Design Guidelines with Scenario Planning for Connected and Autonomous Vehicles in Mid-sized Town- Take Champaign Downtown as a Pilot

Capstone Project Report
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Executive Summary

This capstone project is the result of a year-long process of research. This project is part of ICT-CAV Project. Based on the existing literature findings of uncertainties and scenario planning method, it focuses on several tasks: 1) make design guideline overview and synthesis. 2) refine scenario framework, construct scenarios in downtown Champaign and evaluate the impact. 3) make recommendations for design.

In task1, two main findings concluded from the scanning of design guideline are road prototype and public-realm land use. Road prototype provides information from street level and synthesize the elements of street. Three parts expounded are sidewalk, managed lanes and flex zone (smart curbside). Public-realm land use involves issues including street context, parking and city scale that may be taken into consideration for design in a larger urban scale.

In task2, four ownership models are constructed for the scenarios. Within the scenario profile, uncertainties and impacts are analyzed based on exiting uncertainties framework to evaluate the performances of scenarios. A vision plan, visualizations of high-level scenario, and road prototypes are provided to illustrate the details of scenarios and preliminary design considerations.

In task3, synthesis of key findings from the design guideline and performance of scenarios are concluded with five recommendations as the preliminary design guideline. The themes of recommendations include CAVs ownership, preparation for public-realm infrastructure and promotion for multimodal transportation with pedestrian-friendly design applications and transit-oriented development, aligning mixed land use and balance between community design with reginal goals.

A. Introduction

CAVs background

Technologies of automated and connected vehicles are gradually mature and appear more frequent in market. Connected vehicles are vehicles that use any of a number of different communication technologies to communicate with the driver, other cars on the road (vehicle-to-vehicle [V2V]), roadside infrastructure (vehicle-to-infrastructure [V2I]), and the “Cloud” [V2C] (McCormick, n.a.). Now U.S. Department of Transportation’s National Highway Traffic Safety Administration (NHTSA) has defined five automatic levels for CAVs. CAVs is promised to dramatically alter future mobility landscapes, and will have profound social, economic, and environmental impacts. However, much remains uncertain about the nature and impact of CAVs. Key uncertainties include the pace of technological change and adoption of CAVs, as well as their potentially transformative impact on driving demand, safety, roadway design, jobs, and the broader urban form. Furthermore, these uncertainties may vary by type of travel (freight vs. passenger), geography (highways vs. local), and socioeconomic context (low-income or elderly riders) (Kockelman et al, 2016). Communities need to anticipate how the trajectories of possible changes could affect them and make plans that can help them achieve favorable outcomes.

Many cities and states in US currently are planning and testing this technology and managed to place the technology on ground. New York, Boston, Arlington, San Jose have either a CAV pilot program or a testing case by which citizens are exposed to this technology and their reliability is tested and enhanced.
Active planning for CAVs is still at the early stages. Most planning and transportation agencies as well as AV private companies are uncertain of the various impacts and their magnitude on environment, economy, city infrastructure and mobility (transportation) behavior. As a result of this uncertainty, regulations, and design and policy strategies to be implemented are also unclear.

Object of Project
As the first part of the report, the design guidelines are scanned with various document types in order to understand the status quo of CAV planning from the perspective of city planning, transportation planning, academic research, and CAV consultants. The goals are to 1) provide scenarios and prototypes of design and policy strategies. In the following sections, the profiled scenarios are constructed without specific context based on the ownership models. And it provides framework for the scenarios in Champaign downtown. Three pilot area and right of way prototypes are developed to display the physical outcomes of scenarios. Analysis and recommendations are concluded for the planners and architects to make better preparations for CAVs.

B Guideline Overview and Synthesis
The overview of design guidelines helps to identify the key elements of design. Two aspects synthesized from the street level and land use level. The types of documents reviewed includes white papers, current MPO report, academic paper, and relevant website. The scan of the Design Guideline is driven by these questions:

- What kind of street context or street types are discussed in the guideline? (road prototype)
- How they reclaim the space and what kind of pilot area is proposed in the guideline? (public-realm land use)

Road Prototype
This section made an overview of design considerations for the street from design guideline reports and relevant professional websites (NACTO, Sidewalk Lab, Harvard GSD, SASAKI, etc.). The road prototype is a paradigm for the future street, several zones and sections of the road are introduced including sidewalk, managed lanes for multi-modal transportation, curbside, and buffer area. The following list showing a detailed description and elements of design. However, the actual street design is flexible based on the capacity demand and context.

According to Street Design Guideline of Boston, there are several design considerations for sidewalk. Firstly, it should be accessible for all users. ADA (American Disability Act) standard for accessible design can ban adopted to promote a pedestrian-friendly sidewalk (Boston, 2013). Secondly, a vibrant walking environment can be aided by the active building front with public art, parklet, benches, trees. In addition, a public inviting space make people engaged will make lively sidewalk (Sidewalk Labs, n.a.). Replacing pipes and rigid pavement with green infrastructure such as rain garden not only add landscape, but also benefits stormwater management.

Another important element for street is managed lanes. Although in some cases, the lane management, and considerations for right of way is not necessary for advanced CAVs and infrastructure that cars are identified mutually, and date is shared. However, at this stage with basic technology, lane management is an efficient way for reliving congestion and promote public transit and shared mobility (Boston, 2013).
Managed lanes include HOV (high-occupancy-vehicle) lane, transit lane, demand travel-parking lane, etc. HOV lanes are reserved for ridesharing that vehicles carrying two or more people (Boston, 2013). Dedicated transit lanes such as bus-only lane facilitate the public transit and ensure the reliability of the service. There are several settings for the transit lanes such as median transit lane, curbside transit lane and contra-flow transit lane. The specific design for the lane is based on the demand and context.

In addition to the designs giving priorities to shared mobility, cycles and other scooters are encouraged also with the bicycle lanes and relevant facilities. These transportation modes are utilized most within the first/last mile travel (CUUATS, n.a.). Two kinds of design consideration for bicycle lane are exclusive facilities where roadway space is designated for bicycle use, and shared facilities where bicycles and other vehicles share roadway space. Typically, exclusive cycle lane is appropriate for the boulevard where bicyclists are vulnerable road users and can be seriously injured in a minor collision. However, for the neighborways and shared street, the merging bicycle lane with other space is preferred for easier maintenance and space-saving.

Between the sidewalk and traffic lanes, there is a flex zone which can be used for curbside-parking or buffers. Smart and efficient management of curbs are proposed for a web-based technology future. There are several ideas for the flex zone. For a preparation of ridesharing, curbside can be set for demanding pick-up/drop off area. Other active transportation needs such as including bike racks, bike share stations, shared micro-mobility corrals will be cooperated with the flex zone (NACTO, n.a.). One flexible usage is differing the function for daytime from the night. In the daytime, the flex zone provides spaces for passengers and travelers. During the night, the area provide freight delivering and carriage (NACTO, 2017). Other function for flex zone includes public amenities affiliated to sidewalk and safety buffer form the vehicles.

Public-realm Land Use

1. Street Types

As street lanes, street types are not necessarily continuous along the entire length of a street. A single street may change typology as the surrounding land uses function of the road changes. Each street type will balance the needs of users, giving priority based on the context, land use, existing built environment, and constraint of site. Also, depending on the street type, the degree of accommodation for walking and bicycling will vary. There are some thoughts for the changes of different street types with the advent of CAVs. Several street types and its characteristics are concluded as following:

- **Multiway Boulevard**
  Boulevards are typically are high-speed roads, characterized by long, uninterrupted running ways. Boulevards are less convenient for pedestrians and bicyclists to cross. Therefore, it is extremely important to provide safe and accessible pedestrian and bicycle accommodations. To aid the transit, center transitway is made in Boulevards for buses or light lines, complying with access lanes for pick-up/drop-off are and increase green infrastructure is necessary.

- **Major Transit Street**: There are two kinds of transit corridors. One locates in downtown dense area containing a mix of mid- and high-rise buildings. The transit street meets the demands of nearby commercial and official travelers. Another locates at neighborhood center characterized by dense single-floor commercial and retail use. As the nucleus of community’s economies, it provides residents with daily essentials, locally owned businesses, and services. Dedicated transit lanes for bus and high occupancy vehicle are necessary to aid seamless transit. Micro mobility hubs along squares and pocket parks provides services for walking and bicycling trips. Flex zone for freight and charging or other service and alternativity for public space such as parklet to support gathering and communal events.

- **Downtown Street**
  There is often a high volume of pedestrians and vehicles in dense commercial area. The live mixed land use with retail, residential, office and entertainment use and narrow street space allow the multi-modal transportation works. Shared mobility free up parking space for alternative mixed use. To ensure the active traffic modes, protected bike lane buffered from flex zone for cycle and scooter, safe and short crossings with frequent breaks and narrow lane allowing lower speed for vehicles.

- **Residential Street**
For mid-sized towns, neighborhood residential streets provide immediate access to vast residential fabric of town houses, triple-deckers, and single-family houses. They are used primarily for local trips and are characterized by lower vehicle and pedestrian volumes. A high quality of life for residents are relevant closely with the residential access. Further changes can be made is limiting vehicle access that devote to more communal space and play area for children. The design focus of residential space is encouraging slow speeds that ensure pedestrian safety, space for playing, and ample public facilities and landscape.

![Multiway Boulevard](image1) ![Major Transit Street](image2)

![Downtown Commercial Street](image3) ![Residential Street](image4)

Source: https://nacto.org/publication/urban-street-design-guide/streets/

2. Parking, City Scale, and Land Use

Other promising changes includes the parking and city scale (Litman, 2020). Decreased parking space for other potential service is supposed to deployed by the sustainable land use and flexible parking design. Currently, many companies propose the future flexible parking building for AVs. Self-parking makes the parking efficient (MnDOT, n.a.). The occupant parking area is variable, enabling the flexible design to make the building used in alternative ways, which compatible the usage of retails and offices. Besides, the efficiency of street-parking will maximize, which could make create vibrant curb-side activities for business such as pop-up shops, street market and parklets (NACTO, 2017).

According to the decreased demand of the surface parking, more free land could be used for affordable housing and public green space to promote equity and improve urban environment. Regarding city scale, one possibility is that CAVs combined with multi-modal transportation promote the mixed land use with a denser city center with convenient transit and shared mobility hub. Another possibility is and a sprawl city and expanding suburbs (Litman, 2020).

Design considerations with the impact of CAVs

Two considerations, safety and travel behavior are concluded for the impact of CAVs. First is the increase of safety in both cyber and physical field. Therefore, it is more possible to let people and other
transportation modes sharing road and lanes with vehicle. More details should be explored such as how to share the space in an efficient way and better integrated with surrounding context.

The second impact is caused by travel behavior. If MPO made well preparation such as the infrastructure including public transit hub, multimode mobility hub and boost ridesharing, the VMT will decrease (Catapult, 2017). Therefore, road diet can be implemented into street design. At the same time, free space can be reclaimed for pedestrians as a part of sidewalk and served other public purpose such as parking garage and affordable housing.

C1 Methods
Scenario planning as a tool for imaging possible futures that companies have applied to a great range of issues. Estimated future outcomes from scenarios helps for decision-making. The following scenarios and outcomes are formed within frameworks. There are two frameworks, uncertainties framework and scenario framework are identified. The first one extract the uncertainties into three categories and explore the interrelationships between them. The second framework is constructed based on the external factor(drivers) and internal factor(levers) with the categorized ownership modes and corresponding impacts.

Uncertainties Framework

Three group of uncertainties including drivers, impact and levers are categorized within the uncertainty’s framework. There are some known inclusive elements listed under three categories. As the following figure show, the drivers will influence the CAV impact, CAV impact will result the reaction of levers, and the levers will affect the travel behavior of drivers. They form a mono-directional loop route and inclusive elements are mutually interactive. For example, if levers make multimodal transportation
investment and encourage ridesharing and public transit, the consumer preferences will go to the fleets and shuttles as a service, which bring the impact of decreased VMT, relieve traffic congestion, and improve accessibility.

Ownership Models
The ownership framework is a matrix with the public/private ownership and single/shared occupancy. Examining ownership models as a matrix helps explore future options for drivers. This ownership models as the main factor of drivers helps to identify the uncertainties of levers and corresponding impacts for scenarios.

- **Autonomous Rapid Transit** (public and private shared model)
  AV technology evolves in tandem with roadways and other supporting infrastructure, utilizing combined public and privately owned fleets to create a shared experience for all.

- **Car Sharing** (public and private shared model)
  AV technology evolves in tandem with roadways and other supporting infrastructure, utilizing combined public and privately owned on-demand AVs in a similar fashion to today’s ride-hailing pool options.

- **Fleets** (private shared model)
  Car manufacturers are already testing the idea of partnering with ride-hailing companies to create fleets of privately-owned on-demand AVs.

- **AV Single Taxis** (private single model)
  These privately-owned, on-demand AVs would service individuals as taxis and ride-hailing companies do.

- **AV Single Taxis** (private single model)
  Individually owned AVs will provide a significant convenience for owners but will not significantly abet the current state of traffic, emissions, parking, or VMTs.

Scenario Framework
The matrix is combinations of the uncertainties. Within this framework, the combined future outcomes of the interaction between drivers and levers may be called scenarios. The combination of the uncertainties to anticipate different outcomes.

The horizontal axis represents the development and level of external forces. Drivers is measured from level1 to level4, the higher-level means CAVs are more advanced and more widely adapted in daily life. The Vertical axis represents the internal decisions and response from stakeholders or MPO. Levers is measured from Class A to Class D to reflect the preparation and response degree from local stakeholders and MPO. The combinations shown with numbers are the combination with varied drivers and levers. In this framework, drivers are identified as external forces which are out of control for planners and are affected with the market. The internal forces are levers whom planners communicate and cooperate with. The track of future will achieve the best when levers are proactive with the demand of drivers and technology changes.

The scenarios of ownership including rapid transit, shared mobility, rental CAVs and personal CAVS are proposed on the identified ownership matrix. Personal vehicles category is showing with the unimplemented levers for the preparation of infrastructure and management. Rental single CAVs come
with Class A or Class B levers without fully preparation. Shard mobility and rapid transit all require proactive levers to pave the way for its operation. The following recommendations for the design are trying to figure out the preparations as proactive actions. Impacts elements identified in the uncertainty framework are categorized based on the ownership scenarios to show the outcomes of scenarios which helps decision-making for planners. The negative impact such as increased congestion and decreased accessibility performing with predominately personal CAVs scenario. Higher safety and accessibility, active transportation and decreased emission appears to be main positive impact of shared mobility.
C2 Scenarios profile

Scenario profile concludes the scenarios based on four ownership models. Uncertainties shows the attribution for the advent of the traffic modes and consequent potential changes within the uncertainty framework. The gained impacts facilitate the consideration and decision-making. Preliminary design recommendations promote mobility transit hubs, mixed-use service hubs, adaptive facilities, reinvented curbs, and local residential access.

Mobility hubs as a necessary facility for seamless transit will connect people with destinations and reduce congestion by moving vehicular traffic out of active roadways and into designated curb loading/unloading zones and off the street into parking structures for storage. (McCormick, n.a.) Reinventing the curb will increase pedestrian and vehicle building access and safety and reduce congestion. Effective multimodal deployment of designated traffic lanes and HOV hot lanes to ease congestion can all work in concert. Pedestrian and automotive friendly curbs, walkways, designated drop-off lanes, and loading zones keep roadways clear. A hug-the-curb approach can prevent vehicles from blocking traffic lanes (kockelman et al, 2016).

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Rapid Transit</th>
<th>Car Sharing//Fleets</th>
<th>Rental CAVs/ Single Taxis</th>
<th>Predominantly Personal CAVs</th>
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</thead>
<tbody>
<tr>
<td>Ownership Model</td>
<td>Multiple Public Shared Vehicles</td>
<td>Public Shared Vehicles</td>
<td>Private Shared Vehicles</td>
<td>Private Personal Vehicles</td>
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<td>Technology Requirement</td>
<td>Advancing Technology, Connected Infrastructure, Integrated Mobility</td>
<td>Advancing Technology, Connected Infrastructure</td>
<td>Private Automation</td>
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<td>Metro, Transit Stations</td>
<td>City Roads, HOV Lane</td>
<td>City Roads, Highway</td>
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<td>Pricing/ Affordability</td>
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<td>Medium</td>
<td>High/Medium</td>
<td>High</td>
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<td>City Form Character</td>
<td>Denser Urban and Suburban Center</td>
<td>Denser Urban</td>
<td>City Sprawl</td>
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<td>Common Users</td>
<td>Suburban and Urban Travelers</td>
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<td>Suburban and Rural Residents</td>
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<td>Travel Behavior</td>
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<td>On-demand Shared Travel</td>
<td>On-demand Personal Travel</td>
<td>Freewheeling Personal Travel</td>
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<td>decrease+</td>
<td>increase+</td>
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<tr>
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<td>increase++</td>
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<td>Occupancy Per Vehicle</td>
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<td>Increase+</td>
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<tr>
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<tr>
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<td>Environmental Impact</td>
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Design Recommendations

- Mobility Transit Hubs
- Mixed-Use Service Hubs
- Adaptive Facility, Reinvented Curb
- Residential Local Access
D Pilot and Plan in Champaign

Vision

A vision with detailed urban design show how CAVs might change the land use in downtown Champaign. CAVs may have the most impact in a diverse range of urban neighborhoods that are not quite dense enough to support mass transit. In downtown areas, often the densest areas in their regions, AVs may allow cities to use valuable space more efficiently.

The key elements are building facilities and street design. These area in downtown combine three context settings: major transit street and hubs, commercial mixed-use area, residential district. Two kinds of streets are illustrated. It is important for main street corridor in the dense area with high volume of traffic and commercial buildings to prioritize pedestrians for an active CAVs shuttle network. Residential street could limit the access for certain vehicles to create a safer neighborhood for residents.

Several important building and facilities are also introduced based on the context. The terminal can be renovated to dynamic mobility hub. It locates along the main street to improve the multimodal transportation including regional trains, metros, local buses, indidual rental cars, and cycling. The mobility hub serves as a traffic node in order to improve ridesharing efficiency for the neighborhood. There are scale varied hubs to meet the specific demand of surrounding. The micro-mobility hub locating in the street corner creates a fine-grained network that complements rail and bus services. The mixed-use hub locating at the business district on the reclaimed surface parking and provide alternative mixed use such as workplace and apartments.

Other facilities such as community space, recreation center, local access and storage are embraced with active traffic modes and civic engagement to maintain the operation of CAVs-enabled transportation. Reclaimed public parking along green space are suitable for the recreation center. It provides access for the pedestrians and cyclers in the community to green infrastructure. Community space are designated at the surface parking around churches for the public events and festival. A combination of shuttles, transit, and personal AVs could reduce the need for and create more pleasant community spaces. Local access is designed as the neighborhood transit driveways center that provide pick-up and drop-off space.
for shared mobility. The traditional gas station will be replaced or converted by new types of repair shops and vehicles storage facilities that be strategically located.

Three Pilot Areas
Three pilot sites are selected in Champaign, two of them are in downtown area with a high-density urban context. From the research, CAVs will have much more influence in urban area where have mixed land use and concentrated demography to provide the basis for the renovation in the future. The third sites locate in the intensive residential district in Champaign, which is the typical residential zone within single-family neighborhood in mid-size town.

1. Terminal and University Ave
This area is a representation of the transit hub along main street corridor connect regional traffic with local traffic. Surrounding place is integrated with bus transit center and coach stations. The large surface parking will be freed up for alternative public use. In terms of the main corridor, typically, it is a four-lane higher speed road. Median may accommodate the rapid transit service.

2. Downtown Commercial District
As same as the previous identified commercial street type, this street supports a lively mix of retail, residential, office and entertainment use. This wide range creates many of the city’s most dynamic public spaces. The district normally serves residents, visitors, and workers. It should support high level of
walking, bicycling, and transit, as well as support frequent turnover, including loading zones to foster economic vitality.

3. Residential District

As the findings from the scanning of design guidelines, residential streets types in Champaign residential district typically are no more than two travel lanes (one in each direction) and are not intended for through-traffic. Well defined street paths ensure the convenient travel to surrounding such as nearby parks, bus stops, transit stations, community centers, and libraries.
Scenarios
Based on the scenario framework, five scenarios including status quo, rapid transit, ridesharing, single rental CAVs and predominately personal CAVs for each pilot area.

1. Transit Hub and Main Road Corridor

Status Quo: large area of surface parking, Bus transit center and coach station. The arterial road is two-way with four lanes.

Rapid Transit: Multi-transportation modal will change the transit hubs, integrating different service modals including the metro/rail station, fleet station and lane, car-pooling lane served as first/last mile connection and increase transit effectiveness. Surface parking will be transformed to complex plaza including Pick up/drop off zone, adaptable parking place, modular market. Main road section contains the metro lane in the center and a road diet.

Car Sharing/Fleets: Transit Hub will provide the adaptive station and facilities for the car-pooling. Surface parking will be reclaimed to staging area, etc. Main road section will provide HOV-high occupancy lane.

Rental CAVs/ Single Taxis: Transit Hub will provide the adaptive station and facilities for the rental CAVs such as Pick up/drop off zone. Some part of surface parking will be reclaimed to staging area, etc.

Predominantly Personal CAVs: Surface parking need take more space, take over the surrounding vacant parcel as the parking lot or parking building. Main road will be wider to carry more personal vehicles.
2. Downtown Commercial District

Status Quo: high-density area, provide multiple urban service and commercial activities. Surrounded a lot of parking infrastructure including parking lot, parking building and curbside parking. The main road is one way with two lanes.

Rapid Transit: Reinventing the Curb for building access and make smart curbside management including amenity service and outdoor retails. Reclaim the surface parking for the mixed-use service hubs and add public transportation station, providing modular parking infrastructure for flexible usage including retail, office, and storage, etc. Creating pedestrian-friendly road and bicycle lane without the specific vehicle lane.

Car Sharing/Fleets: Make curb reinvention for car-pooling amenity service and increase business vibration. Reclaim the surface parking as mixed-use service hubs to provide facilities for car-pooling and increase the sharing mobility effectiveness. The main road will add pedestrian-friendly road and bicycle lane with a vehicle lane.

Rental CAVs/ Single Taxis: Reinvent the building access for drop-off and Pick-up zone. Other thing will keep as the current situation.

Predominantly Personal CAVs: Curbside parking will be denser and exclude the possibility for the outdoor retails. Surface parking need take more space, take over the surrounding vacant parcel as the parking lot or parking building. Main road will be wider to carry more personal vehicles.

3. Residential District
Status Quo: Embrace single-family, multi-family, church, library and middle schools, market. The arterial road is one way with three lanes.

Rapid Transit: Surface parking of the community center will be reclaimed for transit plaza to provide local access to public transportation. Vacant corner gas station and vacant lot will be reclaimed as service and storage stations for CAVs. Creating pedestrian-friendly road and bicycle lane without the specific vehicle lane, provide more space for the landscape and activities.

Car Sharing/Fleets: Vacant Surface parking of the community center will be reinvented with the staging area to facilitate car-pooling. Vacant corner gas station and vacant lot will be reclaimed as service and storage stations for CAVs. Add pedestrian-friendly road and bicycle lane along the existing vehicle lane to make road diet for the main road.

Rental CAVs/ Single Taxis: Reinvent the community center access for drop-off and Pick-up zone. Other thing will keep as the current situation.

Predominantly Personal CAVs: Surface parking need take more space, take over the surrounding vacant parcel as the parking lot or parking building. Main road will be wider to carry more personal vehicles and exclude the possibility for the curbside landscape and activities.

ROW Prototype
The right-of-way prototype provides the lanes and transportation modes for three street types which corresponding to the three-pilot context. Each street types shows the status qua, scenario of preferential personal CAVs, and scenario of shared mobility.
The following figures show how managed lanes work for the multi-modal transportation. In the middle of street, there is a public-transit way with safe staging. The prioritized lanes allow other shared mobility such as shuttles and fleets to pick-up/drop-off passengers. Other seamless transit for first/last-mile travel is provided at the curbside flex zone. Road diet with narrow lanes and increased road capacity free up space for a wider sidewalk for vendors, parklet and other green infrastructure. This prototype improves equity with promoting public transit and adding public sharing space.

Mixed land use work cooperatively with multi-modal transportation. The following figure illustrates the surrounding land use changes. The stores along the corridor with more mixed and denser zoning will have an active street front and engaged with sidewalk. The upper floor may be added for alternative usage such as micro transit hub, workplace or apartments. Surface parking and backyard will largely decrease. The free area may be reclaimed for public square and communal space for a lively community. Along the street, green infrastructure can be added to serve as stormwater management or buffer landscape. A safer curb management is inviting for cycles and pedestrians.
### E. Recommendations

<table>
<thead>
<tr>
<th>Urban Core /Outside urban corn (no single use)</th>
<th>Shared/Transit Mobility as a service</th>
<th>Predominately Personal CAVs</th>
</tr>
</thead>
</table>
| **ROW** (street, sidewalks, curb, street parking) | • street: managed lane (right of way, management of speed, road pricing, lane width), sign control  
• smart curbside: charging facility (flex zone based on demand)  
• reduced street parking  
• wide sidewalk: active building façade and sidewalk, pedestrian, and cycler friendly | • street: wide lanes, pedestrian overpass, high speed CAV flow, road separations such as railings  
• standing street parking |
| | • Multi-modal transportation  
• Pedestrian-friendly  
• TOD | • Personal car prioritized |
| **Land Use** (building zoning, building types, off-street parking) | • mixed zoning  
• off-street parking: reduced structured parking  
• building type: increased transit hub and mobility service hub  
• public space and other infrastructure: active building façade and wide sidewalk, increased public space and green infrastructure | • zoning: segregated land use,  
• building type: increased drive-through zone for buildings, pick-up/drop-off lot  
• increased structured parking  
• other infrastructure: limited transit stops |
| | • Mixed-us development  
• Pedestrian-friendly  
• TOD | • Segregated land use |

### E1. CAVs Ownership

**Taking priority for the public transit and shared mobility.**

Public transportation system with high capacity is favorable to mitigate the road congestion. According to research, two kinds of AVs has been tested to compare their behavior and impact. Taxi-Bots are self-driving cars that can be shared simultaneously by several passengers (OECD, 2015). Auto-Vots pick-up and drop-off single passengers sequentially. In terms of congestion, both the Taxi-Bot and Auto-Vot can reduce the congestion by reduced the cars in the peak hours, Taxi-Bot combined with high-capacity public transport make an obvious effect. In terms of VMT, it will increase. However, compared with e Taxi-Bot with high-capacity public transport scenario, the Auto-Vot car sharing without high-capacity
public transport scenario will increase more significantly. “This suggests that where congestion is an issue, travelers should be encouraged to travel within the same vehicle as others.”

Also, integrating the CAV fleet into the existing bus route is more functional and economical (Duarte & Carlo, 2018). The proposed roads in the vision for Champaign are in line with current bus service to create the public fleet route map for coordinated transportation system. Especially for the transit hub, it will focus on transit-aid design for the commuters who rely on the public transportation service. According to research, “it could be an effective way for automated public transport vehicles to penetrate highly built-up areas such as large, busy rail stations, where the number of complex variables make otherwise make the introduction of automated vehicles extremely challenging.”

E2. Public-realm Infrastructure
Preparation for the infrastructure: support facilities and curb management.

Autonomous fleets will need large support facilities to service and charge CAVs. If cities allow private companies to operate vehicle fleets, officials might only need to regulate support facilities, their private partners will bear all infrastructure expenses. But if officials want to create public fleets, they should consider planning for the development of support facilities, much as they do when create or enhancing today’s bus systems. In some cases, they could repurpose existing facilities that are no longer essential, such as parking garages that are no longer seeing high demand. For most support facilities, the major costs will involve rent (unless the public sector owns the structure), labor, and creation of charging infrastructure for CAVs (Dumbaugh & King, 2018). Transportation officials must be thoughtful about the placement of these facilities to avoid disrupting the urban environment and damaging health, traffic, and civic life.

As a significant infrastructure for preparations of CAVs, pick-up and drop-off zone should be considered carefully. Provisions could be made for pick-up/drop-off areas based on pedestrian/traffic density, type of development, type of road, and the availability of space. For example, in quiet areas such as single-family neighborhood, it maybe optional. However, in busier central areas, designated pick-up/drop-off bays need to be created. Areas such as outside shopping centers, train stations, hospitals, and other busy areas would benefit from designated areas. Consideration for where these pick-up/drop-off zones should be located, and how big they need to be, should be considered for new areas of development and the building codes (Kockelman et al, 2016).

In most cities, the curb predominantly serves as a space for parking. Transportation leaders could consider pricing this resource more dynamically, taking market demand into account, to free up spaces (Nodiomian & Kockelman, 2019). They could also designate it for specific purposes at different times (designated with signs or beacons that send signals to AVs). During rush hour, the curb might be a pickup site for AV shuttles that are part of the public transportation system. Later, it could provide parking for food trucks during lunch and a site for freight delivery at night. Transforming the curb may encourage shared mobility because travelers could share costs related to drop-off, especially during times when the price increases. Pricing curb space could also reduce congestion. Pricing this scarce resource consistent with demand would also provide delivery trucks and ridesharing services with more options for conducting drop-offs and pickups, since more spaces would be available (Noland et al, 2015).

In addition to the transformation of parking building, more mobility and service hub will be designed for a seamless transfer between different modes. A commuter might take off a Robo-Taxi from home to the
nearest train station then grab an electric scooter to get the final mile from the train stop to the office. If this process is too difficult, passengers might opt to take a private AV from point to point—a trend that would increase delays and unreliability (None, 2017). To avoid this situation, officials could consider investing in more mobility hubs where travelers going in the same direction can access shared transportation, including AVs. These facilities could include micro mobility-pickup locations (places where people could get scooters or bikes) next to subway stops, or large transit facilities that also contain dining and shopping options at critical nodes.

**E3. Multimodal transportation, Pedestrian friendly design and TOD**

Integrated with CAVs technology, multimodal transportation offers a wide range of choices for commuters and provide a more convenient mode of transportation (Litman, 2017). A commuter might start their journey on a shared electric scooter to a train station, then take a train to work, later cycle to the store on a rented bike, and carry groceries home in a taxi. In this example, one private car is replaced by four separate modes of travel, each of which represents the choice that works best for each journey, or part of the journey. These alternative forms of transportation provide a transport solution—otherwise, commuters will keep their private cars. Based on research, multimodal transportation helps to build the transportation system matching demand and create an interconnected network. It also fills the gaps of existed system through providing more flexible services. Based on these advantages of multimodal transportation, the future of reliable and affordable mobility is promising (Litman, 2017). Integrated shared mobility, public transit with multimodal transportation will boost more opportunities for CAVs, and relieve traffic congestion, promote equity, reduce environmental pollution at the same time.

Providing a balance among transportation modes, bicycling and walking are not functionally different from other transportation mode. Enhancing the bicycle and pedestrian experience can include many avenues: urban design, facility design, public involvement, traffic calming, traffic engineering, landscaping, funding, bicycle, and pedestrian behavior studies, and more. Several facilities for a pedestrian-friendly design and transit-oriented development can be adopted with street design for CAVs.

- Includes raised curb berried cycle track, planting berried cycle track and parking-buffered cycle track. One-way protected cycle tracks are bikeways that are at street level and use a variety of methods for physical protection from passing traffic. A one-way protected cycle track may be combined with a parking lane or other barrier between the cycle track and the motor vehicle travel lane.
- Bus bulbs: Bus bulbs may be combined with amenities such as wayfinding maps, plantings, and trees to enhance the overall transit user experience
- Pedestrian safety island: Safety islands may be used on both wide and narrow streets, they are generally applied at locations where speeds and volumes make crossings prohibitive, or where three or more lanes of traffic make pedestrians feel exposed or unsafe in the intersection.
- Bike boxes: A bike box is a designated area at the head of a traffic lane at a signalized intersection that provides bicyclists with a safe and visible way to get ahead of queuing traffic during the red signal phase.
- Curb extension: Curb extensions increase the overall visibility of pedestrians by aligning them with the parking lane and reducing the crossing distance for pedestrians.
E4. Mixed land use
Multi-modal transportation work with mixed land use mutually. By putting residential, commercial, and recreational uses near one another, alternatives to driving, such as walking or biking, become viable. Mixed land uses also provide a more diverse and sizable population and commercial base for supporting viable public transit (Litman, 2020). Mixed use can enhance the vitality and perceived security of an area by increasing the number and activity of people on the street. It attracts pedestrians and helps revitalize community life by making streets, public spaces and pedestrian-oriented retail become places where people meet.

Several design features are identified for mixed land use. Firstly, a mixed-use district should include a balanced and vibrant mix of compatible uses, with first floor street-front uses generally reserved for retail, restaurant, and in some cases office uses. Secondly, it encourages people to walk from one use to another and to enjoy and socialize in an attractive outdoor setting. Many design features promote this ambience. They include the layout and orientation of buildings, the network of sidewalks and pathways, the location of parking relative to structures and walkways, and the amount and placement of green space, landscaping, benches, and other amenities. Thirdly, under certain circumstances, mixed use districts may set aside less parking than in traditional, single use settings. Reductions could occur near public transportation, where uses are clearly at different times and can share the same spaces, or where there is a strong program to manage transportation demand.

E5. Community Design and Regional Accessibility
Community design consists of the characteristics of development use, form, and location that combine with the multimodal transportation system to support convenience, non-motorized travel, and efficient vehicle trips at the neighborhood and area scale. However, Individual communities may find it challenging to play their pivotal role. Another factor needs to be taken into consideration is regional accessibility, which describes similar characteristics with community design at the regional, interstate,
and international scales (Catapult, 2017). CAVs will lead to an era of regional travel, urban expansion, and land-use transformation. Infrastructure may continue to expand with funding coming from local, state, and federal sources. By accessing the regional accessibility, more targeted and effective community goals can be achieved.

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