navya and EasyMile have substantial experience and success in deploying vehicles, and represent the best, most cautious, and safest options that also meet the objectives of the project. A description of the advantages and disadvantages is below, followed by an overview of the critical specifications in Table A.2.



Navya Autonom Shuttle

Advantages

The Autonom Shuttle has a number of deployments throughout the world, several operating in mixed traffic scenarios. The vehicle is beginning production in the United States, and vehicles will be readily available for a fall 2018 deployment. This vehicle is equipped with an inductive charging system that eliminates the need for a physical detachment from charging before deployment.

Disadvantages

The Navya vehicle is equipped with an on-board ramp that can accommodate persons with disabilities. However, this ramp must be manually deployed by an on-board “ambassador” or other traveler. Additionally, the current Navya shuttle has limitations on the length of the route with a maximum route equivalent to approximately 2.0 miles.

Future Offerings

Navya is in the process of developing system software improvements that will allow an on-demand service within a geo-fenced area, giving the opportunity to deploy the vehicles into a larger area. The software is expected to be ready for use toward the end of 2018.

EasyMile EZ10 Shuttle Gen2

Advantages

The EZ10 Shuttle is a popular choice for closed-traffic systems, with many deployments throughout the United States and Europe. The shuttle offers an automatic handicapped ramp deployment, and has an API that will interface with major transit app creators. Generation 2 of the shuttle is under production, and will be available to the U.S. market by the time of Lincoln’s deployment.

Disadvantages

Produced in France, there will be a lag time for shipping, and may be an issue for the “Buy USA” requirement. The shuttle must be recharged through the use of an external charging cable. Prior to deployment this cable must be detached manually. Additionally, the vehicle is able to operate in a narrower range of temperatures than its competitor, which may be an issue during extreme temperatures in summer and winter.

Future Offerings

Generation 2 will offer a better array of sensors, including LiDAR. The development of Gen. 2 is specifically for commercial applications and deployment, and will include a greater range of deployment types the vehicle is capable of following.

Table A.2 Vehicle Specifications

	Navya Autonom Shuttle	EasyMile EZ10 Shuttle	
Capacity and Dimensions	Passengers	15 total (11 seated, 4 standing)	12 total (6 seated, 6 standing)
	Dimensions	L 15.58' W 6.92' H 8.69'	L 13.18' W 6.55' H 9.41'
	Clearance	7.87"	6.96" running / 3.94" in station
	Operating speed	15.5 mph	12.4 mph
	Empty Weight	5291 lbs	4079 lbs (standard); Options up to 4475 lbs
	Gross Weight	7606 lbs	6680 lbs
	Access Ramp for Wheeled Access	Manual ramp	Automated electric access ramp
	Power / Energy	Power	15 nominal (25 peak) kW
Battery		Battery pack LiFePo4	LiFePo4
Capacity		33 kWh	15.36 kWh (standard); Options up to 30.72 kWh
Average Autonomy		9 hours	Up to 24 hours (doesn't list average)
Charge duration for 90%		8 hours (induction or plug 3.6 kW); 4 hours (plug 7.2 kW)	8 hours (15.36 kWh battery); 6 hours (30.72 kWh battery)
Charging Technology		Induction / Plug	Wired / on-board
Charging Temperature		32 to 104 degrees Fahrenheit	
Operating Temperature		14 to 104 degrees Fahrenheit	23 to 95 degrees Fahrenheit
Localization and Obstacle Detection	LiDAR 1	Two 360 degree multi-layers LiDARs	Hybrid localization technology combining odometry, IMU, LIDAR, GPS, and cameras. Detection LiDARs and cameras. Safety relays, emergency stop switches, audio and visual warning alarm. Permanent 3G or 4G connection to EasyMile cloud infrastructure. High speed WiFi connection. Vehicle to infrastructure communication.
	LiDAR 2	Six 180 degree mono-layer LiDARs	
	Cameras	Front/rear cameras	
	Odometry	Wheel encoder + Inertial unit	
	GNSS	RTK	

Infrastructure and Operational Considerations

There are five main components to the proposed deployment:

- 1. Autonomous, Microtransit Vehicles:** There are expected to be 3 to 4 vehicles running simultaneously during the Pilot Demonstration.
- 2. On-Board Equipment (OBE):** This equipment would be mounted within a vehicle and consist of the following:
 - Autonomous vehicle sensor suite
 - Communications equipment including a DSRC radio and cellular connectivity
 - Central computer that processes the inputs from the sensor suite and the vehicle vendor monitoring and operations center
- 3. Roadside Equipment (RSE):** This equipment would be mounted above or adjacent to the roadside and consist of the following:
 - Traffic control devices
 - Transit vehicle monitoring
 - Communications equipment including DSRC radio and wireless access point (WAP)
- 4. Microshuttle Vendor Monitoring and Operations Center:** This represents the backend monitoring capabilities that microshuttle vendors offer, including the following:
 - Vehicle video camera feed
 - Vehicle status feed
 - Vehicle override system
 - Data warehouse
- 5. Lincoln Operations and Dispatch Center:** The function of this equipment is to monitor, process, store, and present information so that decisions can be made based upon the information. The following elements are included:
 - DSRC message center
 - Data warehouse

There are four primary flows of communication between these components:

- Information is exchanged between the On-Board Equipment and the Microshuttle Vendor Monitoring and Operations Center via cellular connectivity.
- Information is exchanged between the On-Board Equipment and the Roadside Equipment via DSRC connectivity.
- Information is exchanged between the Roadside Equipment and the Lincoln Operations and Dispatch Center via fiber connectivity.
- Information is transmitted between the Lincoln Operations and Dispatch Center and the Microshuttle Vendor Monitoring and Operations Center via fiber connectivity.

A conceptual system architecture is presented in Figure A.2, followed by a more detailed discussion of each element. It is assumed that the onus for decision making beyond the microshuttle's central computer will be the primary responsibility of the microshuttle vendor. The intent of this set-up is to allow the City of Lincoln to monitor vehicle status while limiting agency exposure to making safety-critical decisions.

On-Board Equipment

The OBE consists of the autonomous sensor suite, communications equipment, and a central computer. Each of these elements is described in more detail below.

Autonomous Vehicle Sensor Suite

The autonomous vehicle sensor suite subcomponent consists of the sensors that the vehicles rely on for object detection as typically found in autonomous vehicles as described above.

Communications Equipment

CELLULAR RADIO

This sub-component consists of a cellular modem for transmitting vehicle position, telematics, and the internal video camera feed back to the vendor's monitoring and operations center. The cellular radio will also be capable of receiving vehicle override commands from the vendor's monitoring and operations center.

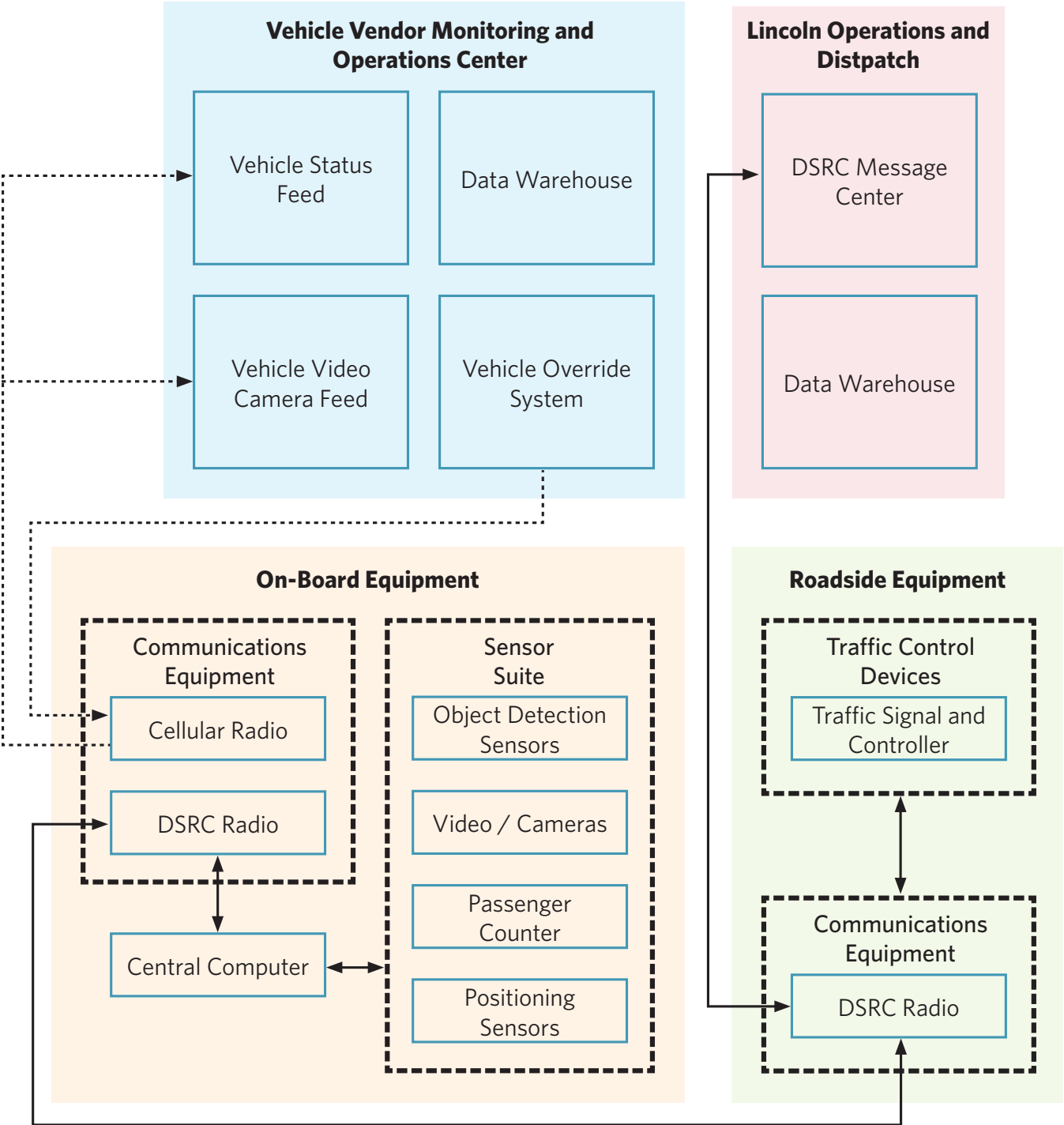


Figure A.2 Conceptual System Architecture

DSRC RADIO

This sub-component is the actual radio processor and associated firmware that is responsible for queuing, broadcasting and receiving connected vehicle messages. This radio provides communication using the SAE J2735 message set in accordance with IEEE 1609.2-2016 and IEEE 802.11p standards. In particular, this sub-system component will be responsible for broadcasting BSMs from the vehicle at a frequency of 10 Hz. This sub-system component will also be responsible for receiving V2I and V2V messages from RSEs and other OBEs, respectively. A second responsibility of this sub-system component is to ensure the authenticity of received messages and to process and provide the necessary encryption and authentication to messages received and transmitted.

J2735 NATIVE MESSAGE APPLICATIONS

Once messages are received by the DSRC Radio Stack, they are forwarded to the J2735 Native Message Application for decoding/parsing and processing. Collectively, these Native Message Applications must be capable of receiving and processing messages associated with:

- Basic Safety Message (Part I, Part II)
- Common Safety Request
- Map
- Signal Phase and Timing
- Traveler Information
- Roadside Alert

This sub-system component is also responsible for generating any or all J2735 messages, which are subsequently passed to the DSRC Radio Stack to be processed and transmitted. In particular, the Basic Safety Message Native Application is responsible for receiving the vehicle telematics, characteristics and positioning information and then packaging this information into a Basic Safety Message (BSM).

VEHICLE TELEMATICS AND POSITION

This sub-system component is responsible for obtaining the current vehicle telematics information such as speed, acceleration and other information from the vehicle and providing it to all other applications within the OBE. This sub-system component is also responsible for obtaining and providing vehicle location

to other sub-system components.

CENTRAL COMPUTER

This sub-system component is responsible for processing inputs from the autonomous vehicle sensor suite, interpreting messages from the on-board communications equipment, and making steering, acceleration, and braking decisions for the vehicle.

Roadside Equipment

The roadside equipment component is the point of connection between vehicles and infrastructure components. It is responsible for bridging communications among vehicles and between vehicles and the Lincoln Operations and Dispatch Center.

Traffic Control Devices

This will consist of the traffic signal, the traffic signal controller cabinet, and the mechanism for transmitting traffic signal preemption from autonomous vehicles to the signal controller. This could allow signal preemption if desired, and can be enabled via DSRC.

Communications Equipment

DSRC RADIO STACK

This sub-system component performs virtually the same functions as the corresponding sub-system component within the OBE.

J2735 NATIVE MESSAGE APPLICATIONS

This sub-system component performs virtually the same functions as the corresponding sub-system component within the OBE.

WIRELESS ACCESS POINT (WAP)

This sub-system component provides wireless coverage along the test track for the CCTV video feed transmission, if desired. WAPs are connected to the City of Lincoln fiber optics network.

COMMUNICATIONS BACKHAUL CONNECTIVITY

This sub-system component provides fiber connectivity, via a network connection, to the Lincoln Operations and Dispatch Center System Component. This connectivity may be accomplished via hardwire or wireless methods.

Vehicle Vendor Monitoring and Operations Center

The manner in which vendors monitor and vehicles and intervene in incidents varies from vendor to vendor. For the purposes of this document, it is assumed that this component will consist of the following sub-components.

Vehicle Status Feed

This sub-component consists of the presentation of vehicle position and telematics data to the vendor monitoring and operations center.

Vehicle Video Camera Feed

This sub-system component consists of the presentation of the internal on-board camera to the vendor monitoring and operations center.

Vehicle Override System

This sub-system component consists of a mechanism for sending a vehicle override command to the autonomous vehicle.

Data Warehouse

This sub-system component would serve to electronically store data from the system for additional processing and analysis.

Data warehouse

This sub-system component would serve to electronically store data from the system for additional processing and analysis.

Lincoln Operations and Dispatch Center

The Lincoln Operations and Dispatch Center is the system component that performs management and configuration activities of the overall system, and collects and stores data and communications.

DSRC Message Center

This sub-system component is responsible for processing all of the received DSRC messages from the RSE and configuring these messages for long-term data storage. In particular, of interest for processing would be the BSMs transmitted to the RSEs by the OBEs. This sub-system component is also responsible for processing any other alert/warning or status messages from the RSE.

Business Models

Overview

There are several potential business models that could be used to fund the pilot project including:

- A fully City funded pilot,
- A pilot funded by obtaining research grant funding, or
- Funding the pilot through a public private partnership(s).

Each of potential operations could also be used in combination as well.

City Funded

Given the relatively new nature of the technology and the objectives of the Pilot, it may be challenging for the pilot to be fully funded through fare revenue collection and/or commercialization of advertising space on the vehicles and/or stops given the short duration of the project and the unknown ridership and market penetration. One important component of the pilot will be to test how a larger deployment of shuttles could be partially supported with a reliable revenue stream. A fare-supported model would charge users of the shuttle service on either a per-month or a per-ride basis, giving passengers the flexibility adapt their payment option to their use of the shuttle. Frequent users of the service might opt for a monthly fee, while infrequent users would be better suited for a per-ride fee. The City will need to balance the fee to be low enough to attract users, but high enough to generate revenue to offset some cost of operation. A business model that partners with other organizations or businesses could offer additional ways to generate steady revenue. Heavy potential users may want a dedicated stop along the route to give better access to off-site parking, or connect to high concentrations of parking and amenities. Additionally, revenue can be generated by selling the exterior of the vehicles with “wraps”, in a similar fashion to what is typically done for buses.

- **Potential ridership revenue** – if we assume a very modest degree of ridership at 100 rides a day on average; over the course of the two year pilot, this would generate ~\$73,000 in funding. As ridership increases, this funding mechanism would also

increase proportionally.

- **Advertising and commercialization of the shuttle fleet.** Typical bus wrap advertising is on the ball-park of \$2,000 - \$8,000 for a 4 week wrap. Over two years, assuming a \$5,000 price for 4 weeks, this would result in ~\$130,000 in funding. Again, as ridership and utilization of the vehicles increases, this could result in increased revenue from advertising.

Research Grants

As an alternative to the city self-funding the pilot, there are a number of research and other grant opportunities that may provide funding. Funding transit technology such as autonomous vehicles is generally an allowable component to many Federal transportation funding grants including the following:

- **Advanced Transportation Congestion Mitigation and Technology Deployment (ATCMTD) Program** (\$60M each year for the next 3 years, 8-9 awardees per year)
- **Federal Transit Administration Mobility Sandbox** (\$12M; ~4-5 awardees)
- **University Transportation Research Center (UTC) Grants**
- **Broad Agency Announcements** – FHWA, FTA for technology research and development (various funding amounts on differing topics) for example, in 2017 FHWA sponsored research under the Exploratory Research Grants on the Impacts of Automated Transit, Pedestrian, and Bicycling Facilities on Urban Travel Patterns.
- **FTA Grants for Enhanced Mobility of Seniors & Individuals with Disabilities - Section 5310** Formula funding to states for the purpose of assisting private nonprofit groups in meeting transportation needs of the elderly and persons with disabilities.
- **FTA Flexible Funding Programs - Congestion Mitigation and Air Quality Program - 23 USC 149** CMAQ provides funding to areas in nonattainment or maintenance for ozone, carbon monoxide, and/or particulate matter. States that have no nonattainment or maintenance areas still receive a minimum apportionment of CMAQ funding for either air quality

projects or other elements of flexible spending. Funds may be used for any transit capital expenditures otherwise eligible for FTA funding as long as they have an air quality benefit.

- **FTA Formula Grants for Buses and Bus Facilities Formula Program - 5339(a)** Provides funding to states and transit agencies through a statutory formula to replace, rehabilitate and purchase buses and related equipment and to construct bus-related facilities
- **FTA Formula Grant Low and No-Emission Component Assessment Program (LoNo-CAP)** On September 29, 2016, FTA announced the opportunity for eligible institutions of higher education to apply for funding to conduct testing, evaluation, and analysis of low or no emission (LoNo) components intended for use in LoNo transit buses used to provide public transportation. The deadline for applications is November 28, 2016.
- **FTA Low or No Emission Vehicle Program - 5339(c)** Provides funding through a competitive process to states and transit agencies to purchase or lease low or no emission transit buses and related equipment, or to lease, construct, or rehabilitate facilities to support low or no emission transit buses. The program provides funding to support the wider deployment of advanced propulsion technologies within the nation's transit fleet.
- **Pilot Program for Transit-Oriented Development Planning - 5309** Provides funding to local communities to integrate land use and transportation planning with a transit capital investment that will seek funding through the Capital Investment Grant (CIG) Program.
- **Safety Research and Demonstration Program** - The Safety Research and Demonstration (SRD) Program is part of a larger safety research effort at the U.S. Department of Transportation that provides technical and financial support for transit agencies to pursue innovative approaches to eliminate or mitigate safety hazards. The SRD program focuses on demonstration of technologies and safer designs.
- **Zero Emission Research Opportunity (ZERO)** - On November 22, 2016, FTA announced the opportunity

for nonprofit organizations to apply for funding to conduct research, demonstrations, testing, and evaluation of zero emission and related technology for public transportation applications.

- **NIST Smart City/NSF Smart and Connected Cities**
- **Bloomberg Smart Cities Grant Award**
- **Congestion Mitigation and Air Quality Improvement (CMAQ)** - Federal Highway Administration (this technology is an allowable activity under the CMAQ grants).

Partnering Opportunities

Finally, there is the potential business model for the City to partner with other public/private entities to establish a microtransit autonomous vehicle proving ground in Lincoln that could attract private investment. For example, in 2017 the U.S. DOT designated 10 Autonomous Vehicle Proving Grounds across the country as locations where testing and research by both public and private entities could be performed. Several of these proving grounds have kick-started their activities through the use of a public-private partnership. For example, as part of the Texas Alliance, the City of Arlington, Texas is establishing a microtransit service within the city limits through a partnership with Chariot, a private transportation provider. The City of Lincoln could engage various industries to utilize the vehicles as a proving ground to test, in a real-world environment, emerging technologies such as those associated with electric battery utilization and charging, emergence of 5th Generation (5G) cellular technology, and new advances in pedestrian and vehicle safety systems.

Technology Considerations

Regulatory Environment for Autonomous Vehicles

Autonomous vehicles are being driven by private industry and are quickly moving into the market. According to the National Council on State Legislatures, “twenty-one states—Alabama, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Illinois, Louisiana, Michigan, New York, Nevada, North Carolina, North Dakota, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia and Vermont—and Washington D.C. have passed legislation related to autonomous vehicles.” Further, “Governors in Arizona, Delaware, Massachusetts, Washington and Wisconsin issued executive orders related to autonomous vehicles.” Much of this legislation involves requirements on the performance expectations and testing needed for an autonomous vehicle manufacturer to operate vehicles on public roads in the respective state. However, some states, such as Michigan, have essentially created an “open door” policy for autonomous vehicle manufacturers.

The legislative and policy landscape for autonomous vehicles is changing and potentially changing rapidly. In September of 2017, the National Highway Traffic Safety Administration (NHTSA) issued their second version of guidelines related to highly autonomous vehicles titled “Automated Driving Systems (ADS): A Vision for Safety 2.0.” This guidance document sets forth NHTSA’s interpretation on roles and responsibilities between Federal and State agencies as well as defines terms and

conditions associated with performance characteristics of highly-autonomous vehicles including defining the “Operational Design Domain,” the “Object and Event Detection” and “Fallback position.” Additionally, the guidelines set forth 12 safety priority elements and a voluntary self-assessment for manufacturers. In this guidance document, NHTSA suggests Best Practices for States Regulatory Actions as well as a division of responsibilities between the Federal and State governments (see Figure A.3).

Following the issuance of the NHTSA guidelines, the US House of Representatives passed the SELF DRIVE Act, a version of which was also subsequently passed out of the Senate Committee on Commerce, Science, and Transportation. The Senate bill has yet to undergo full vote in the Senate, but is expected to garner bi-partisan support. President Trump has further indicated his willingness to sign such a bill should it be presented following Senate vote and resolution with the House Bill. The SELF DRIVE Act would significantly change the legislative environment for States regarding highly autonomous vehicles. In particular, this act:

- **Establishes a timeline for Federal Regulatory Action:** “Not later than 24 months after the date of the enactment of this section, the Secretary of Transportation shall issue a final rule requiring 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.”
- **Preempts State’s Regulations.** “No State or political

Federal Responsibilities

- Setting Federal Motor Vehicle Safety Standards (FMVSSs) for new motor vehicles and motor vehicle equipment
- Enforcing compliance with FMVSSs;
- Investigating and managing the recall and remedy of noncompliance and safety-related motor vehicle defects nationwide; and,
- Communicating with and educating the public about motor vehicle safety issues.

State’s Responsibilities

- Licensing human drivers and registering motor vehicles in their jurisdictions;
- Enacting and enforcing traffic laws and regulations;
- Conducting safety inspections, where States choose to do so; and,
- Regulating motor vehicle insurance and liability.

Figure A.3 Regulatory responsibilities

subdivision of a State may maintain, enforce, prescribe, or continue in effect any law or regulation regarding the design, construction, or performance of highly automated vehicles, automated driving systems, or components of automated driving systems unless such law or regulation is identical to a standard prescribed under this chapter.”

- **Provides Exemptions for Manufacturers.**
“LIMITATION ON NUMBER OF VEHICLES EXEMPTED.—All exemptions granted to a manufacturer under subsections (b)(3)(B)(i) through (v) shall not exceed a total of (i) 25,000 vehicles manufactured within the first 12-month period, (ii) 50,000 vehicles manufactured within the second 12-month period, (iii) 100,000 vehicles manufactured within the third 12-month period, and, (iv) 100,000 vehicles manufactured within the fourth 12-month period.”

Notwithstanding the assuming that some version of the SELF DRIVE Act will be passed by the Senate and confirmed into law in 2017/2018, there are still a number of potential legislative and regulatory actions that States such as Nebraska should consider. These areas include:

- **Providing a technology “neutral” environment.** The Nebraska legislature should consider examining the existing laws and regulations for antiquated conditions that would prohibit the adoption of highly autonomous vehicles and remove these potential barriers. For example, some states have previously had a regulation on motor vehicle operation that included a provision that the operator “must have at least one hand on the wheel at all times.” Such a provision could be an impediment to adoption of highly automated vehicles.
- **Provide licensing and registration procedures for Highly Automated Vehicles.** If vehicles are becoming “drivers,” there will need to be updated policy and procedures for licensing and registration of these vehicles. In particular, Nebraska and other states will have to consider the technological components, software versions, sensors, and self-driving algorithms as part of registration and licensing. For example, changing the software versions or sensor package of a vehicle could be considered to be the equivalent of changing drivers in today’s environment.

- **Review traffic laws and regulations that may serve as a barrier to HAVs.** Similar to providing a technology neutral environment, there may be existing traffic laws and regulations that would serve as a barrier to adoption of HAVs. For example, a “no-texting” law that specifies that the person sitting in the driver’s position in the vehicle must use a “hands-free” device might need to be modified to include situations where the vehicle is serving as the driver.
- **Notification and Permission for Testing Process.** Although the SELF DRIVE Act would prohibit Nebraska from barring adoption of highly autonomous vehicles based upon performance or to require State specific testing procedures. The Nebraska legislature may wish to consider requiring manufacturers to notify the Nebraska Department of Roads and/or the relevant local municipality when new autonomous vehicles and/or autonomous vehicle systems are being tested within the state. Additionally, requirements restricting the Operational Design Domains for testing and operation of highly autonomous vehicles could be defined by the State to exclude or promote the use of highly autonomous vehicles in certain geographic or roadway types.

Ultimately, should the SELF DRIVE Act not become law, the Nebraska legislature should consider establishing testing and performance requirements for highly autonomous vehicles in Nebraska. Even if it does become law, there are still a number of different topic areas that will need to be addressed.

Licensing, titling, and street legality of current vehicles

Street Legality

All passenger vehicles operating on public streets in the U.S. are subject to the Federal Motor Vehicle Safety Standards (FMVSS). The FMVSS is a mandatory set of U.S. federal regulations specifying design, construction, performance, and durability requirements for motor vehicles and regulated automobile safety-related components, systems, and design features. Transit vehicles and commercial vehicles are also subject to aspects of the FMVSS as well as other relevant policy and guidance documents.

Virtually all of the current, available, autonomous microtransit vehicles do not meet many of the FMVSS standards and are therefore not considered to be “street legal” vehicles. In some cases, manufacturers have attempted to utilize the “Low-Speed Vehicle” provision of the FMVSS for their vehicles. This statute exempts vehicles from many of the remaining safety standards provided they meet the criteria on gross-vehicle weight (< 3,000 lbs) and maximum speed less than 25 mph. With the inclusion of large batteries for propulsion, the current versions of autonomous microtransit vehicles weigh roughly twice the allowable gross-vehicle weight for a low-speed vehicle rendering them subject to the full FMVSS standards.

Recently (2017), NHTSA has begun to grant exemptions from the FMVSS standards to specific manufacturers of microtransit autonomous vehicles that have demonstrated minimum safety characteristics and have agreed to other provisions such as reduced speeds. To date, both Navya and Easymile have received exemptions for their respective vehicles from NHTSA. As a result, both companies have been cleared for legal on-street operations within the parameters of their specific exemptions.

Licensing and Titling

Licensing and titling very much remain a State function and States where autonomous vehicles have begun to operate on public roads have licensed and titled these vehicles, exempting them from the relevant requirements that require a driver (if any).

Insurance and Liability

Insurance is a key consideration for the adoption of autonomous vehicles as they represent a potential shift in liability from the human driver to the autonomous operator. Various states have addressed this issue differently. For example, in Michigan, Senate Bill No. 996¹ requires:

“When engaged, an automated driving system or any remote or expert-controlled assist activity shall be considered the driver or operator of the vehicle for purposes of determining conformance to any

¹ <http://www.legislature.mi.gov/documents/2015-2016/publicact/htm/2016-PA-0333.htm>

applicable traffic or motor vehicle laws and shall be deemed to satisfy electronically all physical acts required by a driver or operator of the vehicle. A motor vehicle manufacturer shall insure each vehicle in a participating fleet as required under this act and chapter 31 of the insurance code of 1956, 1956 PA 218, MCL 500.3101 to 500.3179. For each SAVE project in which it participates, during the time that an automated driving system is in control of a vehicle in the participating fleet, a motor vehicle manufacturer shall assume liability for each incident in which the automated driving system is at fault, subject to chapter 31 of the insurance code of 1956, 1956 PA 218, MCL 500.3101 to 500.3179.”

Other States have required a human operator to be on-board and have set minimum insurance requirements. For example, SB 260 in Connecticut requires “...testing, including having an operator seated in the driver’s seat and providing proof of insurance of at least \$5 million.”

Generally, insurance for autonomous microtransit operations will reside with the vehicle manufacturers and the operators of the vehicles. The extent of liability between these two groups will depend upon the nature of the incident/accident as well as other factors such as maintenance and the testing and provisioning of routine system updates and software patches. For the purposes of this pilot, the City is expecting to contract both the system operation as well as the leasing of vehicles, which should limit insurance liability of the City.

Operations and maintenance

Autonomous microtransit vehicles such as those that are being considered for this pilot typically include electric propulsion systems that require very little maintenance beyond a regular recharge cycle and a climate controlled environment for storage to preserve the integrity of the batteries. However, like all vehicles, routine maintenance for replacement of worn tires and some of the other mechanical systems such as the wheelchair ramp and door actuators will need to be performed. Additionally, the vehicles will need to be cleaned regularly.

The City intends to contract these services under an operations and maintenance service contract.

Meeting “Buy USA” requirements

In 2014, the Nebraska Department of Roads in collaboration with the Federal Highway Administration established guidelines for the implementation of and conformance to the “Buy America” (BA) provisions introduced in the “The Moving Ahead for Progress in the 21st Century Act” (MAP-21). These guidelines were intended for all projects that include Federal funds. Provisions for BA remain active and are still requirements for many federally funded projects. For example, as indicated in the Nebraska Department of Roads Division of Safety Grant Contract Proposal Guide ², “The National Highway Traffic Safety Administration (NHTSA) indicated any product (equipment or materials) purchased using NHTSA federal highway safety grant funds must be made or assembled in America (documentation is also required). NHTSA may waive Buy America requirement if: (1) the application would be inconsistent with the public interest; (2) such materials and products are not produced in the US in sufficient and reasonably available quantities and of a satisfactory quality; or (3) the inclusion of domestic material will increase the cost of the overall product by more than 25 percent.”

These grant requirements would become relevant to the City if Federal funds are employed as part of this pilot project. However, in the case of autonomous microtransit vehicles, the City should expect to receive an exemption as there are very limited numbers of manufacturers that can provide vehicles capable of operating in mixed-traffic, on-road capacity. To date, only three manufactures have vehicles that would meet the expected performance requirements (Easymile, Navya, and Local Motors). Of these, the Local Motors vehicle is produced in the U.S., Navya is expecting to launch U.S. production in the first quarter of 2018, and EasyMile has established a U.S. office in Denver, but production is still being performed in France.

Personal security of riders

The personal security of riders is always a key consideration for any transit agency. In this pilot, the City will include an on-board ride facilitator who will be there to assist riders and to ensure that the vehicle and its occupants are safe and secure. Additionally, each vehicle

will be remotely monitored and will have the ability to remotely access in-vehicle video to monitor on-board conditions for the safety of the traveling public.

Cyber-security and the vehicles

The autonomous microtransit vehicles will be remotely monitored in real-time with information being transmitted to a centralized monitoring center every 15 milliseconds. All vehicle communications and access to electronic communications are only available through proprietary software systems that include the manufacturer’s cyber security protocols. Data collection by the system will not be available to the City or to the general public. However, summary records such as the number of travelers from a given origin to a given destination can be obtained. Video records are subject to subpoena and other legal initiated access, but will not otherwise be made available to the City or the traveling public. These records are considered to be proprietary information needed by the manufacturers to monitor performance.

Electrical components within the vehicle are secured behind locked access panels and require password protection and other security credentials to access.

² <http://dot.nebraska.gov/media/6207/policies17.pdf>

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