Reimagining Urban Morphology for Equitable Mobility: Adapting to Collective Multipurpose Autonomous Vehicle Systems for Accessible and Inclusive Transportation Systems

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MSSD Thesis Summer 2023
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Guiilbert Gates

NHTSA / SAE / BAS level of autonomous cars
https://cei.org/blog/no-politicians-shouldnt-outlaw-driving-to-usher-in-self-driving-cars/

NACTO Blueprint for autonomous urbanism Second Edition
Transforming inequalities
- Values of specific groups of people: gender
- Altering quality and quantity of access to mobility
- Organization of urban space: urban sprawl

Transforming labour
- Job loss in transportation employment
- Spatial variation
- Labour relations: employment rights

"Uber drivers are independent contractors, not employees"
— National Labor Relations Board

A localized implementation of AV systems in integration with multipurpose shared mobility network will enhance urban inclusivity and contribute to a more equitable and livable city by providing shared rides or customized service for better access between urban and suburban areas, stimulating mixed-use community development, etc.

Research Gaps

- **Limitations on local-government power and political support** in the U.S. federal system result in the gap between frequently recommended policies and the potential for their implementation.

- Current AV datasets have a strong **bias on urban context** for commercialized experiment, little research is based on suburban area and look at regional transit system as a whole from a long-term sustainability perspective.

- Current AV sensors collect data from the single viewpoint from cars prioritizing car users over pedestrian/bikers safety and monitors collect data from the intersections, resulting in the **dataset grey area between the intersections**.

- Existing AV implementation guidebook/research haven’t draw a strong connection between **driving/commuting behaviors/preferences and urban morphologies and densities**.
Opportunities:
● Color segmentation tools
  ○ Detectron2 Facebook AI (Object Detection)
  ○ Semantic Segmentation on MIT ADE20K dataset in PyTorch (Semantic Detection)
● 3D depth estimation
  ○ AdelaiDepth

Literature Review

Background

Hypothesis

Methodology

Result

Conclusion

Methodology

High mobility needs

Limited transit access

Problem area

Social Patterns

City Patterns

mobility

mobility + social gathering

mobility + recreation

mobility + care + social gathering

mobility + care + recreation

mobility + care + social gathering

TYPE 1: Narrow residential streets

TYPE 2: Steep slope

TYPE 3: Blocked sidewalks

TYPE 4: Dilapidated houses

TYPE 5: Vacant lots

Number of Facilities

Average Travel Time to Closest Facility

Walkability/Accessibility Score

stress

improve
Methodology

#1 Transit inequity and accessibility

- Literature Review → Weighing Metric → Site Selection
Transit Inequity

- Equity evaluation serves to identify areas that have a higher proportion of disadvantaged populations or populations that may have greater mobility needs. This evaluation is completed through the development of an equity index of various demographic factors to give areas an equity “score”. Areas that score higher in the equity evaluation process are considered higher priority areas for the AV system to serve.
Methodology

#1 Transit inequity and accessibility

Literature Review → Weighing Metric → Site Selection
The federal poverty line for a family of 4 in 2018 was $25,100.2. Therefore, Census data for households earning less than $25,000 per year was used as an indicator of poverty for Allegheny County.

**Percentage of Low income households**

The percent of low income households among the total households in each census tract was calculated.

**Percentage of Cost burdened renters**

Household size was not taken into account due to unavailability of information.

For each census tract the total number of households spending 30% or more of their income for rent was calculated. Then the percent of rent burdened households among the total households in each census tract was calculated.

**Percentage of Low wage workers**

Workers that had a wage of $1250/month ($15k per year) or less were considered to be low income, as this was the wage bracket that most closely matched the Federal Poverty level.

The percent of full-time workers year-round earnings lower than 15k among all full-time workers in each census tract was calculated.
Disabilities

The percent of population with disabilities among the total civilian noninstitutionalized population was calculated for each Census tract. Then the tracts are sorted from highest to lowest for the percentage. Source: S18000ABILITY CHARACTERISTICS
https://data.census.gov/iaqable?
cid=0S1800ABILITY&g=tq00X000US4214000000&cp=AC5T5Y2018.41810

Minority Race and Ethnicity

All the categories of race and ethnicity except “Not Hispanic or Latino: White alone” were aggregated for each Census block group to find the total number of minorities. Source: 2010HISPANIC OR LATINO, AND NOT HISPANIC OR LATINO BY RACE
https://data.census.gov/iaqable?
cid=race&g=tq00X000US4214000000

No Vehicles

The number of households with “No vehicle available” was used here. The percentage of such households in each Census tract was calculated. Source: B08201:HOUSEHOLD SIZE BY VEHICLES AVAILABLE
https://data.census.gov/iaqable?
cid=B08201:HOUSEHOLD-SIZE-BY-VEHICLES-AVAILABLE&

Data source: US Census Bureau
Data source: US Census Bureau

The percentage of households with female householders and one or more people under 18 years was calculated for each Census Tract.

Source: B11055:HOUSEHOLDS BY PRESENCE OF PEOPLE UNDER 18 YEARS BY HOUSEHOLD TYPE

Households were selected where one or more persons speak a language other than English and do not report as speaking English "very well".

Source: C16002:HOUSEHOLD LANGUAGE BY HOUSEHOLD LIMITED ENGLISH SPEAKING STATUS
https://data.census.gov/表?g=C16002:HOUSEHOLD+LANGUAGE+BY+HOUSEHOLD+LIMITED+ENGLISH+SPEAKING+STATUS&g=050000US24140000&tid=ACSDT5Y2018.C16002&nofoot=false

All the "Limited English Speaking Households" data was aggregated per census tract to find the total number of households with limited English proficiency. Then the percentage limited English proficiency households for each census tract were calculated.
### Average of 6 factors for disadvantaged population


### Normalized score of the percent of households/population

| lowcome | lowcome_pe | Construction | Disable | minority | No. vehicle | No_empror | Lim_Bed | Use_dwmb | Agent | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wifi | Use_email | Use_internet | Use_wi
Transit Accessibility

- Accessibility evaluation serves to identify areas that have a poorer access to public transit. This evaluation is completed through the development of an access index of distance to light rail, bus stops and park and ride stops to give areas an accessibility “score” of 0 (no access) to 1 (accessible). Areas that score lower in the equity evaluation process are considered higher priority areas for the AV system to serve.
Data source: PRT open data

Light Rail Access (10min walking)
10 min walking buffer is created to visualize the area accessible by the light rail and given a score of 1, while the rest of the area is scored 0.
Source: Rail_1409_Public

Data source: PRT open data

Access to public transit (10min walking)
Public transit network is created from the Port Authority GTFS dataset and the areas within 10min walking from the nearest bus stop are considered to be of easy access and given a score of 1, while the rest of the area is scored 0.
Source: Port Authority GTFS - OpenMobilityData,

Data source: GTFS feed data from Port Authority

Park and Ride (2 mile)
2-mile buffer is created to visualize the area near park and ride stops where the commuters park their own car and take public transit to commute to work and given a score of 1, while the rest of the area is scored 0.
Source: PRT Park and Rides current (2002)
https://open-data-pgh-transit-hub.arcgis.com/datasets/2ac1cd1e90c6d466da72158b92f1bca-0cili2e LOCATION=40.434398%2C-79.96176%2C12.12

Data source: PRT open data
Transit Accessibility

Suitability model remap the score of accessibility from 0-1 to 5-10 and adds up the score of these three maps. Color ranges from green (high accessibility) to red (low accessibility).

Transit Inequity

The percent of households/population in each census tract was normalized by the census tract with the highest percentage. This meant the highest percentage will have a score of 1 and the other census tract will get respective scores lower than 1. Finally, for each Census tract all 6 scores were averaged into one final score which is the “Equity Index Score” for Allegheny County. The dark red shows higher mobility need areas and as it gets more green it means lesser mobility need.
Methodology

#1 Transit inequity and accessibility

- Literature Review → Weighing Metric → Site Selection
Top ten (Highest Mobility Need) Municipalities

1. Rankin Borough
2. Braddock Borough
3. Mount Oliver Borough
4. Duquesne
5. North Braddock Borough
6. Homestead Borough
7. McKees Rocks Borough
8. Wilkinsburg Borough
9. North Versailles Township
10. East Pittsburgh Borough
c of top 10 municipalities and neighborhoods in highest mobility need
Top ten (Highest Mobility Need) Neighborhoods

1. Northview Heights
2. Larimer
3. Bedford Dwellings
4. Homewood South
5. Homewood West
6. Middle Hill
7. Homewood North
8. Crawford Roberts
9. West Oakland
10. Lincoln-Lemington-Belmar
Walkability analysis
Data source: http://www.wprdc.org/news/measuring-walkability/
Lincoln-Lemington-Belmar is entitled with CDBG grant to develop viable urban communities by providing decent housing and a suitable living environment, and by expanding mobility, principally for low- and moderate-income persons.

Data source: https://pittsburghpa.gov/omb/community-development-block-grant
Lincoln-Lemington-Belmar is within 10-min ride from park and ride stops, AV shuttle bus can save commute time and enhance first/last mile connectivity.
<table>
<thead>
<tr>
<th>Methodology</th>
<th>#2 AV plugin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing condition</strong></td>
<td></td>
</tr>
<tr>
<td>Street typology</td>
<td></td>
</tr>
<tr>
<td>Modes of transportation</td>
<td></td>
</tr>
<tr>
<td><strong>Intervention</strong></td>
<td></td>
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<tr>
<td>AV service</td>
<td></td>
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<tr>
<td>Mobility hub prototype</td>
<td></td>
</tr>
<tr>
<td><strong>Experiment</strong></td>
<td></td>
</tr>
<tr>
<td>Number of facilities</td>
<td></td>
</tr>
<tr>
<td>Travel time to closest facility</td>
<td></td>
</tr>
<tr>
<td>Walkability/Accessibility Score</td>
<td></td>
</tr>
</tbody>
</table>
TYPE 1: Narrow residential streets riddled with potholes (2-way)
Location: 6412 Apple Street

TYPE 5: Vacant lots
Location: 1309 N Murtland St

TYPE 3: Surplus spaces at neighborhood street intersection (4-way)
Location: 6883 Fifth Ave

Legend:
- parking area
- building footprint
- area on a slope >=25%
- PRT bus route
- street centerline
TYPE 2: Steep slope at triangle neighborhood street intersection (4-way)

Location: 7201 Apple St at Stranahan St

TYPE 4: Dilapidated houses on one side of residential streets

Location: 7150 Apple Street
Transit inaccessibility in Lincoln-Lemington Belmar
<table>
<thead>
<tr>
<th>Methodology</th>
<th>#2 AV plugin</th>
</tr>
</thead>
</table>

**Existing condition**
- Street typology
- Modes of transportation

**Intervention**
- AV service
- Mobility hub prototype

**Experiment**
- Number of facilities
- Travel time to closest facility
- Walkability/Accessibility Score
Diversified Block with AV service

The new super block should change the development limitations of independent residential and commercial districts, fully consider the spatial and functional needs of all types of people, realize a diverse mix of functions, and respond to the social differenciation caused by urbanization with an open and inclusive attitude problem.

Mobility Hub Prototypes

The new hub should tap its potential urban value and public attribute while satisfying the traffic distribution function and achieve the integration of the city in terms of urban texture, architectural scale spatial function. The mobility hub will act as a catalyst for urban life and actively join the urban narrative.
Shared AV Service

**Neighborhood**
- hop on hop off
- AV community transit

**Cross-Neighborhood**
- Station parked
- AV shuttle bus
- hop on hop off
- AV shuttle bus

Customized AV Service

- mobile clinic
- mobile fitting room
- mobile office
- mobile store
- mobile cafe
Solution set

- Driveway
- Sidewalk
- Bikelane
- AV parking
- Slowzone

Charging station
- Resilient parking
- Bike racks
- Parklet at street parking
- AV transit stop
- Transit bay

Dining table
- Delivery locker
- Community garden
- Public seating
- Public installation
- Flex zone
- Pedestrian platform

Roundabout
- Roundabout sign
- Raised green median barrier island
- Raised central island
- Green island as median

Open play street
- Close end street
- Diverted one-way street
- Multimodal slow zone
- Diagonal diverter
TYPE 1: Narrow residential streets

Existing Condition

AV stop

Moderate mobility hubs

High mobility hubs

Legend:
- driveway
- sidewalk
- bike lane
- lawn

AV parking zone
flex zone
bus stop
bike racks
charging station
planting pool
TYPE 1: Narrow residential streets

AV stop

Moderate mobility hubs

High mobility hubs

Super mobility hubs

- driveway
- sidewalk
- AV parking
- AV transit stop
- charging station

- Parklet at street parking
- Open play street
- Close end street
- diverted one-way street
- multimodal slow zone
TYPE 2: Steep slope at triangular block intersection (4-way)

Existing Condition

AV stop

Moderate mobility hubs

High mobility hubs

Legend
- driveway
- sidewalk
- green island
- AV parking zone
- slow zone
- flex zone
- bus stop
- bike racks
- charging station
TYPE 2: Steep slope at triangle intersection (4-way)

AV stop
Moderate mobility hubs
High mobility hubs
Super mobility hubs

driveway
sidewalk
AV transit stop
charging station
Bike racks
Traffic island
slow zone
slow traffic sign
green island as median
TYPE 3: Surplus spaces at neighborhood street intersection

Existing Condition

AV stop

Moderate mobility hubs

High mobility hubs

Super mobility hubs
TYPE 3: Surplus spaces at neighborhood street intersection

- AV stop
- Moderate mobility hubs
- High mobility hubs
- Super mobility hubs

- driveway
- sidewalk
- bikelane
- AV transit stop
- charging station
- roundabout
- roundabout sign

- green island as median
- raised green median barrier island
- raised central island
- slow zone
- Pedestrian platform
- charging stations as barrier
- diagonal diverter
TYPE 4: Dilapidated houses

Existing Condition

AV stop

Moderate mobility hubs

High mobility hubs

Super mobility hubs

Legend:
- driveway
- sidewalk
- green space
- resilient parking
- bus stop
- street light
- charging station
- bike rack
TYPE 4: Dilapidated houses

- AV stop
- Moderate mobility hubs
- High mobility hubs
- Super mobility hubs

- Driveway
- Sidewalk
- Resilient parking
- AV transit stop
TYPE 5: Vacant lots

Existing Condition

AV stop

Moderate mobility hubs

High mobility hubs

Super mobility hubs

Legend

- AV parking zone
- Slow zone
- Bus stop
- Street light
- Charging station
- Delivery locker

- Driveway
- Sidewalk
- Bioswale
- Green space
TYPE 5: Vacant lots

AV stop    Moderate mobility hubs    High mobility hubs    Super mobility hubs

- driveway
- sidewalk
- AV parking
- transit bay
- Public seating
- Community garden
- Community parklet
- Public installation
- Slow zone
- Dining table
- Delivery locker
- flex zone
**Existing condition**
- Street typology
- Modes of transportation

**Intervention**
- AV service
- Mobility hub prototype

**Experiment**
- Number of facilities
- Travel time to closest facility
- Walkability/Accessibility Score
Existing bus stops are transformed into AV mobility hubs within the neighborhood based on the residential density: super mobility hubs with multiple social functionalities are inserted in higher density areas; high mobility hubs are inserted in mid-high density areas; moderate mobility hubs are inserted in mid density areas; AV mobility hubs are located in low density areas to improve overall connectivity.
w/o AV hubs

starting location

walking/bike

stop

destination

w AV hubs

starting location

walking/bike

nenborhood AV

shared bikes

destination

customized AVs
RECREATION:
recreation center/community room
playground/green space

SOCIAL GATHERING:
food/convenience store
+moderate mobility transit hubs (grocery store)

CARE:
public/private school
CMS approved health facility
+high-mobility transit hubs
+super mobility transit hubs

Reachable area

w/o AV hubs
15min walk
30min bus

w AV hubs
15min walk
15min AV drive

*rural driving time=AV drive time/1.2 (considering the stopping time and AV speed limit)
### Walkability score index

<table>
<thead>
<tr>
<th>Travel time</th>
<th>Walkability score</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3min</td>
<td>5</td>
</tr>
<tr>
<td>3-6min</td>
<td>4</td>
</tr>
<tr>
<td>6-9min</td>
<td>3</td>
</tr>
<tr>
<td>9-12min</td>
<td>2</td>
</tr>
<tr>
<td>12-15min</td>
<td>1</td>
</tr>
</tbody>
</table>

### Accessibility score index

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>0-6min</td>
<td>5</td>
</tr>
<tr>
<td>6-12min</td>
<td>4</td>
</tr>
<tr>
<td>12-18min</td>
<td>3</td>
</tr>
<tr>
<td>18-24min</td>
<td>2</td>
</tr>
<tr>
<td>24-30min</td>
<td>1</td>
</tr>
</tbody>
</table>
AV transit time = rural driving time * 1.2

Num of facilities in 15min AV drive area

<table>
<thead>
<tr>
<th>Types of CMS approved Facilities</th>
<th>Average transit time</th>
<th>Number of facilities</th>
<th>Accessibility score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital</td>
<td>5.1min</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Federally qualified health centers</td>
<td>3.1min</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Ambulatory surgical center</td>
<td>9.1min</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Skilled nursing facility</td>
<td>6.2min</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>High mobility hubs</td>
<td>3.8min</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Accessibility score index

<table>
<thead>
<tr>
<th>Travel time</th>
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<td>3</td>
</tr>
<tr>
<td>18-24min</td>
<td>2</td>
</tr>
<tr>
<td>24-30min</td>
<td>1</td>
</tr>
</tbody>
</table>
**Walkability map w/o AVs**
*Data source: https://codeforpittsburgh.github.io/FoodAccessMap/index.html*

<table>
<thead>
<tr>
<th>Playground</th>
<th>Food/Store</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average walk time</td>
<td>11min</td>
</tr>
<tr>
<td>Number of facilities</td>
<td>2</td>
</tr>
<tr>
<td>Walkability score</td>
<td>2</td>
</tr>
</tbody>
</table>

**Walkability map w AVs**

<table>
<thead>
<tr>
<th>Playground</th>
<th>Food/Store</th>
<th>Moderate mobility hubs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average walk time</td>
<td>11min</td>
<td>5min</td>
</tr>
<tr>
<td>Number of facilities</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Walkability score</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>
Access to healthcare map w/o AVs

Data source:
https://openac-alcogis.opendata.arcgis.com/datasets/AlCoGIS::allegheny-county-private-schools-locations/explore

Access to healthcare map w AVs

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Federally qualified health centers</th>
<th>Ambulatory surgical center</th>
<th>Skilled nursing facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average transit time</td>
<td>24min</td>
<td>inaccessible</td>
<td>NA</td>
</tr>
<tr>
<td>Number of facilities</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Accessibility score</td>
<td>1</td>
<td>0</td>
<td>NA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Federally qualified health centers</th>
<th>Ambulatory surgical center</th>
<th>Skilled nursing facility</th>
<th>PRT bus route</th>
<th>Street centerline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average transit time</td>
<td>5.1min</td>
<td>3.1min</td>
<td>9.1min</td>
<td>6.2min</td>
<td>3.8min</td>
</tr>
<tr>
<td>Number of facilities</td>
<td>7</td>
<td>7</td>
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<tr>
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<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
Access to school map w/o AVs

Data source:
https://data.wprdc.org/dataset/hospitals
https://data.wprdc.org/dataset/allegeny-county-primary-care-facilities

<table>
<thead>
<tr>
<th></th>
<th>Public school</th>
<th>Private school</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average transit time</td>
<td>27min</td>
<td>19min</td>
</tr>
<tr>
<td>Number of facilities</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Accessibility score</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Access to school map w AVs

<table>
<thead>
<tr>
<th></th>
<th>Public school</th>
<th>Private school</th>
<th>Super mobility hubs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average transit time</td>
<td>5min</td>
<td>4.1min</td>
<td>2.9min</td>
</tr>
<tr>
<td>Number of facilities</td>
<td>28</td>
<td>83</td>
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<tr>
<td>Accessibility score</td>
<td>5</td>
<td>5</td>
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</table>
**Background**

**Hypothesis**

**Methodology**

**Conclusion**

<table>
<thead>
<tr>
<th>Walkability score</th>
<th>3</th>
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<tbody>
<tr>
<td>Accessibility score</td>
<td>0.8</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Walkability score</th>
<th>3.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility score</td>
<td>4.1</td>
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</tbody>
</table>
Thank you for listening!

https://miro.com/app/board/uXjVMvGJP3s=/?share_link_id=935208701224