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POTENTIAL IMPACTS OF AUTONOMOUS VEHICLE DEPLOYMENT ON PARKING AND DEVELOPMENT

URBANISM NEXT CENTER

UNIVERSITY OF OREGON

ECONorthwest

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Source: Waymo - Cover Photo and Above

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Urbanism Next Center

The Urbanism Next Center at the University of Oregon conducts research and convenes partners from around the world to understand the impacts of new mobility, e-commerce, urban delivery, and autonomous vehicles on the built environment. Going beyond these emerging technologies, we explore the possible implications on equity, health, safety, the economy, and the environment to inform decision-making that supports community goals. Urbanism Next brings together experts from a wide range of disciplines including planning, design, development, business, and law and works with the public, private, and academic sectors to help create positive outcomes from the impending changes and challenges confronting our cities.

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ECONorthwest is an independent economic consulting firm who works with a variety of public and private clients across the country, offering economic perspectives on issues ranging from wildfire recovery to education inequities and affordable housing.

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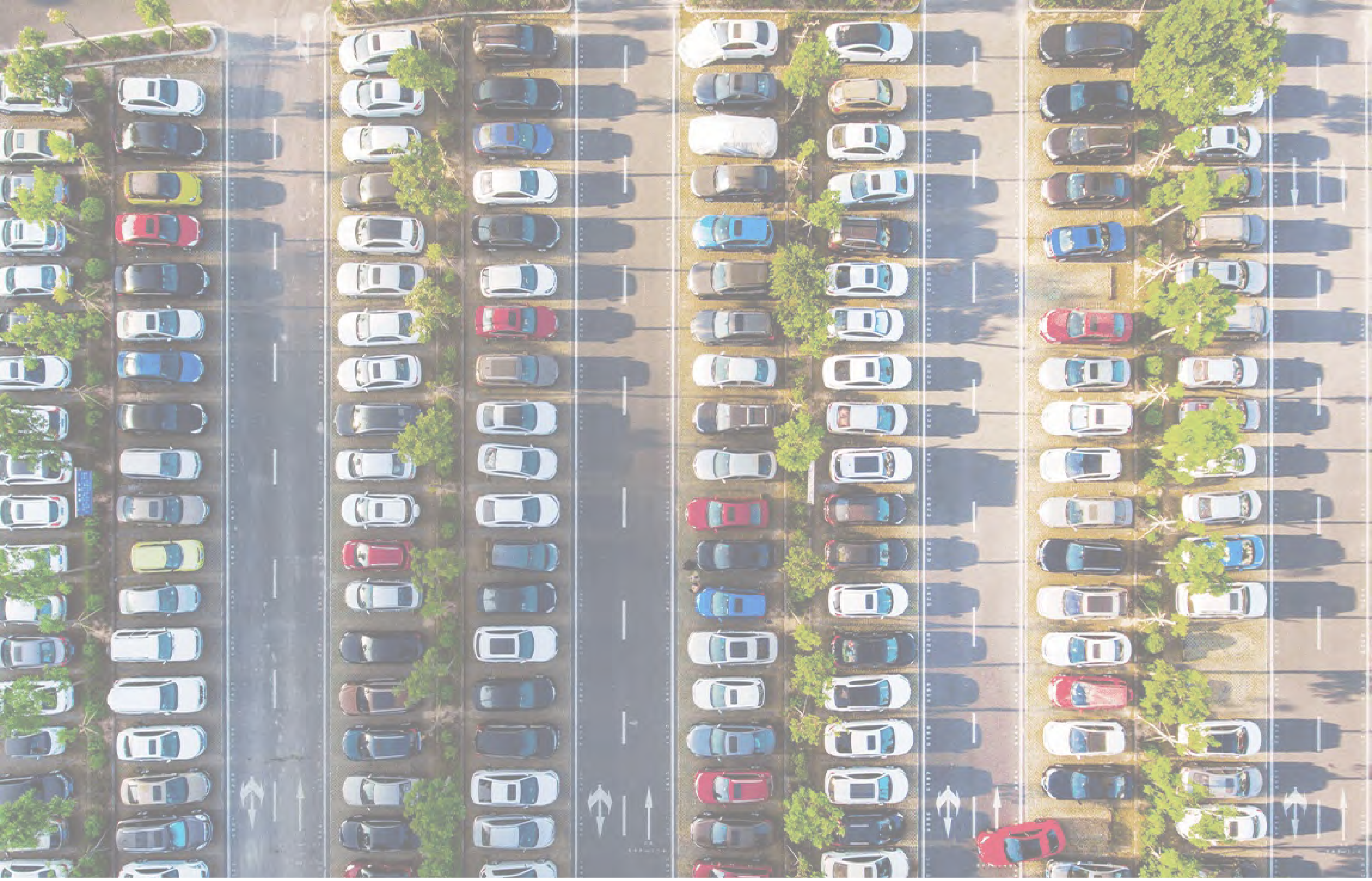
EXECUTIVE SUMMARY

An often-claimed benefit of autonomous vehicle (AV) deployment has been its reduction on parking demand and the potential impact this could have on development. If demand for parking is drastically reduced by the deployment of AVs, the logic is that developers would need to build far less parking than is required today by code and/or is deemed necessary to serve users, freeing up land for development and making projects financially viable. Using San Francisco as a case study, researchers at the Urbanism Next Center and ECONorthwest explored this idea in depth, modeling the potential impacts that AVs could have on development.

To inform our analysis, we first conducted a literature review of modeled/predicted reductions of parking demand based on the deployment of AVs. **Efforts to estimate the potential impact of AVs on parking demand have produced varied results ranging from as much as a *90% decrease* in demand in some scenarios to an *overall increase* in demand in others.** The inconsistency in results underscores the complexity of the topic and the difficulties that are associated with trying to model future demand. Model results are dependent on the parameters and assumptions made about factors such as fleet mix (e.g., shared vs. individually owned AVs), market penetration/adoption rate, the percentage of rides that are pooled, and more.

Predicting the actual amount of parking demand reduction due to AV deployment is beyond the scope of this study. We did, however, want to understand how and if different levels of parking demand reduction would impact the development potential of an area. Based on this, the research team compared four different scenarios to test the magnitude of impact that reductions in parking demand could have on development. In the most conservative scenario, it was assumed that the deployment of AVs would result in a 20% reduction in parking demand/provision, followed by 40%, 60%, and finally, an 80% reduction. These four scenarios were compared to the existing development potential given current parking trends. The research team also used two different methods to estimate development potential. In the *Optimal Development Method*, it was assumed that new developments could occur over the entire parcel, which could involve demolishing and displacing the existing use, rather than being constrained to only the surface parking lot. In this approach, redevelopment options could exist on sites under today's baseline conditions, without AV-related parking demand reduction. In the *Residual Parking Method*, we assumed that existing uses cannot be displaced, and the only developable land is the portion of existing surface parking lots that are freed up by reduced parking demand.

The research team analyzed 2,675 parcels within three 0.75 x 0.75 square mile study areas in San Francisco. These sites were selected to represent a range of urban conditions, including the density and scale of existing development, the size and number of surface parking lots, the strength of the office/residential market, and general accessibility measures. The first study area includes part of the Western Addition area of San Francisco, and the second straddles the Mission and SoMa Districts. These two areas are characterized as being highly accessible with generally small surface parking lots. The third study area encompasses the Stonestown Mall with large surface parking lots and is comparatively less accessible by transit than the other two areas.



Source: DKart on Unsplash

The model results suggest that in the Western Addition and Mission/SoMa study areas there is a moderate to large existing potential for residential redevelopment under current conditions assuming that existing uses may be replaced when financially viable (i.e., Optimal Development Method). Additionally, incremental parking demand reductions appear to have minimal impact. In other words, **it would be financially feasible to redevelop these Western Addition and Mission/SoMa areas in the future without any reduction in parking demand.** Assuming that only the surface parking lots are developable (i.e., Residual Parking Method), development opportunities increase with reductions in parking demand. However, the scale of the opportunities is limited by the small size of lots and the small total amount of land currently used for surface parking in these study areas.

The model results for the Stonestown Mall study area were comparatively quite different. Using either the Optimal Development Method or the Residual Parking Method, **there is some existing potential for residential redevelopment in the Stonestown Mall area under current conditions, but the development potential changes significantly with each parking reduction scenario.** For example, with a 40% parking demand reduction using the Optimal Development Method, about 3,680 more residential units are estimated to be financially feasible. With a 60% reduction, the net impact on residential capacity would rise to 5,600 units. When and whether the financially feasible development potential will be realized as actual development depends on other economic and non-economic factors. Smaller impacts, both total and incremental, are estimated if we assume existing uses do not change (i.e., Residual Parking Method), although we believe this would be an unrealistic outcome since it would mean that no parts of the Stonestown Mall other than its parking lots are redeveloped.

It is important to note that San Francisco is a unique case study. Compared to other U.S. cities it has a relatively low density of surface parking lots, and San Francisco's new Transportation Demand Management policies have virtually eliminated all parking requirements. Developers build parking to meet consumer demand, not because they are required to do so. Developers we spoke with for this research also talked about how market conditions can make development difficult in San Francisco—the market value of land, construction costs, and prevailing wages are all high. In spite of this, we find that development is market feasible, and more development opportunities exist with lower parking demand.

Achieving significant reductions in parking demand will not be easy. To achieve significant parking demand reductions, AVs will need to be shared (SAVs) and most rides will also need to be pooled. Unfortunately, the public's willingness to pool is low, according to existing data although it is possible that this could change with SAVs if the vehicles are strategically placed where demand is high and routing efficiency is optimized. SAVs will also need to complement high-capacity transit systems to achieve maximum benefits. And finally, it will take widespread metropolitan level SAV deployment—beyond the bounds of a single city—for people to forgo vehicle ownership. Until then, SAVs may be used to replace some *trips*, which could have impacts on parking demand in specific areas like airports, offices, and entertainment districts, but they are less likely to replace *privately owned vehicles*. Without a significant reduction in vehicle ownership, parking demand will likely not decrease significantly either.

Source: Clayton Cardinalli on Unsplash

SECTION 1: BACKGROUND

LITERATURE REVIEW TAKEAWAYS

To determine the potential impacts that AVs could have on future development, the research team first conducted a review of existing literature on the topic. This section presents key findings from the literature, including evidence about the impacts that parking has had on development in the past and the variables of AV deployment that could most impact actual future parking demand. (The complete literature review is in Appendix D.)

- **Parking impacts development potential.** Typically, parking supply is often higher than actual parking demand, which is due in part to high required parking minimums. Mandated parking minimums generally reduce the amount and density of development in an area, increase development costs, and push development to less dense areas. The impact of parking on the feasibility of development is especially salient in lots less than 2,500 square feet. The costs of building parking raise the cost of affordable housing, even as affordable housing residents in some areas use less than half of the parking required.

- **There is no consensus on how much AVs will impact parking demand.** AV parking demand models have produced a wide range of results suggesting that parking demand could be reduced by as much as 95% in some scenarios or it could increase by nearly 4% in other scenarios. Results vary so widely because the models are dependent on inputs such as the model of ownership, adoption rate, time horizon, riders' willingness to pool, and more.

- **Actual AV impacts on parking demand will depend on many factors, but mostly on pooled rides.** Shared AVs (SAVs)—and particularly pooled rides—are essential to achieving significant reductions in parking demand. Use of personally owned AVs (PAVs) will have minimal to no effect on parking demand. Parking demand reductions are likely to be highest in central business districts while parking demand may actually increase in residential zones.

- **SAV use projections and data on ridehail pooled rides point to challenges in acceptance of shared vehicles and pooled rides.** Based on stated preference surveys, SAV adoption is projected to be highest for higher income people, men, and people living in dense, mixed-use areas. Riders' willingness to pool appears to vary based on time of day (higher for daytime), amount of trip delay/travel time increase (higher for shorter delays/increases), and trip purpose (higher for commutes than leisure trips). Research suggests that only 22% of riders are willing to pool if it adds no time to trip, and this drops to 6% if pooling adds 10 minutes to the trip. According to reports published prior to 2020, between 13%-20% of riders chose pooled ride options offered by transportation network companies (TNCs) such as UberPool and LyftLine.

- **As demand for parking decreases the need for dedicated pick-up/drop-Off (PUDO) areas will increase both on- and off-Street.** PUDO needs will vary based on the street location, adjacent land use(s), and resultant travel demand. While a significant amount of PUDO activity can likely be accommodated on the street (i.e., curbside), land uses that generate a higher number of trips such as high-rise office buildings, shopping centers, elementary schools, and park-and-rides may need dedicated off-street PUDO zones. The amount of space needed to accommodate the vehicle (i.e., the area it needs to pull in/out) and the anticipated dwell time (i.e., the amount of time it takes to load/unload) will impact the productivity of the zone.

Source: Waymo

DEVELOPER WORKSHOP AND INTERVIEWS

Because today's right-of-way areas and building uses are not designed for a future with a high rate of AV adoption/penetration, there is no observable evidence of how the real estate sector may respond to various AV deployment scenarios. In order to both better understand potential developer response to AV deployment and to validate some of the assumptions used in the development analysis, the research team interviewed three senior members of different real estate companies with experience in the San Francisco Bay Area. Topics of discussion included: how they would adapt their real estate offerings in a world with much lower parking demand; the likely locations of AV pick-up/drop-off areas; the AV conditions that would be needed to change real estate offerings; and the near-term real estate offerings that could potentially serve as a bridge between a world with and without AVs. Key findings include:

- **Developers build parking to meet real and/or perceived consumer demand, even when policy does not require it.** San Francisco's new Transportation Demand Management (TDM) policy virtually eliminates parking requirements. Even existing standards are relatively less restrictive for development than elsewhere in the state or country. However, developers will still build parking when there is demand for it. All luxury developments and most ownership residential developments, which are prevalent in San Francisco, will include parking even when none is required because it is considered essential to sell/lease units.

- **AV deployment will likely have minimal to no impact on development in San Francisco until AVs are deployed throughout the greater Bay Area.** A large-scale behavioral change (i.e., widespread AV adoption) is not anticipated until AV services connect across multiple cities and provide rides at prices far below current rideshare rates. It will also depend on future trends in remote work. Less time in the office translates to less need for AVs.

- **SAV PUDO facilities are not anticipated to add premium value to a property.** SAV PUDO will also likely need to be outside a building and potentially curbside. Providing SAV access to private parking garages or building interiors (e.g., porte cocheres) creates unwanted risk for building users.

- **In terms of a transition to a future with less parking demand, there is growing interest in convertible parking decks (i.e., parking garages that are designed to be easily retrofitted into commercial or residential space as needs change).** However, there is very limited experience with this in the industry. Some existing requirements for convertible parking facilities are being met by developers through efforts that meet the letter of the policy can sometimes not be feasibly converted.

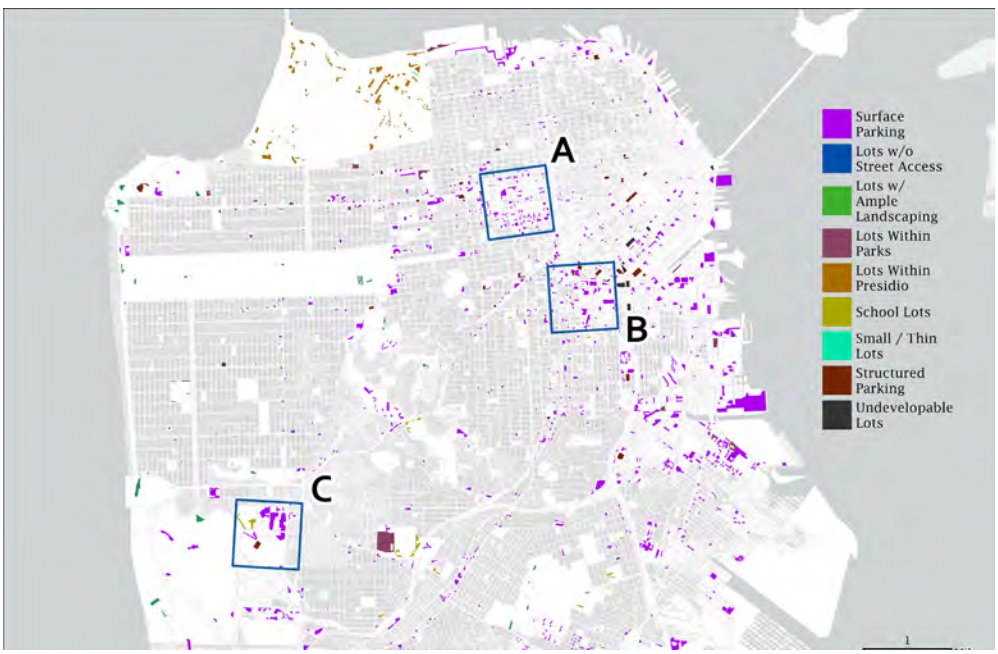
- **San Francisco is a unique case.** Simply adjusting prices using a construction cost index will underestimate true construction costs because of the high likelihood of fair wage requirements and strong presence of union labor in San Francisco. Added labor costs make projects in San Francisco at least 15% more expensive than elsewhere in the Bay Area. This applies to the entire development, including the cost to deliver parking stalls.

SECTION 2: STUDY AREAS

STUDY AREA SELECTION

To determine the potential impact that AV deployment could have on parking demand and, subsequently, development in San Francisco, the research team selected three study areas to analyze. To begin, the research team used satellite imagery of San Francisco to systematically identify and trace every surface parking lot in the city. Once all surface parking lots had been traced, the research team identified areas that had a relatively high density of surface parking. Because San Francisco is a dense city that is mostly developed, there were a minimal number of potential study areas with undeveloped surface parking lots. The research team ultimately selected three 0.75 x 0.75 square mile areas to analyze that represent a range of urban conditions, including the density and scale of existing development, the size and number of surface parking lots, the strength of the office/residential market, and general accessibility measures. Figure 1 shows the three study areas within the context of the city.

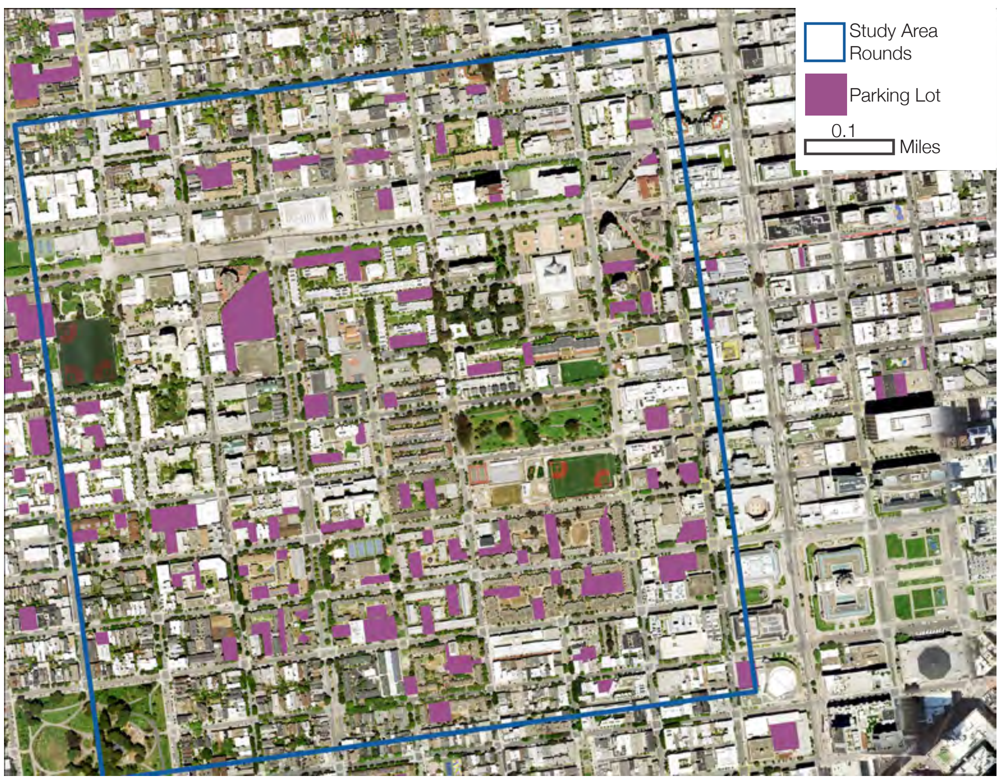
Figure 1. Study Areas within the Context of San Francisco



STUDY AREA CHARACTERISTICS

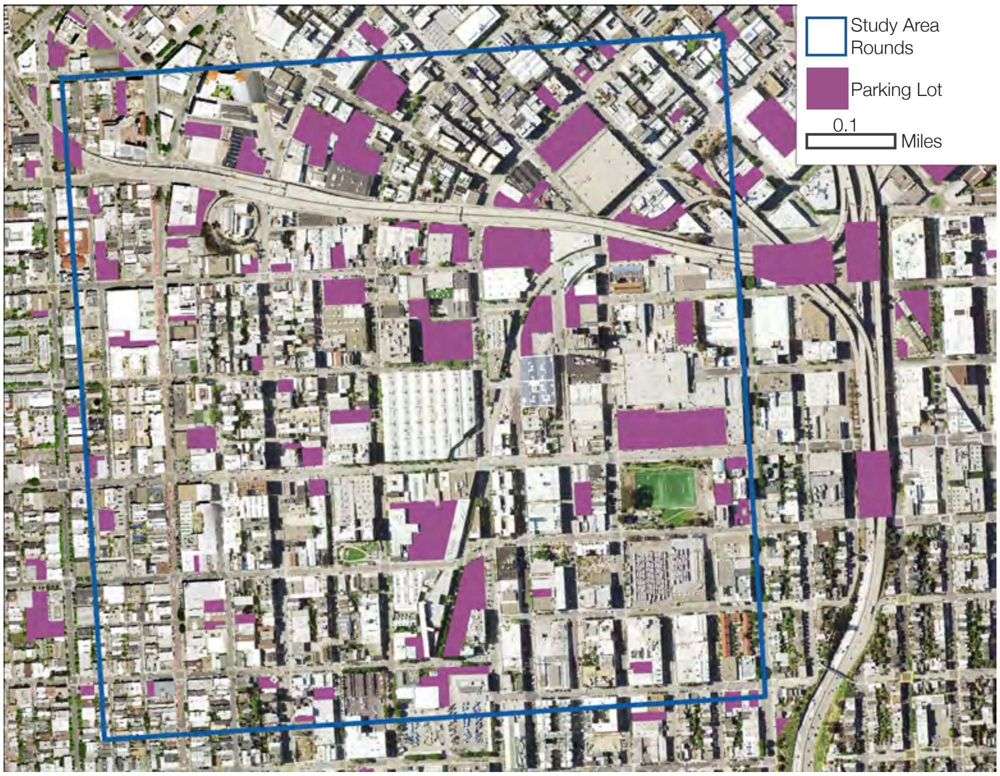
- **Study Area A** (Figure 2) includes part of San Francisco's Western Addition and is an area generally composed of moderate density residential and neighborhood commercial uses. It is characterized as having a relatively strong multifamily market, a very low parking requirement, and very high access to public transit. The research team analyzed 925 block lots, of which 31 acres (13%) are either zoned for public or institutional use or are unlikely to redevelop due to non-market factors. (See Appendix A for definition of block lots and further explanation of undevelopable lots.) Our final dataset included 904 block lots with approximately 2,725 parking stalls. The median site value is the highest of the three study areas.

Figure 2. Study Area A (Western Addition)



- **Study Area B** (Figure 3) includes part of the Mission District and the southern end of the SoMa District with a mix of industrial, commercial, and residential uses. It is close to downtown and near several large technology providers' headquarters. The area is characterized as having a relatively strong office market, a low parking requirement, and very high access to public transit. We analyzed 1,250 block lots, of which 53 acres (21%) are either zoned for public or institutional use or unlikely to develop due to non-market factors. Our final dataset included 1,204 block lots with approximately 2,486 parking stalls.

Figure 3. Study Area B (Mission District/SoMa District)



- **Study Area C** (Figure 4) includes the Stonestown Mall, which is an area already slated for redevelopment under the Stonestown Development Project[1]. Under the proposed plan, many of the existing 26.9 acres of surface parking would be redeveloped into a primarily residential neighborhood with up to 2,900 new residential units. The area is surrounded by San Francisco State University with low-density residential development, most of which includes single-family units. It is characterized as having a moderate parking requirement and moderate transit access. We analyzed 588 block lots, of which 147 acres (53%) are either zoned for public or institutional use or unlikely to develop due to non-market factors. Our final dataset included 567 block lots with approximately 2,071 parking stalls. The median site value is the lowest of the three study areas. We opted to include this study area in our analysis to compare the proposed number of new units to be built under the current plan with the potential development that could occur in a future with significantly reduced parking demand.

[1] Additional details about the Stonestown Development Project available at: https://sfplanning.org/project/stonestown.

Figure 4. Study Area C (Stonestown Mall)

Table 1. Study Area Accessibility Scores

	Walk Score	Transit Score	Bike Score
Study Area A	97	81	91
Study Area B	99	86	97
Study Area C	87	68	66

Data: WalkScore.com

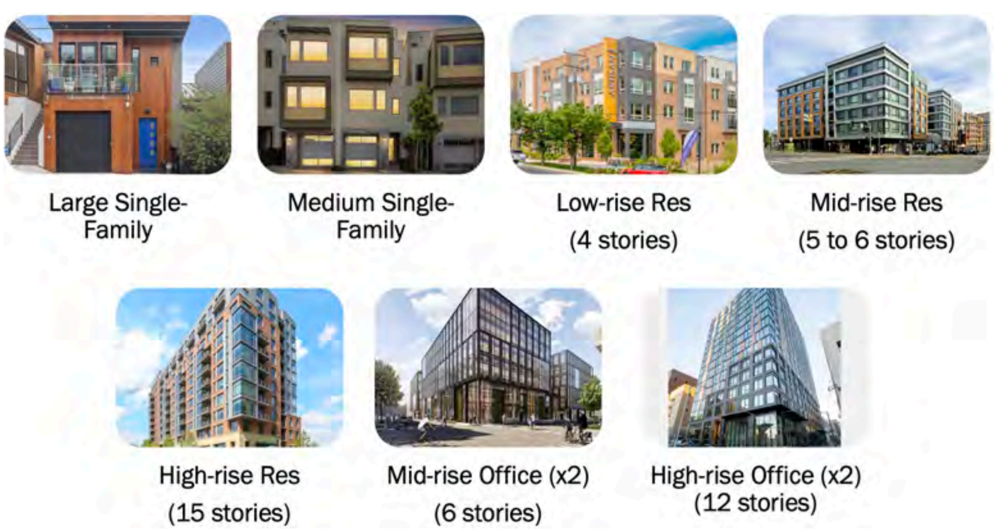
SECTION 3: DEVELOPMENT ANALYSIS

The goal of ECONorthwest's real estate feasibility model ("feasibility model") was to estimate the impacts of various parking reduction scenarios on the potential for redevelopment in San Francisco. The model evaluated the type, scale, and location of potential developments that might be feasible under current and possible future conditions. The process involved gathering a substantial amount of data on local market conditions and regulations beyond the information provided through the study area GIS data. Financial calculations were performed using "pro forma" financial analysis, which real estate actors regularly use to model the revenues and costs of potential developments and evaluate their returns on specific sites. These calculations were carried out for a variety of building typologies across all parcels in the GIS data using an online application called MapCraft Labs. The building typologies that were feasible on sites varied between scenarios and the difference between the outcomes reflects the impact of the scenario variances on real estate development opportunities in the study areas. (For a complete description of the development analysis and the variables included in the models, see Appendix B.)

PROTOTYPES

Development feasibility was evaluated for various building types, or "prototypes." The physical features of the prototypical building structures (such as average unit size, building height, parking type, etc.) were based on observations of recently built properties in the Bay Area. To represent the variety of allowed development options in the simplest way possible, nine prototypes were analyzed for this study.

Figure 5. Prototypes Tested for Development Analysis



Source: ECONorthwest

PRO FORMA MODEL

The research team analyzed the feasibility of the prototypes using "pro forma" financial analysis, which incorporated location-specific information for each site. For Study Areas A and B, only prototypes that would be permitted under a site's zoning allowances were considered. Although entitlements can change in the future and may change in response to the adoption of AVs, we evaluated development capacity under current regulations, which provides a conservative estimate of development capacity if one expects that AVs can lead to relaxed regulations. For Study Area C, we evaluated all prototypes even if they exceeded today's zoning allowances. The approach for Study Area C reflects recently approved plans to redevelop the Stonestown Mall into a mix of uses ranging up to 18 story buildings.

The primary outputs were development capacity for residential buildings measured as total units and development capacity for office buildings measured as square footage of office space. Because the model incorporated the City of San Francisco's Inclusionary Housing (IH) policy, another output was the number of IH units (affordable housing units produced due to the IH policy). The model also tabulated the existing number of units and square feet of non-residential building area on sites where redevelopment was determined to be feasible. These estimates can be considered a measure of potential displacement since the occupants of existing units and buildings would need to relocate for a new development to occur.

PARKING SCENARIO LOGIC

The feasibility model accounts for the parking needs of existing uses and new developments by applying two separate approaches. **In the *Optimal Development (OD) Method*, new developments can occur over the entire parcel, which could involve demolishing and displacing the existing use/buildings, or only on the surface parking lot portion of the parcel, assuming the new developments are allowable and financially feasible.** In the former case, the parking needs of new developments would be directly influenced by the parking reduction scenarios since the required parking in the new development would change in each scenario. In the latter case, there are both direct and secondary effects. The direct effects of parking reduction still exist for the new developments. But the new developments would also need to provide additional parking stalls to replace the parking needs of the existing use. When a parking scenario reduces parking needs of an existing use, it has a secondary effect on the parking needs of the new development. In this approach, redevelopment options could exist on sites under baseline conditions, without AV-related parking reductions. Such instances are not unexpected, including cases where homeowners choose to not sell their home to a developer that could feasibly redevelop the property.

In the *Residual Parking (RP) Method*, we assumed that existing uses cannot be displaced, and the only developable land is the portion of existing surface parking lots freed up by reduced parking demand. It is assumed that redevelopment of these areas would be allowable and financially feasible, but not impact existing uses. This simplification reflects the reality that property owners may not pursue the highest and best use of a property. Even if a financially better redevelopment opportunity exists, property owners may decide not to take the risk or may favor the current uses of the property. The Residual Parking Method has two implications for resulting development capacities. First, the development capacities are zero for the baseline scenario in which there is no parking reduction because no land is available for development. Second, the incremental development capacities are lower in low parking reduction scenarios because the land that becomes available for development may be too small for many prototypes. For example, a scenario that frees up 20 stalls, or about 7,000 square feet of land, is not large enough for multifamily or office developments.

The differences between the two approaches are summarized in Figure 6.

Figure 6. Optimal Development and Residual Parking Methods Comparison

	Optimal Development Method	Residual Parking Method
Eligible development sites	Assumes existing buildings, full surface parking lots, and partial surface parking lots can be redeveloped if financially and physically feasible.	Only surface parking lots can be redeveloped. Assumes parking lot owners will not redevelop their buildings or allow redevelopment of the parking lot area that is in use.
Surface parking redevelopment logic	Surface parking lot redevelopment requires that any parking stalls in use by the existing building remain surface parking or are replaced within the new development.	Only the portion of parking lots that are no longer in use due to AV-related parking changes can be redeveloped.
Development capacity logic	Units and commercial square footage capacity reflects market-feasible development that fits on the eligible site and has the highest positive residual land budget among viable development options.	
Baseline results (0% AV-related parking reduction)	Baseline includes many possible developments that are viable on eligible sites today without any AV-related parking changes.	Baseline assumes there is no land available for development because surface parking lots are fully used today, thus there is zero development capacity.

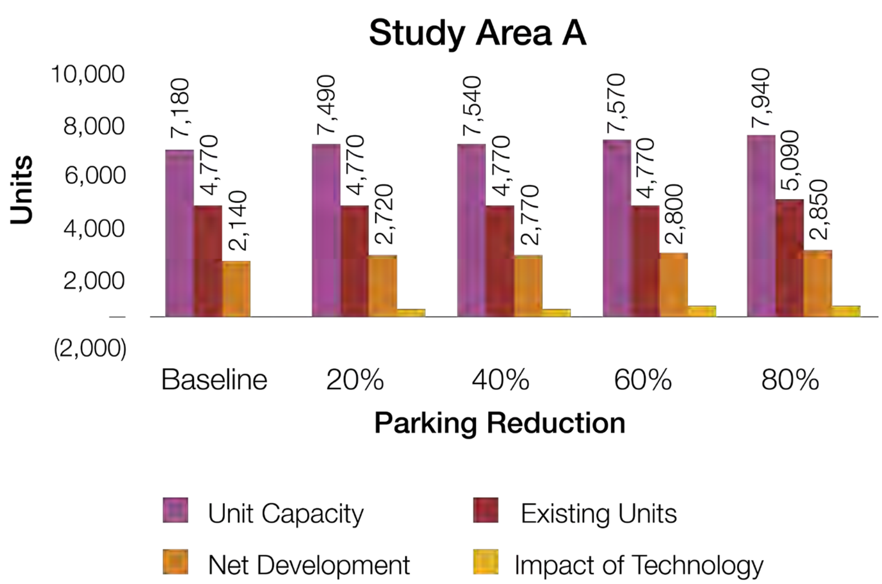
SECTION 4: RESULTS

STUDY AREA A (WESTERN ADDITION)

Using the *Optimal Development Method* (Figure 6), the research team found many opportunities for residential redevelopment under the baseline scenario (i.e., current conditions) in Study Area A. Developments with 7,180 new units are financially feasible along with 410,000 sq. ft. of non-residential space in some mixed-use residential structures. After accounting for existing units that might be displaced by new developments, the net impact on residential capacity in the study area would be 2,410 incremental units (Figure 6). Nearly a quarter of the units would be affordable to households earning 75 percent of the Area Median Income (AMI) due to the City of San Francisco's Inclusionary Housing (IH) policy in all Optimal Development scenarios. No office redevelopment was found to be feasible. **Interestingly, the incremental impact of parking demand reduction induced by AV technology was found to be minimal.** Under the 20% parking demand reduction scenario, the net impact on residential capacity rises 310 units from the baseline to 2,720 units. With 80% parking demand reduction, the net impact on residential capacity is 440 units higher than the baseline.

Figure 7. Study Area A Residential Development Potential (Optimal Development Method)

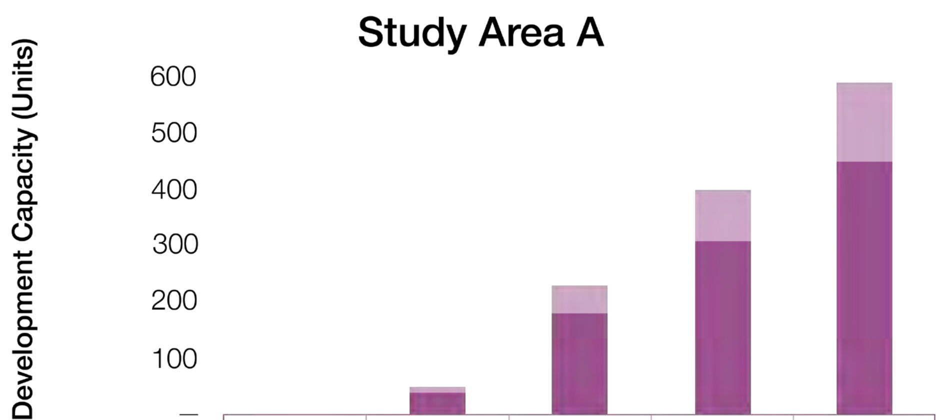
Impact	+310	+360	+390	+440



Using the *Residual Parking Method*, which considered redevelopment on portions of the study area's 904 block lots, a 20% parking reduction would result in 50 additional residential units compared to the baseline, jumping to 230 units in the 40% reduction scenario (Figure 7). Comparatively, the OD Method resulted in 310 net units in the 20% scenario or 360 units in the 40% scenario. However, in the scenario where parking demand was reduced by 80%, the RP Method resulted in more incremental units than the OD Method (590 units vs. 440 units, respectively).

The difference in results can be explained by the methodological differences. Whereas the RP Method assumes no parking lot area is available for development in the baseline, the OD Method contemplates redevelopment of sites under current conditions, so accounts for a substantial amount of feasible development in the baseline scenario. Also, the OD Method allows redevelopment of whole parcels, which may be feasible with lower parking reductions. However, development is limited to parking lots in the RP method, which may only become feasible with higher parking reductions that free up large areas for redevelopment.

Figure 8. Study Area A Residential Development Potential (Residual Parking Method)



	Baseline	20%	40%	60%	80%
Total Units	–	50	230	400	590
Inclusionary Units	–	10	50	90	140
Market Rate Units	–	40	180	310	450

Parking Reduction

Market Rate Units   Inclusionary Units   Total Units

Conclusion: The model results suggest that there is an existing potential for many redevelopment projects in Study Area A, though when they take place will depend on investor interest and willingness of owners to sell or develop their properties at any given point in time. Parking demand reductions can marginally accelerate this redevelopment trend, but it is unlikely to significantly change trends in the real estate market. In other words, parking is not a deciding factor in project development in this area.

STUDY AREA B (MISSION DISTRICT/SOMA DISTRICT)

Under the *Optimal Development Method*, the research team found a small existing potential for residential redevelopment under the baseline scenario (Figure 8). However, there is a large existing potential for office redevelopment (Figure 9). Up to 970 new units and 4 million sq. ft. of office space are financially feasible for development on sites where 470 units and 730,000 sq. ft. of non-residential spaces exist. The net impact on residential capacity in the study area would be an increase of 500 units and over 3 million sq. ft. of office space. About 22% of market feasible units are affordable to households earning 75 percent of the AMI due to the IH policy in all Optimal Development scenarios.

Using the OD Method in Study Area B, **the incremental impact of parking reduction induced by AV technology was found to be minimal.** Small to moderate parking demand reductions (up to 40%) did not have an impact on residential or commercial redevelopment opportunities. Under the 60% parking demand reduction scenario, the net impact on residential capacity rose by 130 units to 630 units (Figure 8). Under the 80% scenario, more office space became feasible compared to the baseline. These results demonstrate how new residential and office developments may both be feasible in a location but have different parking reduction impacts. Residential use is more favorable until the 80% parking reduction, which makes office more feasible than residential on some parcels.

Figure 9. Study Area B Residential Development Potential (Optimal Development Method)

Impact	+0	+0	+130	+70

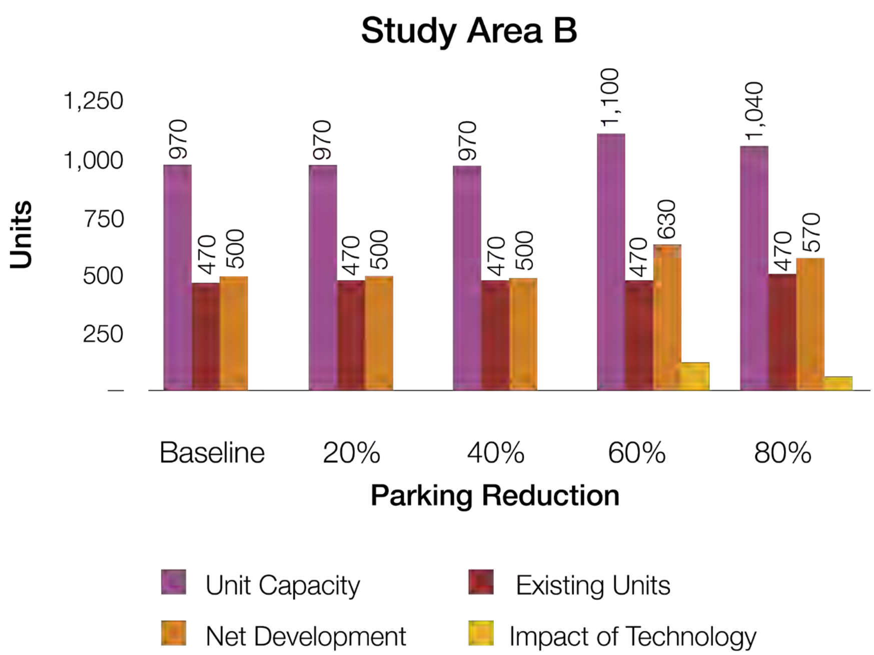
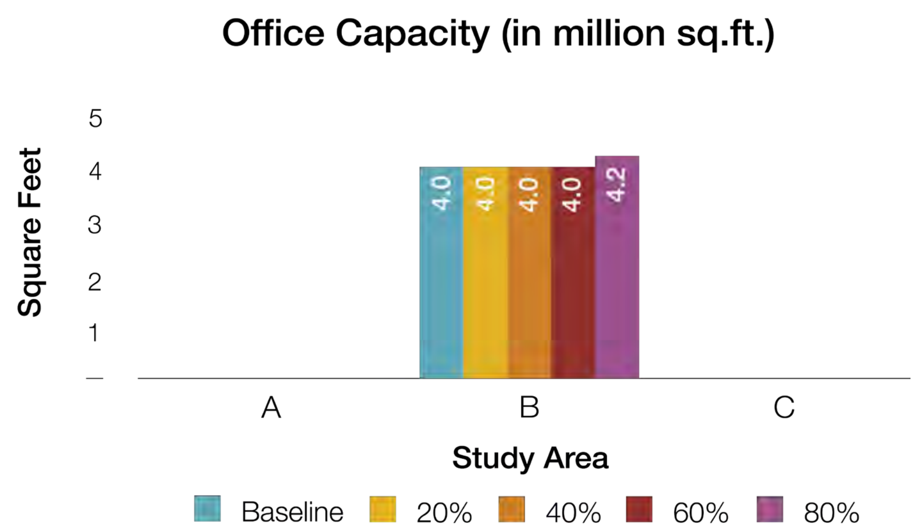
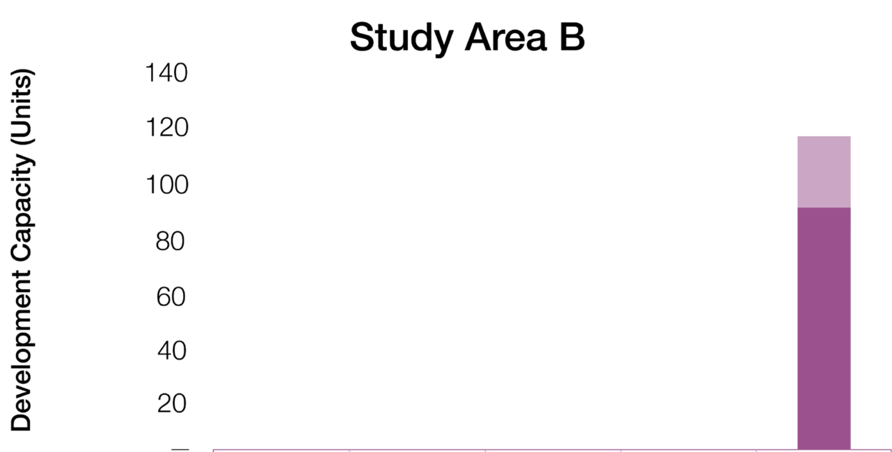


Figure 10. Study Area B Office Development Potential (Optimal Development Method)



Under the ***Residual Parking Method,*** no net impact on residential capacity was estimated until there was a very large (80%) parking demand reduction (Figure 10). However, the study area has a strong office market and incremental change in office space capacity was estimated with each parking reduction scenario (Figure 11).

Figure 11. Study Area B Residential Development Potential Residual Development Method)

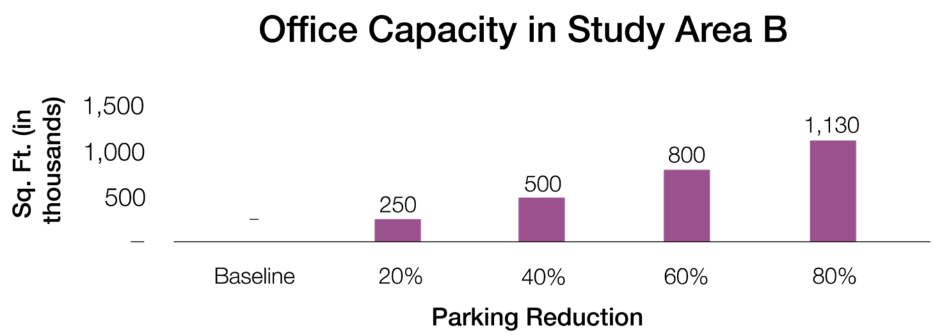


	Baseline	20%	40%	60%	80%
Total Units	–	–	–	–	590
Inclusionary Units	–	–	–	–	140
Market Rate Units	–	–	–	–	450

Parking Reduction

Market Rate Units Inclusionary Units Total Units

Figure 12. Study Area B Office Development Potential (Residual Development Method)



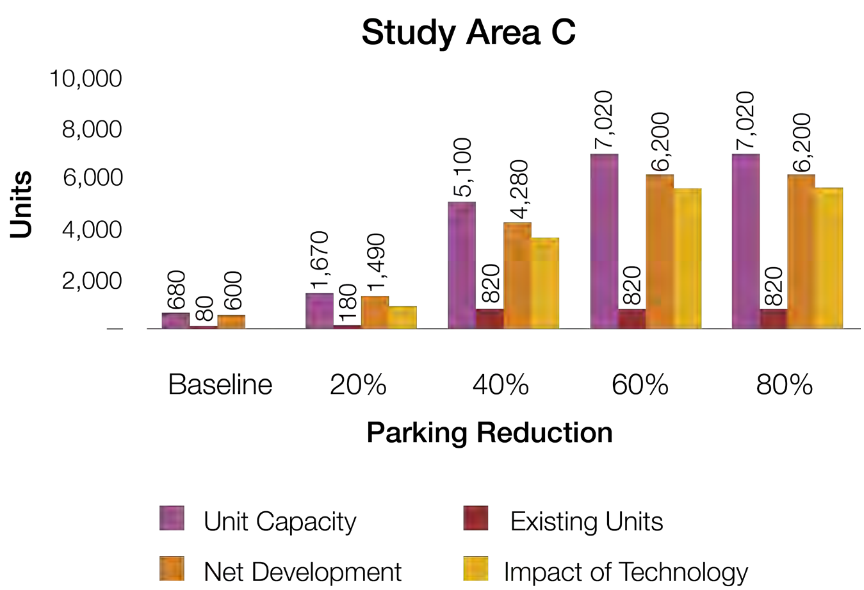
STUDY AREA C (STONESTOWN MALL)

Under the *Optimal Development Method*, the research team found a small existing potential for residential redevelopment under the baseline scenario—600 new units are financially feasible where 80 units and 180,000 sq. ft. of non-residential spaces exist. **Unlike in the other study areas, however, the development potential changes significantly with each parking reduction scenario.** For example, with 40% parking demand reduction, about 3,680 more net units are estimated to be financially feasible. With a 60% reduction, the net impact on residential capacity would rise to 5,600 units. The feasible redevelopments include the Stonestown Mall and some nearby single-family and multifamily buildings. Increasing the parking demand reduction in the model to 80% did not yield any new redevelopment potential, suggesting that large feasible opportunities are achieved with 60% percent parking demand reduction.

In the baseline scenario, a large portion of the estimated development potential is for single-family or other low-density developments that would not be subject to IH requirements. Thus, only about 10% of units would be required to be affordable to households earning 75 percent of the AMI. Multifamily buildings' share of total development potential rises with each parking reduction scenario. So, with 60% parking reduction, about 22% of the units would be affordable to households earning 75 percent of the AMI due to the IH policy. Office redevelopment was found to be less feasible than residential. That said, some non-residential development is likely to occur alongside or within large residential developments, but this is not contemplated in our simplified modeling approach.

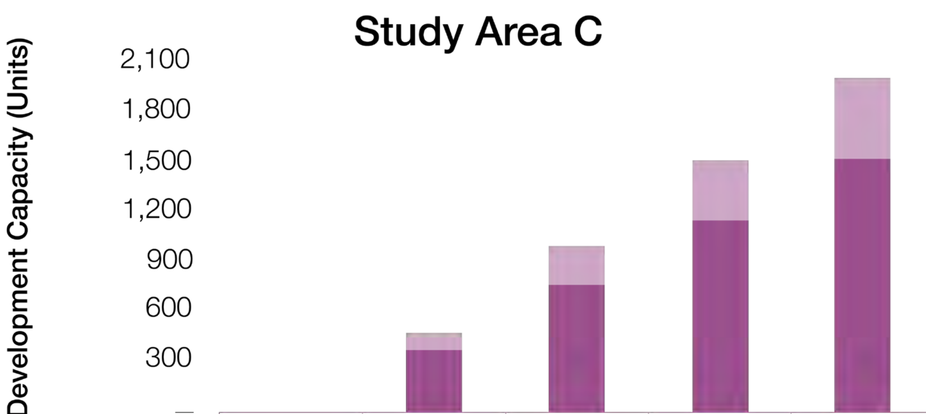
Figure 13. Study Area C Residential Development Potential (Optimal Development Method)

Impact	+890	+3,680	+5,600	+5,600



Smaller impacts, both total and incremental, are estimated under the ***Residual Parking Method*** due to methodological assumptions. The RP Method estimates redevelopment potential only on surface parking lots and does not contemplate redevelopment of the mall structures and surrounding buildings. The model contemplates large residential structures between the mall and its outbuildings (e.g., restaurants and strip retail), which the research team believes to be an unrealistic outcome.

Figure 14. Study Area C Residential Development Potential (Residual Development Method)



	Baseline	20%	40%	60%	80%
Total Units	–	470	990	1,500	1,990
Inclusionary Units	–	110	240	360	480
Market Rate Units	–	360	750	1,140	1,510

Parking Reduction

Market Rate Units   Inclusionary Units   Total Units

Conclusion: The model results suggest that with reduced parking demand there is a great potential for many redevelopment projects in Study Area C . Large surface parking lots, relatively high existing parking demand, and relatively low land values make Study Area C a place where real estate development would benefit greatly from reduced parking demand.

SECTION 5: DISCUSSION

The results of this study raise important questions about the impacts of AV deployment and how this might vary in different areas of a city as well as different areas of the country. First, it is important to note that **San Francisco is a unique case study, particularly near the core.** San Francisco was the focus of this study because it has been and continues to be a leader in AV deployment with numerous companies testing and piloting AVs in the area. That said, the city is not like most other U.S. cities in terms of its higher density of development, smaller lot sizes, low amount of existing parking, limited parking regulation, high availability of public transit, high land prices, high labor and construction costs, and high development pressure. This makes it—particularly the areas near the central core (Study Areas A and B)—an outlier as to the impacts parking demand changes might have on development. Parking requirements or parking demand generally do not play much of a role in development decisions in this area. This can be seen in the results of Study Areas A and B where it would be financially feasible to redevelop these Western Addition and Mission/SoMa areas without any reduction in parking demand.

The Stonestown Mall Study Area is likely a better proxy for areas outside of San Francisco. This area (Study Area C) represents a development pattern more typically seen throughout the country. It includes large lot developments with large expanses of parking, more limited transit access, and a generally more auto-oriented environment. Even though it is still subjected to the higher land, labor, and construction costs of the region, the differences in this area compared with study areas A and B give parking a more central role in development. This can be seen in the model results showing a more linear change in the development potential of the area as parking demand subsides. We would assume similar, and potentially even more dramatic, changes would be seen in physically similar areas in other parts of the country—particularly in cities that are less dense and more auto-oriented than San Francisco.

Getting to the point where AV deployment will have a significant impact on parking demand will be difficult, however, and will require substantial changes and incentives. While our study focused on a range of potential parking demand reductions, from 20% up to 80%, our literature review points to the fact that realizing this scale of reductions will require a unique mix of conditions, including AV deployment being dominant (large market penetration), geographically widespread (throughout the metropolitan area, not only within a central city core), shared (not privately owned), pooled (not individual rides), and happening alongside increased parking costs.

Even under ideal conditions, parking lots may not go away immediately – Our conversations with developers highlighted the reality that they will likely continue to build parking until they are absolutely sure real and perceived demand is declining, particularly in the higher-end housing market. The study we conducted looked at different ranges of reductions in parking demand and assumed that these changes in demand would result in reductions in parking supply. If developers are conservative in their belief that demand has reduced, they will continue to build parking to ensure it does not negatively impact the financial strength of their projects. Reduced demand may not result in reduced demand. Reduced supply will only happen when developers are certain that vehicle ownership rates are declining, and that prospective buyers or renters are not factoring parking into their choices about location or cost.

Source: Tadeja Pavšič on Unsplash

APPENDICES

APPENDIX A: PARCEL DATA PREPARATION

Surface Parking Lot Identification

To identify potential sites for development the research team first needed to identify where there were existing surface parking lots in San Francisco. Using satellite imagery of San Francisco, members of the research team went block by block, systematically tracing all identified surface parking lots. Land use data for San Francisco was used to cross-reference the satellite imagery and confirm actual lot lines. Wherever possible, the traced polygon was drawn to match the lot lines since satellite imagery is taken at an angle.

There were many cases where a single parking lot spanned multiple polygons. In these cases, the research team opted to draw a single polygon for these parking lots. However, if there were fences or other obvious obstructions that followed property lines or made it clear that the parking lots were not continuous, individual polygons were drawn. Tree foliage also made it difficult in some cases to achieve the exact dimensions of some parking lots. Some lots were on the border of San Francisco and South San Francisco. If at least 30% of the lot was in San Francisco it was included in the dataset.

This process for identifying surface parking lots resulted in a unique geographic variable called “block lots” in the analyzed data set. When a parking lot spanned across parcel boundaries, the parcels were combined into one. When multiple, noncontiguous parking lots were identified in a parcel, the parcel was split into parking lots and one or more lots without surface parking. In most instances, combining or splitting of a parcel was not necessary and thus the block lots share the same boundaries as parcels.

A visual inspection of each lot was done during the process and each lot was assigned a code based on its attributes. The codes indicate various situations in which a lot is unlikely to be redeveloped and, thus, the lots are excluded from analysis. Table A-1 shows the complete list of lot codes. The codes are assigned for about 1.4% of block lots and 9.4% of the analyzed site sizes. The remainder of the block lots are not assigned a code and, thus, included in the analysis.

Table A-1. Lot Codes

green_space	This refers to parking lots with adjacent green spaces or other nonuse spaces within or near the parking lot itself.
undevelopable	This refers to parking lots that seem undevelopable on their own. Largely, this was used for parking lots below freeways.
small_thin	Minutely small or thin. Not suitable for added development.
park	Flag for parkland or park resembling land.
school	Flag for school looking lots verified with land use.
presidio	Lots located in San Francisco Presidio.
utility	Flag for utility parking lots deemed inapplicable for this analysis. Examples include: park maintenance lots, etc.
center block	Flag for parking lots that are in the center of a block and do not have a side of the parking lot along the streetside. 

Development Parcel Preparation

Once all the surface lots were identified and drawn and the study areas had been selected, the research team then needed to determine the Largest Inscribed Rectangle (LIR) in the polygon. (The LIR is the largest possible orthogonal shape that can fit within a parking lot.) This served as a rough outline for a potential rectangular building that could be developed on the existing surface lot. This analysis was completed in ArcGIS using advanced editing features. If a given lot was already orthogonal, the lot lines were simply replicated. If the lot was a complex shape, various measurements were taken and the one with the best fit was selected. This methodology did not take into account any zoning limitations, side lot setbacks, or Floor Area Ratios (FAR), which could impact the actual lot development size.

Parcel Dataset

Additional attributes that would be necessary for the development analysis were appended to the dataset once the LIRs were completed. Data were joined in ArcGIS using the parcel's unique identifier (FID). The finalized parcel dataset was delivered to ECONorthwest for further analysis. Table A-2 shows the list of appended and/or post-processed data, along with the data source.

Table A-2. Parcel Data Attributes and Data Sources

Attribute	Data Source
Land Use	From the Open SF Parcel data set (called Existing Use in original data).
Zoning Code	From the Open SF Parcel data set
Building Square Feet	From the Land Use data set.
Residential Units	From the Land Use data set.
Land Value	From Parcel Atlas data set.
Improvement Value	From Parcel Atlas data set.
Total Value	From Parcel Atlas data set.
Parcel Area	Calculated area of Parcel in square feet. (Post-processed)
Parking Lot Area	Calculated area of Parking lot in square feet. (Post-processed)
Non-Parking Lot Area	lot_area subtracted from prcl_area in square feet. (Post-processed)
LIR Area	LIR area in square feet. (Post-processed)
Stalls	Count of parking stalls for a parking lot. (Post-processed)

Table A-3. Total Parcels Included in Final Dataset

Study Area	Block Lots	Area (sq. ft.)	Area (acre)	Parking Stalls
A	925	10,595,717	243	3,226
B	1,250	11,170,573	256	2,833
C	588	11,982,058	275	2,726
Grand Total	2,763	33,748,349	775	8,785

Table A-4. Number of Analyzed Parcels (After Excluded Undevelopable Lots)

Study Area	Block Lots	Area (sq. ft.)	Area (acre)	Parking Stalls
A	904	9,248,878	212	2,725
B	1,204	8,878,326	204	2,486
C	567	5,591,599	128	2,071
Grand Total	2,675	23,718,803	545	7,282

Data Sources

- Satellite imagery was from the National Agriculture Imagery Program and it was acquired from the USGS's Earth Explorer. Date of imagery was May 24, 2020.
- Land use data was acquired from Data SF. It was last updated September 6, 2019.
- Parcel data was acquired from Data SF (SF Parcel) and Parcel Atlas.

Limitations

It is worth noting that polygons are not as accurate as on-site, real-world measurements. Satellite imagery only has a 1m pixel resolution, so measurements could be off a meter or more. Additionally, the angle of the imagery also distorts the perception of the ground. The results should be considered best estimates based on available data, but on-site measurements of each parcel would need to be taken to confirm accuracy.

APPENDIX B: DEVELOPMENT ANALYSIS

Framework for Real Estate Feasibility Analysis

Market-driven or technology-induced changes in land uses and regulations can result in new developments (e.g., apartments, retail stores, and offices) where existing developments exist (i.e., redevelopment) or on undeveloped parcels. In addition to market demand for occupiable space, development is informed by allowed land uses, zoning entitlements, parking requirements, and parking demand. Land uses can change—and developments can occur—when multiple necessary but insufficient factors are aligned.

Figure B-1 illustrates various factors that influence the legal, physical, and financial feasibility of real estate development.

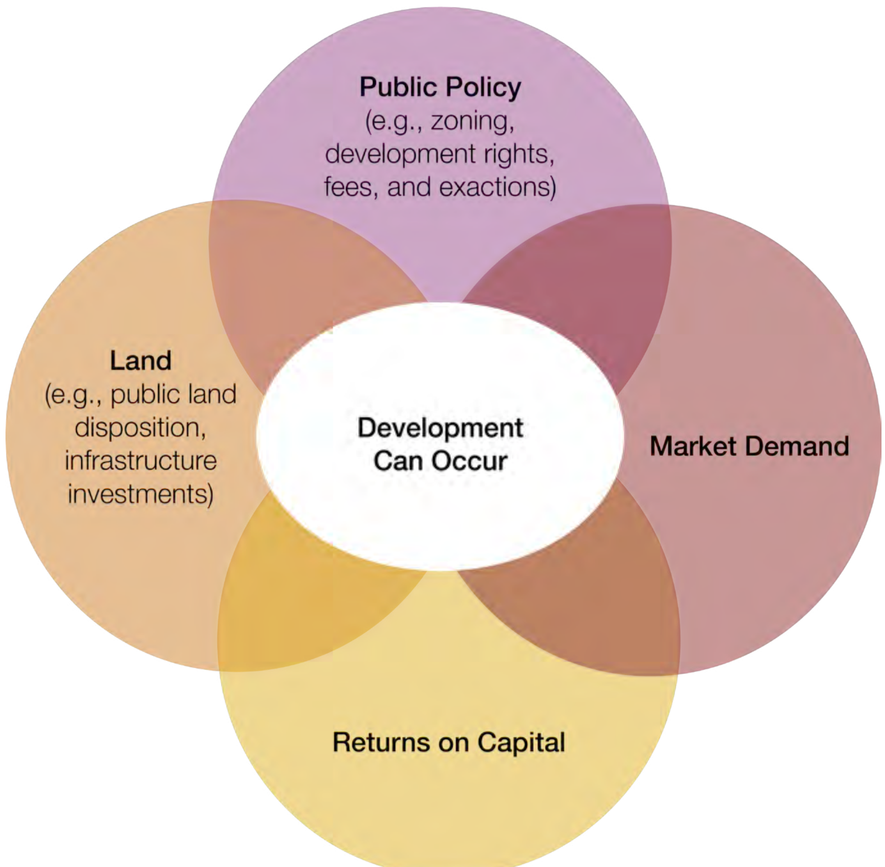
- **Land:** There must be sites that are large enough for the type of building a particular developer wants to build. The availability of infrastructure, complementary nearby uses, and amenities also help determine whether land is suitable for a given type of development. A developer must also be able to acquire or control a suitable site for a reasonable price or changing the land use will be financially infeasible.

- **Public Policy:** For development to occur, the use and scale of development must be allowed under the relevant regulations and codes, including zoning regulations, development standards, fire codes, and building codes. Public policy also sets the review processes, fees, and exactions required for development to move forward, all of which can affect whether development is feasible. In some cases, it also drives labor costs for construction (e.g., through prevailing wage requirements).

- **Market Demand:** For market-driven development, a sufficient number of end users must be willing to pay enough for the finished space to cover the costs of building it. For non-market development, such as affordable housing or public buildings, there must be both a need for the development and sufficient public and/or philanthropic funds to close the gap between what occupants pay and the cost to build and operate the development. Market demand is influenced by locational factors, including nearby amenities and accessibility, along with features of the development itself.

- **Return on Capital:** For private development to occur, the value of the finished space must exceed the total cost of the development—including land, material and labor costs, design and permitting costs, fees and taxes, and holding and financing costs—by a sufficient margin so that those who invest money and/or time into the development will earn a financial return commensurate with their perceived risk. There must also be investors and lenders willing to fund a given type of real estate investment in the relevant real estate market at a rate of return that can be generated by the development. Moreover, for-profit developers must make a sufficient financial return themselves to stay in business and to justify their investment risk and opportunity costs.

Figure B-1: Major Factors that Influence Real Estate Development



Source: ECONorthwest

If any one of these conditions is not met, market-driven development generally will not occur. Changes to any of these factors can determine when, where, and whether development is viable, as well as the types of development that can occur. All these factors are accounted for by real estate professionals to help make their investment decisions. Each is reflected in the pro forma accounting. ECONorthwest's approach incorporates these categories of conditions to model a realistic decision-making process of private, for-profit developers under various scenarios.

The feasibility model is not intended to predict timing of development or provide precise estimates of development capacity for individual properties. The timing of development is not only dependent on development potential but also influenced by the depth of demand for a given type of development at any given time, availability of willing property owners, and the capacity among developers and builders to construct them. While the model shows generalized development opportunities under typical conditions, the actual development on each property will depend on many site-specific characteristics, such as property owner interest in selling or redeveloping and site remediation factors that are beyond the scope of the model.

The model analyzes market-feasible development capacity, and its results should not be used as a forecast of real estate production or absorption. The analysis considers some site-specific information (such as site size, value, and current use), filters out certain properties that are committed to public uses, estimates the capacity for new development based on zoning allowances, and determines market-feasible capacity for potential development based on prototype characteristics and market variables. Because the model cannot consider all site-specific characteristics and lacks information on the property owners' willingness to sell or redevelop, its results should be interpreted as realistic options, but not a forecast of land use change. The model results can be used to understand the relative impacts of policy choices on development opportunities.

Data

The feasibility model requires a substantial amount of data on local market conditions and regulations. These data inputs reflect the myriad factors that inform development feasibility, which are described above. The following data were used:

- **GIS Data:** The parcel data contains information of site location, size, assessed value, and zoning designations, which are typically available through public agencies. It also includes information on existing parking areas and stalls as well as existing uses that could make redevelopment unlikely (e.g., schools, narrow lots).

- **Entitlements:** While zoning designations are available through the GIS data, they cannot be interpreted without understanding the City of San Francisco's development standards. We focused our research efforts on a limited set of zoning characteristics as follows: height limit, residential density limit, floor area ratio, and allowed uses. These entitlements are used to determine which building types are allowed in and evaluated for each parcel within a zone. A limitation of this study is that we did not account for development standards that are less likely to impact outcomes, including setbacks, open space requirements, ground floor use requirements and limitations, and street frontage requirements.

- **Demand Data:** Residential demand is reflected in the average prices households are willing to pay to purchase or rent a dwelling unit. Commercial demand is reflected in the lease rates people are willing to pay for a commercial space. In the model, single-family and townhouse prices are based on Zillow data, specifically the Zillow Home Value Index (ZHVI), which is available by number of bedrooms and three tiers of price points across San Francisco. Multifamily rents, vacancy, and parking demand as well as office rents, vacancy, and parking demand are generated using data from CoStar. CoStar is a commercial real estate information company with a robust database of commercial real estate transactions in the United States, including office, industrial, and multifamily. CoStar data points are widely available in San Francisco. The accuracy of sales price and rent estimates were verified by comparing them to listed for-sale and rental properties.

- **Inclusionary Housing:** The City of San Francisco's inclusionary housing (IH) policy requires new multifamily buildings of a certain size to set aside a share of units as regulated, income-restricted units. The policy specifies the minimum share of total units to be designated as IH units and the maximum rent levels that are tied to income thresholds. The median family income is determined and updated annually by the U.S. Department of Housing and Urban Development (HUD). Income limits – measured as a percentage of the median family income – in California are determined by California Department of Housing and Community (HCD). The City's inclusionary requirements and HUD income limits were used to determine the number of units and revenue for relevant prototypes.

- **Development Costs:** Construction costs vary by building material (e.g., wood, concrete) and various site uses (e.g., building, parking, landscaping). Development costs include soft costs (e.g., architecture, engineering, taxes, insurance, and overhead), city fees, developer fees, and profit margin. Estimates for these values were researched, estimates triangulated from multiple sources, and validated through developer interviews.

Prototypes

Development feasibility was evaluated for various building types, or "prototypes." The physical features of the prototypical building structures (such as average unit size, building height, parking type, etc.) were based on observations of recently built properties in the Bay Area. To represent the variety of allowed development options in the simplest way possible, nine prototypes were analyzed for this study. The key features of each prototype are the following.

- **Large Single-Family:** attached or detached, 4 bedrooms, 2 stories, 2-car garage, and a large backyard. Typical sales price between $2.3 million and $2.8 million.

- **Medium Single-Family:** attached, 3 bedrooms, 3 stories, 1-car garage, and a small backyard. Typical sales price between $1.2 million and $1.4 million.

- **Low-rise Apartment:** 4 stories with a surface parking lot. Typical price between $0.7 million and $1.1 million, depending on unit size and bedroom count. Typical rent between $2,900 and $3,700, depending on unit size and bedroom count.

- **Mid-rise Apartment:** 5 stories with an integrated parking garage. Typical price between $0.8 million and $1.3 million, depending on unit size and bedroom count. Typical rent between $3,700 and $4,700, depending on unit size and bedroom count.

- **High-rise Apartment:** 15 stories with an integrated parking garage and underground parking. Typical price between $0.9 million and $1.5 million, depending on unit size and bedroom count. Typical rent between $3,400 and $5,600, depending on unit size and bedroom count.

- **Mid-rise Office A:** 7 stories with an integrated parking garage and underground parking.

- **Mid-rise Office B:** 14 stories with underground parking (only).

- **High-rise Office A:** 6 stories with an integrated parking garage and underground parking.

- **High-rise Office B:** 12 stories with underground parking (only).

Pro Forma Model

We analyzed the feasibility of the prototypes using "pro forma" financial analysis, which incorporated location-specific information for each site. For Study Areas A and B, only prototypes that would be permitted under a site's zoning allowances were considered. Although entitlements can change in the future and may change in response to the adoption of AVs, we evaluated development capacity under current regulations, which provides a conservative estimate of development capacity if one expects that AVs can lead to relaxed regulations. For Study Area C, we evaluated all prototypes even if they exceeded today's zoning allowances. The approach for Study Area C reflects recently approved plans to redevelop the Stonestown Mall into a mix of uses ranging up to 18 story buildings.

A pro forma model is a spreadsheet-based tool summarizing the revenues, costs, and financial returns of potential real estate developments. A redevelopment is considered financially feasible if the residual land value of the new development is greater than the existing property value. For a given site, the prototype that had the greatest residual land value that also exceeded the in-place value was considered the most financially feasible option. If all residual land values were negative or lower than the site value, redevelopment was considered infeasible.

Site values are based on the assessed values for land and improvements in the GIS data. Outlier values were excluded using an interquartile range approach. An initial evaluation of the assessed values revealed that about 40 percent of the studied sites had zero values. Missing and inaccurate information is common in publicly available datasets for assessed values, but these datasets are generally the best available information. A follow-up analysis showed that less than 10 percent of the missing or zero site values were on vacant parcels or unused parking lots. Although it is still unrealistic for the land value of those sites to be zero, the assessed value data was used. For all other sites with zero assessed values, the median value of sites with non-zero values were used.

The primary outputs were development capacity for residential buildings measured as total units and development capacity for office buildings measured as square footage of office space. Because the model incorporated the City of San Francisco's IH policy, another output was the number of IH units. The model also tabulated the existing number of units and square feet of non-residential building area on sites where redevelopment was determined to be feasible. These estimates can be considered a measure of potential displacement since the occupants of existing units and buildings would need to relocate for a new development to occur.

A pro forma model is different from regression models in that it is not a statistical analysis that draws inferences based on past observations. A pro forma model is a set of financial calculations based on realistic expectations about prices in a local or a regional market. Therefore, the estimates generated from a pro forma model cannot be tested for statistical significance. Rather, its accuracy is related to the accuracy of the input data.

MapCraft Labs

The pro forma calculations are implemented and run on MapCraft Labs, an online platform for spreadsheet-based calculations across spatial geographies. The model evaluates the value of allowable prototypes on each parcel and identifies the most feasible prototype. Metrics describing these market-feasible development opportunities are aggregated for each study area.

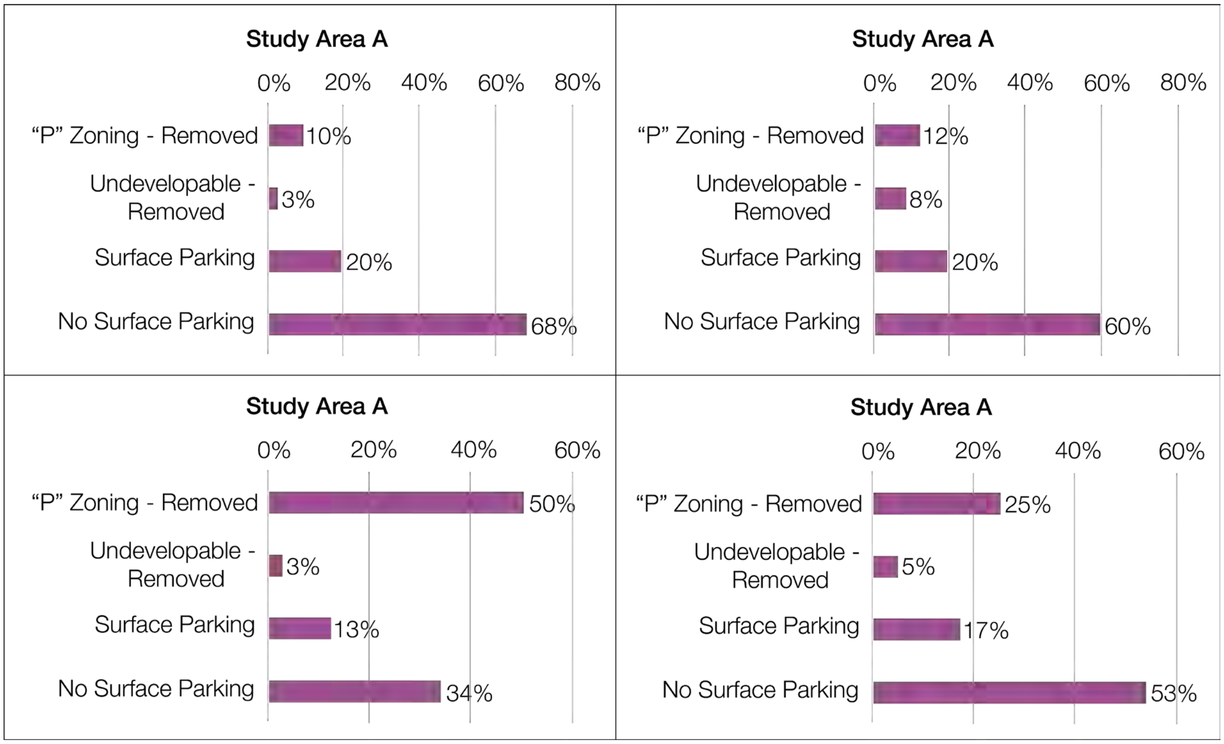
The model's input data was calibrated to reflect market-feasible development potential in early 2022, providing a baseline result for each block lot and study area. The model's inputs were then adjusted to evaluate the effects of AV-induced reductions in parking demand. In the model, parking provision influences which sites can accommodate various prototypes and the cost of parking stalls has a financial impact on each prototype's feasibility. The MapCraft Labs tool was used to evaluate these parking scenarios across thousands of parcels in the three study areas.

Excluded Lots

The feasibility model does not run calculations on all 2,675 block lots in the study areas. Some parcels are excluded from analysis to remove unrealistic development outcomes. First, parcels with "P" zoning designation are removed from analysis because they are designated public properties, which often includes schools, parks, and government buildings. For example, a large portion of Study Area C is removed because it is owned by San Francisco State University. Other areas are also removed from the analysis because they are assumed to be undevelopable. They are indicated by the Lot Code attribute in the GIS data. These parcels may be extremely small or thin lots, occupied by utility or telecommunications service companies that require a parking lot for their utility vehicles, or inhibited by natural barriers.

Figure B-2 shows for each study area the portion of the study area that had a "P" zoning or was otherwise considered undevelopable. Parcels in the Surface Parking category are considered for analysis for both the Optimal Development Method and the Residual Parking Method. Parcels in the No Surface Parking category are considered only for the Optimal Development Method.

Figure B-2. Percentage of Parcels Excluded from Analysis by Study Area



APPENDIX C: MODEL RESULTS

Table C-1. Model Results Using Optimal Development Method

Optimal Development Method				
Study Area A				
	Unit Capacity	Existing Units	Net Development	Impact of Technology
Baseline	7,180	4,770	2,410	-
20%	7,490	4,770	2,720	310
40%	7,540	4,770	2,770	360
60%	7,570	4,770	2,800	390
80%	7,940	5,090	2,850	440
Study Area B				
Baseline	970	470	500	-
20%	970	470	500	-
40%	970	470	500	-
60%	1,100	470	630	130
80%	1,040	470	570	70
Study Area C				
Baseline	680	80	600	-
20%	1,670	180	1,490	890
40%	5,100	820	4,280	3,680
60%	7,020	820	6,200	5,600
80%	7,020	820	6,200	5,600
Office Development Capacity				
	Study Area A	Study Area B	Study Area C	
Baseline	-	4,000,000	-	
20%	-	4,000,000	-	
40%	-	4,000,000	-	
60%	-	4,000,000	-	
80%	-	4,200,000	-	
Existing Sq. Ft. on Redevelopable Sites				
	Study Area A	Study Area B	Study Area C	
Baseline	410,000	730,000	-	
20%	410,000	730,000	180,000	
40%	410,000	730,000	180,000	
60%	410,000	730,000	180,000	
80%	410,000	750,000	180,000	

Figure C-1. Existing Sq. Ft. on Redevelopable Sites (Optimal Development Method)

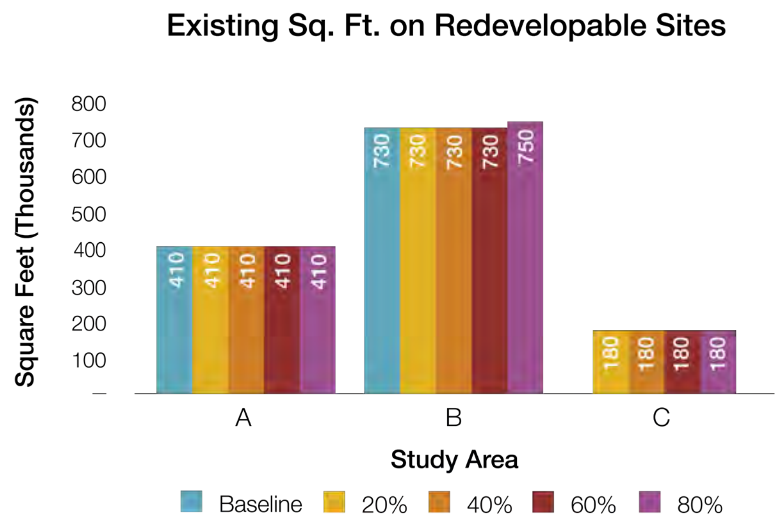


Table C-2. Model Results Using Residual Parking Method

Residual Parking Method			
Study Area A			
	Market Rate Units	Inclusionary Units	Total Units
Baseline	-	-	-
20%	40	10	50
40%	180	50	230
60%	310	90	400
80%	450	140	590
Study Area B			
Baseline	-	-	-
20%	-	-	-
40%	-	-	-
60%	-	-	-
80%	90	30	120
Study Area C			
Baseline	-	-	-
20%	360	110	470
40%	750	240	990
60%	1,140	360	1,500
80%	1,510	480	1,990
Office Development Capacity			
	Study Area A	Study Area B	Study Area C
Baseline	-	-	-
20%	-	250,000	-
40%	-	500,000	-
60%	-	800,000	-
80%	-	1,130,000	-

APPENDIX D: LITERATURE REVIEW

Introduction

Parking has long been a contentious issue in urban areas as it is often seen simultaneously as a requirement for development to succeed and a burden that limits the potential for development. Providing too little parking can limit who visits an area and can limit the rents or sales price people are willing to pay but requiring too much parking can be an unnecessary burden on development costs, increasing rent and limiting the feasibility of projects.

As the development of autonomous vehicles (AVs) has continued to advance in the last several years, researchers have been attempting to quantify the potential impacts that AVs could have on travel behavior, trip generation, parking demand, and other important transportation outcomes. While there are many interesting questions to explore regarding AVs, this research is focused on the potential of fully autonomous vehicles to significantly reduce demand for parking, and how this might impact an area's development.

Efforts to estimate the potential impact of AVs on parking demand have produced **varied results ranging from as much as a *90% decrease* in demand in some scenarios to an *overall increase* in demand in others.** The inconsistency in results underscores the complexity of the topic and the difficulties that are associated with trying to model future demand. Model results are dependent on the parameters and assumptions made about factors like fleet mix (e.g., shared vs. individually owned AVs), market penetration/adoption rate, the percentage of rides that are pooled, and more. Given the complexity of the topic as well as the relative nascency of the technology, the literature on the topic is limited but growing. This literature review explores the existing impacts of parking on development and then looks at the current state of understanding on the potential impacts AVs might have on parking demand.

Parking Impacts on Development Potential – A Review of the Research

As we seek to understand the potential impacts that AVs may have on parking demand and, by extension, on the development potential of urban areas, we can look at current parking regulations, regulatory changes, and their impacts on development for insights. Parking regulations, while often contentious and fiercely debated, are imperfect instruments that are typically not the result of careful local demand analysis, but instead are often simply carbon copies of policies observed in other cities (Shoup, 2005; Inci, 2015). This means that the current supply of parking, often dictated by parking minimums, is not necessarily an accurate estimation of actual parking needs.

In a best-case scenario, parking minimums would reflect parking demand and help supply sufficient parking to satisfy that demand, or at least would reflect what the market requires. Studies comparing development trends before and after the reduction or elimination of parking minimums show, however, that parking minimums can lead to an over-supply of parking. Hess & Rehler (2021) found that in Buffalo, NY, a removal of minimum parking requirements led to developers providing 53% less parking than what had been previously required in mixed-use projects. Similarly, Gabbe et al. (2020) found that a reduction in parking minimums in Seattle, WA led to a 40% reduction in the number of parking stalls built in comparable projects.

Studies looking at actual parking utilization in projects with typical minimum parking requirements find a similar oversupply of parking. This is true for multifamily housing in King County, WA (Rowe et al., 2010), for transit-oriented developments in Portland, OR and the San Francisco Bay Area where parking demand was 25-30% below the amount supplied (Cervero et al., 2010), and for on-street parking in Davis, CA where, on average, only two out of seven available spots were typically used in predominantly residential areas (Thigpen & Volker, 2017). All these studies point to the idea that regulated parking minimums are often not well aligned with the actual demand by residents and/or the desired supply of parking by developers.

Even so, parking can have a considerable impact on what is developed as it can add substantial costs to projects and can itself compete for land available for other uses. Shoup (1999) found that providing four parking spaces per 1,000 square feet of commercial space (a typical minimum ratio) increases overall construction costs by 27% with above ground parking and 67% with below ground parking. Focusing on parking requirements in service retail projects, Cutter & Franco (2012) found that “minimum parking requirements lower site density, increase land consumption, oversupply parking, and reduce profits per unit of land covered.” Similarly, Gabbe & Pierce (2017) concluded that nationally, on average, bundled garage parking was responsible for a 17% increase in rental costs in urban areas. The added project development cost burden of parking can make housing projects financially infeasible—particularly for infill projects—effectively limiting the supply of housing in an area (Landis et al., 2006).

Numerous studies have attempted to quantify the degree to which minimum parking requirements have impacted the amount and density of residential development. For instance, Manville & Shoup (2010) took advantage of a natural experiment created in 1999 when Los Angeles eliminated the parking requirements in its downtown area for any housing built on land that previously held vacant commercial or industrial buildings. This shift led to the construction of thousands of housing units on these parcels while adjacent properties did not see this degree of construction. While developers did include some parking in the new projects, the ratios were less than what had been required and developers took advantage of the opportunity to provide some of this parking offsite. Interviews with developers specifically pointed to the elimination of the parking requirement being a key component that made project development possible.

Manville et al. (2013) followed this study with an analysis of parking minimums' impacts in New York City. They estimate that every 10% increase in required parking minimums results in a 6% reduction in an area's housing and population density. The unnecessary burden parking places on development potential is found to be more salient in dense areas where land costs are higher (Manville et al., 2013; McDonnell et al., 2011). Landis et al. (2006) found parking requirements have a particularly strong impact on development on smaller lots. Through interviews with developers and stakeholders, they determined that lots less than 2,500 square feet (sf), but also as high as 5,000 sf, are difficult to build on in large part due to the financial burden of providing the required parking on smaller lots.

While parking impacts the supply and density of housing generally, it can also have substantial impacts on affordable housing given the costs associated with building parking. This is particularly true when parking and housing units are bundled as a single rental item, which can result in individuals without cars paying for stalls they do not use. A study by Willson et al. (2012) in San Diego, CA found that parking utilization in affordable housing was at a rate less than half of what the city had required. This varied by type of housing with parking occupancy higher in family-targeted housing (1-3 bedrooms) but still not full, while parking occupancy at senior housing developments, single room occupancies (SROs), and studios was at less than half of the required amount. Willson et al. also found a strong differentiation between urban and suburban locations, with much lower utilization of parking spaces in urban areas.

Litman (2021) found that in affordable housing developments, parking increased the cost of housing by 12.5% per spot when bundled with the housing unit. Lower income households typically have fewer vehicles, making parking requirements and bundled parking a regressive burden. In addition, high minimum parking requirements can push development outside of city centers as a means of reducing housing development costs (Litman, 2021). While this can reduce housing costs, it also increases transportation costs for residents and often reduces accessibility to needed services, jobs, healthcare, and education.

Potential Impact of S/AVs on Parking Demand

As the provision of parking has a substantial impact on development, a potential reduction of parking demand—and, presumably, future parking provision—associated with the deployment of AVs could change development potential and patterns within urban areas. The degree to which AVs will change parking demand, however, is a complicated topic with many unknowns.

In an early study published by Zhang et al. in 2015, researchers using an agent-based simulation approach to model a 10 mi x 10 mi hypothetical city with a gridded street network found that there could be as much as a 90% reduction in parking demand.[2] To build their model, the researchers made two important assumptions: 1) AVs will be shared (e.g., SAVs) rather than individually owned; and 2) some percentage of SAV users will be willing to take pooled rides. The researchers also assumed a 2% market penetration rate (i.e., adoption rate) to represent a particular point in time in the adoption curve.[3] In the modeled scenario, parking demand could be reduced by as much as 90% for the 2% of the population that has adopted SAVs if those people were to replace all the trips they would have otherwise taken in a conventional vehicle with an SAV. However, the researchers found a 90% reduction was only achievable if 50% of SAV users were also willing to pool rides (i.e., share a ride with others going in the same direction), revealing that parking demand is highly sensitive to willingness to pool. Their calculations suggest that one SAV could replace approximately 14 privately owned vehicles (Zhang et al., 2015). While the results are promising, the researchers caution that the model does not account for other factors that influence parking demand, such as the price of parking, and it assumes that SAV users have homogeneous socio-economic characteristics (i.e., they have the same purchasing power, willingness to pool rides, etc.).

Researchers with the International Transport Forum similarly found that demand could be reduced by upwards of 90% in certain scenarios based on modeling the potential impacts of SAVs on parking demand in Lisbon, Portugal (International Transport Forum, 2015). Like Zhang et al., they used an agent-based model approach but instead of a hypothetical city, they applied their analysis to Lisbon using travel survey data to create a simulated set of trips. Trips that were under 1 kilometer were assigned as walk or bike trips, while the remaining trips were assigned to either transit, an SAV, or a conventional vehicle depending on the scenario. They assumed that there would be three types of vehicles in the SAV fleet that can accommodate either two, five, or eight passengers. They use the term “TaxiBot” to refer to a car that can be shared by passengers (i.e., pooled), while an “AutoVot” is a car that picks up and drops off riders sequentially. The researchers tested a variety of different scenarios, varying the following parameters: the penetration rate of the shared, self-driving fleet (50% or 100%), the availability of high-capacity transit (yes or no), whether rides are pooled or individual, and whether the model simulates a 24-hr weekday or just peak travel periods.

[2] Note that the model does not differentiate between on- and off-street parking demand. The model is designed to optimize the use of the SAV fleet so that the vehicles spend a minimum amount of time parked. In this modeled scenario, a fleet of 700 SAVs can serve 2% of the hypothetical population if 50% of people choose pooled rides, resulting in SAVs being parked just 10% of the time.

[3] In other words, the researchers assumed that 2% of the population of this hypothetical city have adopted SAVs and the other 98% of people are using conventional vehicles. This reflects one point in time, but you could look at other points in time further along the adoption curve and assume that a higher percentage of the population will have adopted SAVs as they become more ubiquitous.

In the most extreme scenario that assumes a market penetration rate of 100%, the presence of high-capacity transit, and all rides being pooled, the researchers found that just 5.6% of the baseline parking supply (including both on- and off-street spaces) would be needed to accommodate demand (International Transport Forum, 2015). In other words, parking demand could decrease by as much as 95%. However, results vary significantly as the scenarios change. If the market penetration rate is set to 50% and rides are sequential rather than pooled, parking demand would only be reduced by about 21% assuming the presence of high-capacity transit. Even assuming all rides are pooled at the 50% penetration rate, demand would decrease by just 25%. This study also found that in certain scenarios parking demand could even increase by as much as 3.8%. Figure 1 shows a summary of their scenario results.

Figure D-1. International Transport Forum's modeled impacts on parking demand based on different scenarios

			Max. Parking requirements	% of baseline
		Baseline	160 000	
100% shared self-driving fleet	**Ride sharing (Taxibot)**	No high-capacity public transport	11 563	7.2
		With high-capacity public transport	8 901	5.6
	Car sharing	No high-capacity public transport	25 621	16.0
		With high-capacity public transport	17 110	10.7
50% private car use for motorised trips	**Ride sharing (Taxibot)**	No high-capacity public transport	5 928 + 153 122*	99.4
		With high-capacity public transport	4 622 + 116 689*	75.8
	Car sharing	No high-capacity public transport	12 705 + 153 330*	103.8
		With high-capacity public transport	9 561 + 116 467*	78.8

Data: International Transport Forum (2015). Urban Mobility System Upgrade: How shared self-driving cars could change city traffic. p. 26. (Note: '% of baseline' refers to the amount of parking needed. A 5.6% of baseline equates to a 94.4% reduction in parking demand. The baseline assumes there are currently 50,000 off-street parking spots and 110,000 on-street spaces in Lisbon.)

Building on their previous work, Zhang & Guhathakurta published new findings on the potential impacts of AVs on parking demand in 2017. This work is differentiated from their previous study in that it simulates operations of SAVs in Atlanta, GA rather than a hypothetical city using existing data, and it also attempts to account for the cost of parking . They investigated three parking scenarios, including one scenario where parking is free, one where the parking price is set regardless of the length of time parked, and one where parking is charged based on the length of time. To build their model, they assumed a 5% market penetration rate of SAVs, that residents are willing to pool rides, and that the cost of a ride is $0.5/min for an individual ride and $0.3/min for a pooled ride (Zhang & Guhathakurta, 2017). They found that approximately 1,000 SAVs are sufficient to meet demand of the 5% of residents who adopt SAVs in the modeled scenario, and that parking demand is highest in the scenario where parking is free and lowest when parking is charged based on time spent. Even in the scenario where parking is free, however, Zhang & Guhathakurta found that parking demand could be significantly reduced. They suggest that at a 5% market penetration rate SAVs could free up 4.5% of the public land devoted to parking in Atlanta, indicating that one SAV could remove more than 20 parking spaces. These results are consistent with their previous findings that SAVs could reduce parking demand by as much as 90%. They note, however, that while charging for parking further reduces parking demand, it can also result in larger vehicle miles traveled (VMT) generation, more congestion, and the possibility that vehicles will seek lower- or no-cost parking where it is available, which could have disproportionate impacts on low-income neighborhoods.

A follow-up study conducted by Zhang & Wang (2020) further iterated on this line of inquiry. Atlanta served as the study area again, but in this case the researchers modeled adoption of AVs over time rather than at one point in time to capture the market transition. They differentiated between personally-owned AVs (PAVs), shared AVs (SAVs), personally-owned conventional vehicles (PCVs), and shared conventional vehicles (SCVs) at four points in time. Figure 2 shows the forecasted penetration rates of the different vehicle types over the analysis period. The model randomly assigns trips to different vehicle types, and importantly, it assumes that SAVs and SCVs do not provide pooled trips (i.e., rides are made sequentially).

Figure D-2. Zhang & Wang's forecasted market penetration of vehicle type by year

Mode Type	Year			
	2015	2020	2030	2040
PAVs	0.0%	4.95%	23.7%	37.35%
SAVs	0.0%	0.55%	10.1%	37.35%
SCVs	0.0%	9.45%	19.9%	12.65%
PCVs	100.0%	85.05%	46.3%	12.65%

Data: Wenwen Zhang & Kaidi Wang (2020). Parking futures: Shared automated vehicles and parking demand reduction trajectories in Atlanta. Land Use Policy. Vol 91.

[4] Note that one of the inputs to the model is existing parking supply in Downtown Atlanta, which includes on-street parking, surface lots, and parking garages, but does not include off-street residential parking such as driveways or multi-family apartment parking.

The researchers found that “parking space reduction is positively and linearly correlated with the market of SAVs and SCVs” and that “PAVs cannot be used as an effective tool for parking space reduction” (Zhang & Wang, 2020, p. 8). Their model results suggest that parking demand will see the highest reductions in the central business district, reaching a high of 75% in the 2040 scenario, while parking demand may actually increase in residential zones. Overall, the model predicts a net decrease in parking demand across the Atlanta region of about 35% by 2040 (Zhang & Wang, 2020).

The more conservative parking demand reduction rate of 35% more closely aligns with a short perspective paper published by the parking consultancy firm Walker Consultants in 2018. Based on their review of the studies modeling the impact of AVs on parking demand and interviews with the researchers responsible, they concluded these research findings are often taken out of context, particularly since they are limited in scope and often model pooled AV scenarios. They instead estimated that a more realistic overall maximum reduction in parking demand ranges from 10% on the low end to 40% on the high end, varying by geographic area and land use (Walker Consultants, 2018). The sources for their analysis include: 1) a University of Michigan study (Schoettle & Sivak, 2015) estimating that automobile ownership in the U.S. could decrease from 2.1 vehicles per household to 1.2, a 43% reduction, if an AV could handle some household trips; and 2) a Columbia University study (Burns et al., 2012) that estimates that if everyone who could use a ridehail vehicle does, the number of vehicles on the road could be reduced by 49%.

To support their work on Seattle’s New Mobility Playbook, consulting firm Sam Schwartz used an economic model to determine the potential rates of vehicle ownership reduction under a variety of different scenarios (Seattle New Mobility Playbook Appendix B, 2017). While they did not explicitly discuss reduction in parking demand, they calculated the break-even VMT at which it may be cheaper for a person to choose to give up a car and use a new mobility service. This is significant for our research in that parking demand and vehicle ownership are correlated. The Sam Schwartz study found that approximately 17-45% of existing vehicles in King County could be reduced, depending on the scenario. The highest potential reductions of personal vehicles are associated with two SAV scenarios. In one scenario, they assumed that a person would replace their personal vehicle trips with SAV trips, but the rides would be individual. In the second scenario, they assumed that a person would take an individual SAV ride 50% of the time, and a pooled SAV ride the other 50% of the time. The potential vehicle reductions for those scenarios are 31% and 45%, respectively (Seattle New Mobility Playbook Appendix B, 2017). Similar to the work done by Walker Consultants, these findings are based on the potential reduction of vehicle ownership, whereas the other studies described above examine the number of existing trips and then reassign those trips to AVs.

[5] As in the previous work by Zhang & Guhathakurta (2017), this study uses actual parking data for Downtown Atlanta, encompassing on-street parking, surface lots, and parking garages.

Forecasting Adoption of SAVs

Most of the studies modeling the impact of SAVs on parking are predicated on two important assumptions: 1) a minimum number of people will forgo vehicle ownership and will adopt shared AV fleets; and 2) a minimum people will be willing to utilize pooled ride options. Research findings on these topics have produced mixed results, however, with willingness to adopt dependent on a variety of sociodemographic, attitudinal, and locational characteristics. For instance, Hossain & Fatmi (2022) found that exposure to technology in daily life will likely be a significant factor influencing adoption of AVs, and that tech-savvy individuals may be more likely to prefer personally owned AVs over shared AVs fleets. Higher-income individuals also appear more likely to own personal AVs according to their study results, while people living in areas with a higher land use mix may be more likely to adopt SAVs. This corroborates the findings of an earlier study conducted by Lavieri et al. (2017) suggesting that residents of higher-density neighborhoods are more likely to prefer SAVs.

Meanwhile, Wadud & Chintakayala, (2021) found that women may value individual ownership of AVs more than men, while people who do not currently own a vehicle or do not have access to free parking do not value individual ownership more highly. Conversely, people living in more suburban or rural environments where wait times may be longer for an SAV value individual ownership more than their urban counterparts (Wadud & Chintakayala, 2021). Early adopters of AVs in general, whether shared or privately owned, are more likely to have higher levels of education and higher incomes, and to fall between the ages of 18 and 44 (Lavieri et al., 2017).

As for people's willingness to pool rides, researchers find that this is largely dependent on factors such as time of day, travel time, trip cost, trip purpose, and sense of privacy and security. Gurumurthy & Kockelman (2020) used stated preference survey data of U.S. residents to examine the circumstances under which people are more willing or less willing to pool rides. They find that more people are willing to pool rides for daytime trips than evening trips. However, people are more willing to tolerate trip delays and added travel time at night than during the day. Safety features like making location information accessible to family and friends increases willingness to pool, but travel time is one of the most significant factors influencing people's decisions about whether to pool. Twenty-two percent of survey respondents indicated a willingness to pool a ride during the middle of the day if it does not require any additional time, but only 18.5% are willing to pool if it adds five minutes to the travel time, while just 6% are willing to if it adds 10 minutes to the trip (Gurumurthy & Kockelman, 2020).

In a study examining use of pooled ridehail services (e.g., UberPOOL) as well as potential use of pooled AV trips, Lavieri & Bhat (2019) found that privacy concerns discouraged actual use of pooled ridehail as well as projected use of pooled rides in AVs. They also found that high-income individuals were frequent users of ridehail services but preferred individual over pooled rides. These researchers suggest that encouraging high-income individuals to pool rides will continue to be a challenge in the future (Lavieri & Bhat, 2019). Similar to Gurumurthy & Kockelman, Lavieri & Bhat found that individuals are more tolerant of pooling a ride with strangers for a commute trip, but they also consider those trips to be more time sensitive. Conversely, they are less tolerant of pooling with strangers for leisure trips but have less time sensitivity. As a result, the researchers suggest that from a policy standpoint, it may easier to promote the use of pooled rides for commute trips than for leisure trips (Lavieri & Bhat, 2019).

Given that both of the major TNCs in the U.S., Uber and Lyft, have offered pooled services in the past we can draw some conclusions of riders' willingness to share based on actual usage rates of those services prior to the COVID-19 pandemic. Studies conducted in 2018 and 2019 found that between 13%-20% of riders chose pooled rides if given the option (Gehrke et al., 2018; Henao & Marshall, 2019). These numbers are generally aligned with data shared by Uber—in 2016 they announced that 20% of all rides globally were on UberPool (Lunden, 2016). However, researchers note that those numbers only represent the percentage of people that requested a pooled ride, but it does mean that the request successfully resulted in matching multiple riders. Henao & Marshall (2019) found that just 8% of pooled ride requests received a matching ride. This is worth noting because it impacts the profitability of the ride. If a rider receives a discounted ride by requesting a pooled ride but the ride request is not successfully matched, the service may operate at a loss. In fact, both Uber and Lyft revamped their pooled service options when they reinstated them in 2021 with an increased focus on profitability (Dotan, 2021; Lyft, 2021; Peters, 2021).

Trading Off Parking with Pick-up/Drop-off Space

As the use of ridehail services has increased over the past decade, so too has the demand for short term passenger loading/unloading, also referred to as pick-up/drop-off (PUDO). This demand is anticipated to increase substantially in an AV future, regardless of whether AVs are individually owned or shared fleets, since passengers will, presumably, be able to be picked up and dropped off at their destinations without having to park. Several studies analyzing ridehail use have been conducted to identify their use of curbside loading space and average dwell time, including two by the transportation consulting firm Fehr & Peers in collaboration with Uber. Looking at five study areas in San Francisco, Fehr & Peers (2018) determined that none of the study areas had sufficient curb space dedicated to passenger loading/unloading to accommodate the observed demand. As a result, some PUDO activity occurs in travel lanes. Unlike conventional vehicles, AVs may be required to stop only at designated PUDO locations, which will further increase the need for effective curb management.

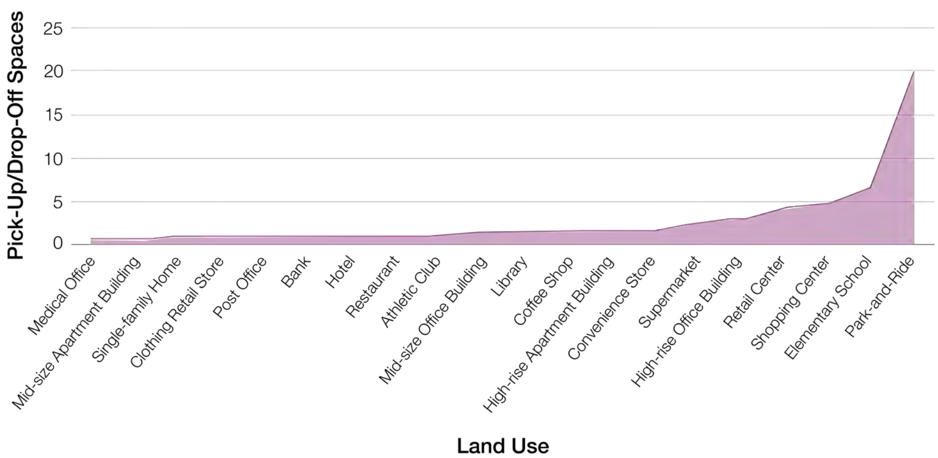
Comparing the curb productivity of bus, transportation network companies (TNCs), taxis, shuttles, and parked cars, Fehr & Peers (2018) determined that TNCs have the second highest productivity rate behind buses in the five San Francisco study areas. In other words, more passengers are able to make use of the curb space over the course of an hour if the space is used for passenger loading than if it is used for parking. This is because passenger loading/unloading events happen quickly. Fehr & Peers found curbside dwell times were approximately 30-40 seconds, while in-street dwell times were approximately 10-30 seconds. Fehr & Peers also analyzed the amount of space required for a standard vehicle to pull over from a travel lane to the curb and back into traffic, which they determined to be about 60 feet midblock for one PUDO zone (Fehr & Peers, 2018). Two loading zones could be accommodated with just 100 feet midblock, or 140 feet for three zones. Fehr & Peers recommended the reallocation of some parking spaces to passenger loading to better accommodate demand in the five study areas.

Chai et al. (2020) also examined parking demand in San Francisco's CBD, but instead of looking at TNC trips they focused their efforts on AV trips to better understand the magnitude of impact they may have. They modeled increasing market penetration of privately owned AVs—no SAV scenarios were examined—with demand for passenger loading increasing in increments of 10%. They began with a scenario wherein 0% of trips require passenger loading, 100% are parking and end with the opposite, where 100% of trips require passenger loading and 0% are parking. They found that in order to manage the levels of congestion that may occur when there is 100% passenger loading demand, parking space would need to be reallocated to passenger loading incrementally as well (Chai et al., 2020). However, the researchers concluded that the match must be specific to streets and times of day to maximize benefits, similar to the block-by-block granularity at which Fehr & Peers made their recommendations.

Both of the aforementioned studies are focused on passenger loading/unloading demand at the curb, but research on off-street PUDO demand is lacking. It is not clear how many off-street spaces will need to be reserved for passenger loading if vehicle ownership, and by extension parking demand, decreases. The City of Chandler, AZ was one of the first to update their development code to allow for a reduction in the number of required parking spaces in exchange for the provision of a passenger loading zone. They determined that parking requirements could be reduced by 10% for each loading zone, up to a maximum reduction of 40%, differentiated by land use. Multifamily residential buildings, for example, could have one loading zone per 150 units (City of Chandler, 2018). As Chai et al. (2020) suggest, the conversion rate of off-street parking spaces to passenger loading zones will likely need to increase incrementally—similar to curbside parking—as AVs become more ubiquitous and travel behavior changes.

Consulting firm Sam Schwartz also attempted to quantify the number of PUDO spots needed for different land uses in Seattle depending on the number of trips occurring during the peak period as part of their work on the New Mobility Playbook. To develop a "spatial drop-off model" they relied on the Institute of Transportation Engineers

Figure D-3. Pick-up and drop-off space required for each land use (Sam Schwartz & Associates)



Source: Seattle New Mobility Playbook Appendix B (2017) Chapter 5, p. 41.

The number of PUDO spaces required to accommodate demand varies from one to 20 depending on the land use, although the authors are quick to note that they do not suggest replacing 100% of the parking supply with 100% PUDO zones. This model is just meant as a starting point to estimate the approximate number of spaces needed to accommodate demand for pick-up/drop-off events. They also note important limitations of the model, such as the assumption that trips arrive at a constant rate throughout the peak hour, which is unlikely in actuality. Furthermore, the model assumes that there is only one land use per building and does not account for mixed-use developments. Despite these limitations, this work provides a useful framework for thinking about the potential space needed to accommodate pick-up/drop-off events by utilizing ITE's Trip Generation and Parking Generation manuals since those are regularly used by developers and transportation practitioners.

Table D-1. Summary AV Parking Reduction Studies

Author(s)	Year	Modeled Scenario(s)	Assumption(s)	Results
Zhang et al.	2015	Potential parking demand reduction in a hypothetical city with an SAV fleet	2% market penetration rate of SAVs Some rides are pooled, some are individual	Up to a 90% reduction in parking demand if 50% of people are willing to pool rides Parking demand is highly sensitive to riders' willingness to pool
International Transport Forum	2015	Potential parking demand reduction in Lisbon, Portugal at different market penetration rates, fleet mixes, and other parameters	50 or 100% market penetration rate Presence of high-capacity transit Rides are pooled or not depending on the modeled scenario	Parking demand could be reduced by upwards of 90% in the most extreme scenario, or parking demand could increase in the other extreme Mixed scenario results suggest a parking demand reduction between 21-25%
Zhang & Guhathakurta	2017	Potential parking demand reduction in Atlanta if parking is free vs. if it is charged	Parking is either free, or it is charged based on entry to a parking lot or charged based on length of time parked 5% market penetration rate Some riders are willing to pool	SAVs could free up 4.5% of the public land devoted to parking in Atlanta at a 5% SAV penetration rate, with one SAV being able to remove 20 parking spaces
Walker Consultants	2018	No models, but they consider projections of AV sales, historic vehicle scrappage rates, and automobile ownership rates		Maximum parking reductions estimated to be 10% on the low end and 40% on the high end
Zhang & Wang	2020	Potential parking demand reduction in Atlanta at multiple points in time assuming increased penetration rates of AVs	There will be a mix of vehicles including personal AV, shared AVs, personal conventional vehicles, and shared conventional vehicles Rides are NOT pooled	Net reduction in parking demand of about 35% by 2040 although demand will vary by area with the highest reductions in the CBD Parking demand may increase in residential areas

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