MANAGING INCREASING DEMAND FOR CURB SPACE IN THE CITY OF THE FUTURE

FINAL PROJECT REPORT

by

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16. Abstract

The rapid rise of on-demand transportation and e-commerce goods deliveries, as well as increased cycling rates and transit use, are increasing demand for curb space. This demand has resulted in competition among modes, failed goods deliveries, roadway and curbside congestion, and illegal parking. This research increases our understanding of existing curb usage and provides new solutions to officials, planners, and engineers responsible for managing this scarce resource in the future. The research team worked with local agencies to ensure the study’s relevance to their needs and that the results will be broadly applicable for other cities. This research supports the development of innovative curb space designs and ensures that our urban streets may operate more efficiently, safely, and reliably for both goods and people.

The research elements included conducting a thorough scan and documenting previous studies that have examined curb space management, identifying emerging urban policies developed in response to growth, reviewing existing curb management policies and regulations, developing a conceptual curb use policy framework, reviewing existing and emerging technologies that will support flexible curb space management, evaluating curb use policy frameworks by collecting curb utilization data and establishing performance metrics, and simulating curb performance under different policy frameworks.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
It	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
tf	square feet	0.093	square meters	m"
yd"	square yard	0.836	square meters	m"
ac	acres	0405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	■
ff	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m■
	NOTE: volumes greater than 1000	shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	shorttons(20001b)	0.907	megagrams (or "metric ton")	Mg (or"t")
		TEMPERATURE (exact degrees)		
0F	Fahrenheit	5 (F-32)19 or (F-32)11.8	Celsius	0C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbflin'	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	It m
meters		1.09	yards	yd km
kilometers		0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m"	square meters	10.764	square feet	tf
m"	square meters	1.195	square yards	yd"
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m■	cubic meters	35.314	cubic feet	ff
m3	cubic meters	1.307	cubic yards	yd3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or"t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
0C	Celsius	1.8C+32	Fahrenheit	0F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. Revised March 2003)

TABLE OF CONTENTS

APPENDIXES ....

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The authors recognize PacTrans (University Transportation Center, Region 10) for its support of this research project.

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LIST OF ABBREVATIONS

ACHD	Ada County Highway District
ADA	Americans with Disabilities Act
API	Application programming interface
AV	Autonomous vehicle
COM	Component object model
COMPASS	Community Planning Association of Southwest Idaho
COVID-19	Coronavirus disease 2019
CV	Cooperative vehicle
CVLZ	Commercial vehicle loading zones
D.C.	District of Columbia
DDOT	District [of Columbia] Department of Transportation
GBFS	General Bike Feed Specification
GIS	Geographic information system
GLZ	Green loading zone
GMA	Growth Management Act
GPS	Global Positioning System
GTFS	General Transit Feed Specification
GUI	Graphical user interface
HGV	Heavy goods vehicle
ITE	Institute of Transportation Engineers
LADOT	Los Angeles Department of Transportation
LED	Light emitting diode
LiDAR	Light detection and ranging
LLUPA	Local Land Use Planning Act (Idaho)
LPR	License plate recognition
MaaS	Mobility as a service
MDC	Mobility Data Collaborative
MDS	Mobility Data Specification
MPO	Metropolitan planning organization
NACTO	National Association of Transportation Officials
OFM	Office of Financial Management

OTF	Open Mobility Foundation
OTP	Open Transport Partnership
PLZ	Passenger loading zone
PNNL	Pacific Northwest National Laboratories
PSRC	Puget Sound Regional Council
PUDO	Pick-up/drop-off
RMSE	Root mean squared error
SCAG	Southern California Association of Governments
SDOT	Seattle Department of Transportation
SFMTA	San Francisco Municipal Transportation Agency
SLU	South Lake Union
T4A	Transportation for America
TNC	Transportation network company
UCLA	University of California Los Angeles
UFL	Urban Freight Lab
UFL	Urban Form Lab
UGA	Urban growth area
UPS	United Parcel Service
VMT	Vehicle miles traveled

EXECUTIVE SUMMARY

With the rapid rise of on-demand transportation and e-commerce goods deliveries, as well as increased cycling rates and transit use, the demand for available curb space has resulted in competition among modes, failed good deliveries, roadway and curbside congestion, and illegal parking. This research effort increases the understanding of existing curb usage and provides new solutions to the individuals and agencies who are responsible for managing this scarce resource.

The research team conducted a thorough scan to document previous studies that have examined curb space management and identify and review data sources that are already present. While curb space management research has historically focused on the study of parking, more recent efforts have expanded the field to consider the curbside impacts of ridesharing, shared mobility, mobility as a service, and other emerging technologies. Multifaceted pressures on scarce curb space have prompted new research on comprehensive, multimodal demand management strategies. Growth management policies, which contain elements such as land use, transportation, and economic development, were also examined as part of this documentation effort.

An assessment of curbside management policies included interviews with 22 staff members across 14 cities and three regional metropolitan planning organizations. On the basis of these interviews, the trend from incremental, reactive curb management structures to a holistic, framework approach is explained. Changes in regulatory structures and the current challenges in curbside management are explored. Recent policy experiments and pilot programs launched in response to these challenges, along with results and lessons learned, are also chronicled.

With new and competing demands for curb space, cities are increasingly using technology to collect data, track users, and gain insights into efficient curb space management. This report describes the reviews of emerging technologies based on interviews with city planners, curb-space managers, and technology company representatives. The report classifies companies on the basis of four broad uses of curb management technology, namely data collection technologies, data-sharing platforms that allow cities to communicate curb regulations, third-party platforms for communicating company data to cities, and automated parking reservation and enforcement tools.

Because curb space goals and daily enforcement practices broadly vary from agency to agency, each entity would be well served to examine current policies with the emergence of new mobility and on-demand delivery, as well as advances in technology and data collection. Two versions of a conceptual curb management policy framework are described based on best practices.

The first framework provides general agency guidance while the second framework details guidance pertaining to the use of evolving technologies.

Cities and municipalities are working to revise their curb management plans to better manage their limited resources, and they are testing multiple strategies through pilots. Simulation technologies offer the opportunity to test different curb management strategies without requiring many resources. In this study, a microscopic agent-based traffic simulation was used to simulate curb blockface activity under different traffic demand and policy frameworks.

CHAPTER 1. INTRODUCTION

The rapid rise of on-demand transportation and e-commerce goods deliveries, as well as increased cycling rates and transit use, is increasing demand for curb space, resulting in competition among modes, failed good deliveries, roadway and curbside congestion, and illegal parking. This research effort sought to improve mobility by increasing our understanding of existing curb usage and providing new solutions to city officials, planners, and engineers responsible for managing this scarce resource in the future. The lessons learned will allow for the development of innovative curb space designs that will ensure that our urban street system may operate more efficiently, safely, and reliably for both goods and people.

1.1. Research Background and Problem Statement

The strategies employed by city officials and transportation professionals for managing curb space have not kept pace with change. They lack the conceptual approaches and analytic methods needed to manage scarce curb space in the new world of on-demand transportation, one- to two-hour e-commerce goods deliveries, rising cycling and transit usage, and autonomous and cooperative vehicle technologies (AV/CV). These trends are happening in cities where the lack of curb space capacity is already a significant problem. A recent curb parking utilization study in the City of Seattle indicated 90 percent or greater occupancy rates for some areas for much of the workday [Dowling et al. 2017].

The issue of managing curb space is further exacerbated by the effects of several evolving factors. On-demand passenger services (such as Uber and Lyft) have created a negative feedback loop affecting curb demand, as parking problems are the top reason people use a ride-hailing service instead of driving [Clewlow and Mishra 2017]. The explosion of e-commerce sales is shifting the retail landscape at the same time that many U.S. cities are adding population and growing denser, and major cities face increasing pressure because of the high demand for limited curb and alley space. Autonomous and connected vehicles will become more common in cities, and they may exponentially increase demand to drop off and pick up people and goods at the curb. Lastly, many new opportunities exist for technical innovation in curb management. Relevant technologies include a wide range of vehicle occupancy smart sensors and cameras that can determine whether a curb space is available and can serve as data feeds into software and apps that communicate the status of a curb or parking space to users [SFMTA 2013, Buecheler 2014, Dey et al. 2017, Dowling et al. 2017]. The opportunities are substantial, but research is required to better understand curb use requirements and match technical solutions with operational policies that will produce the best outcome for each agency.

1.2. Policy Implications

Recent curb occupancy studies by the research team have suggested that actual curb use does not match designated curb use and that the current allocation of curbs is not spatially or temporally based on demand [Wygonik et al. 2015, Goodchild et al. 2017]. In addition to being unenforceable in congested areas, current curb allocation schemes in cities may cause unsafe conditions for road users, blocked access for emergency vehicles, and disruption of traffic flow.

City officials need new conceptual frameworks for curb management to support modern city life. They could be based on a temporal principle, in which each curb space has multiple authorized uses that take into account the predominate usage at different times of day, or a spatial principle that provides ratios of passenger car and service van parking (vehicle storage) to passenger and delivery vehicle load/unload space (short-term drop-off/pick-up) for blocks or corridors in context of the surrounding load/unload network.

1.3. Study Approach

As an initial starting point, the research team conducted a thorough scan to document previous studies that have examined curb space management and identify and review data sources that are already present.

In order to understand how urban policies are being developed in response to growth, and to determine how cities are reacting to and planning for future growth, the researchers conducted a literature review to examine how urban policies have evolved, and the perceived effectiveness of these policies over time. Growth management programs do not always include explicit goals or targets, so detailed evaluation can be difficult to quantify [Bengston 2004]. The review included public policies for managing urban growth and protecting open space. To understand the ability of current curb space polices and regulations to meet increasing demand, the research team also conducted a literature review to determine which factors have shaped curb policies and how those policy decisions have impacted the mobility of people and goods. This research offers a timely and beneficial contribution to the management of curb space in cities of the future, and more broadly, to how this management will benefit the mobility of both people and goods moving forward.

Given the advances in technology, this study reviewed existing and emerging technologies that support flexible curb space management. The technology options included, but were not limited to, signing and marking technology as applied to curbs, parking spaces, and lanes; parking space occupancy sensor systems; apps and software that optimize parking and curb usage; autonomous and connected vehicles and parking; and other speculative or emerging technologies that can be used to monitor or control curb usage.

Policy frameworks were developed that identified different approaches to curb management. The framework will help cities better understand how they may allocate vehicle storage use (for parked cars and service vans) as well as flexible load/unload space (for quick car and truck drop-offs) at the curb to serve their policy goals.

Building on the established understanding of the policy environment and potential technologies, various scenarios were simulated. Using a discrete event simulation framework, curb block activity based on on-site field data were simulated under different policy frameworks and demand patterns. The results were based on established performance metrics.

1.4. Report Structure

The remainder of this report is presented as follows. In Chapter 2, a literature review on curbside management is provided. Chapter 3 details existing curb management policies from throughout the United States. In Chapter 4, recent and current developments using technology for curb management purposes are examined. Chapter 5 provides a curb management framework for local agencies and highlights the key takeaways from current policies and practices. The results from a discrete event simulation are described in Chapter 6. Lastly, in Chapter 7, the report conclusions and opportunities for future study are shared.

CHAPTER 2. LITERATURE REVIEW

The research team conducted a thorough scan tp document previous studies that have examined curb space management and identify and review data sources that are already present. A separate section on growth management policies, which complement curb space management given their focus on land use, transportation, and economic development, is provided in the Appendix.

Before 2017, curb space management research was largely the study of parking. In the past three years, the field was expanded to consider the curbside impacts of ridesharing, shared mobility, mobility as a service (MaaS), and other emerging technologies. Multifaceted pressures on scarce curb space have prompted new research on comprehensive, multimodal demand management strategies.

The following review of the existing curbside management literature focuses mainly on peer-reviewed articles but also incorporates whitepapers from consultants and professional organizations, as well as city planning documents. These studies have primarily addressed five broad topics: dynamic pricing, travel behavior, regulatory structures, urban freight, and new mobility. Future studies can expand on research into productivity metrics, data-sharing, and on-demand delivery.

2.1. Dynamic Pricing

The first area of comprehensive curb management strategy centers on dynamic pricing schemes. Shoup (2011) popularized the notion of active demand management at the curb. Shoup proposed doing away with free parking, replacing outdated zone-based pricing schemes with prices that varied according to demand, and returning the revenue to public services in the same area through "parking benefit districts [Shoup 2007, Shoup 2018]." Since then, numerous cities have adopted Shoup's performance pricing guidelines, which aim for a target occupancy rate of around 80 percent, or one open space per block.

A substantial corpus of literature has evaluated the nation's most ambitious on-street performance pricing schemes, namely LA Express Park (in Los Angeles) and SF Park (in San Francisco). In a review of LA Express Park, Ghent (2018) concluded that given the relatively stable demand for parking, performance pricing strategies proved most effective when they were actively communicated to the public and when revenue collection was not the primary goal [Ghent 2018]. Pierce and Shoup (2018) dubbed SF Park a "promising" pilot program for its ability to internalize the costs of parking. In 2015, Perez outlined a data-driven approach to selecting performance pricing zones in Washington, D.C., drawing on geographic information systems (GIS), transit agency, and parking meter data [Perez 2015, Perez and Dahal 2018]. Although real-time changes have proved to be prohibitively expensive for even major cities, semiannual or quarterly rate adjustments could also produce results. Smaller jurisdictions without sophisticated technology could still undertake this form of "lean demand management" [Deakin 2018]. The most successful pricing plans, according to existing literature, frequently changed prices, set a wide range of rates to account for the price inelasticity of parking, used data to target specific districts, and broadly communicated changes to the public.

2.2. Travel Behavior

Another subset of literature has addressed travel behavior at the curb through ethnographic methods, including surveys and observational studies. Shoup spotlighted parking behavior in 2007, collecting on-the-ground observations of parking "cruising" behavior in 20 U.S. cities. He concluded that most curb parking was underpriced, incentivizing circling for parking that resulted in emissions and traffic [Shoup 2007]. A 2016 agent-based simulation suggested that a reservation-based system could improve this search process, while simply providing information might not [Chen et al. 2016]. More recently, other researchers have examined ridehailing pick-up and drop-off behavior from the perspectives of both drivers and passengers. While driving for Uber and Lyft, Henao and Marshall (2019) collected survey data suggesting that ridehailing replaced car trips, lowering overall curbside parking demand. Ranjbari et al. (2020) uncovered similar effects in intercept surveys of passengers in Seattle's South Lake Union neighborhood. They found that single-passenger rideshare trips were replacing some transit use.

2.3. Regulatory Structures

While many jurisdictions continue to follow a reactive, patchwork approach to regulating curbside behavior, recent studies have documented major shifts toward comprehensive management strategies. Zalewski et al. (2012) characterized the prevailing gradual, complaint-driven process as an "incremental" policy approach. In interviews with staff in eight cities, the researchers found two alternatives: performance-pricing or a "framework model" that set broad standards for districts based on land use and other planning considerations. San Francisco's 2020 Curbside Management Strategy exemplifies this approach, presenting a matrix of curbside functions prioritized by land-use category [SFMTA 2020]. As they shift to a framework model, many cities have reimagined their curb management regulatory structures and workforce distribution, calling for managers with more technical skill sets, including policy research and data science [Perez and Whetstone 2019]. Interviews with ten municipalities revealed that the incremental approach still prevailed in many places, but eight of the ten cities reported restructuring departments and increasing staff to deal with new curbside management pressures [Butrina et al. 2019].

2.4. Urban Freight

With the rise of e-commerce and on-demand delivery, freight is becoming an increasingly important stakeholder at the curb. Many cities provide inadequate loading zones and disproportionately allocate their curb space to parking, leading operators to risk tickets or double park to avoid unnecessary circling and missed deliveries. In addition, limited resources for enforcement in many cities encourages illegal parking in loading zones [Dey et al. 2019]. In 2017, Chen et al. documented a spike in demand for deliveries in residential areas of New York City, likely a symptom of the growing adoption of e- commerce [Chen et al. 2017]. Through an analysis of open datasets on parking regulations and violations, they concluded that the city's parking regulations were inadequate to accommodate this new demand. Although these researchers made valuable progress toward addressing curbside challenges for freight, more research is needed in this area, especially on curbside impacts from the rise of home deliveries.

Several studies have redesigned curb space to better accommodate freight. Fehr and Peers (2018) found that cities could allow drivers more room to maneuver in loading zones by placing them adjacent to passenger pick-up/drop-off zones, driveways, and intersections. In Washington, D.C., District Department of Transportation (DDOT) planners addressed enforcement issues by modifying their pay-by-cell program to mitigate non-trucks parking in loading zones, increasing disincentives for violations, and extending loading zone availability and operating hours [Dey et al. 2019]. New York City focused its adaptation strategies on time management, incentivizing off-peak deliveries and eliminating loading in busy areas during peak times [FHWA 2009, Simon and Conway 2019]. Generally, the most successful curbside management schemes for freight have been flexible, opted for incentives over regulations, and stemmed from an on-the-ground understanding of driver behavior.

2.5. New Mobility

More recently, curbside studies have turned to the topic of new mobility. In their interviews with municipal curbside management staff, Butrina et al. (2019) reported that nearly every interviewee observed a significant challenge with accessing and making sense of shared mobility data. A 2020 study of British and Australian cities noted the importance of proactive state intervention to address the increasing competition among new mobility services at the curb [Marsden et al. 2020]. Given the rapid diversification of curb use, the authors forecast that conditions would deteriorate before they improved. While many planners and policymakers described current transportation network company (TNC) operations as chaotic, these services also offer an opportunity to improve curb productivity. A 2018 study found that loading zones for TNCs could serve four times as many passengers per hour as the same space used for parking [Lu 2018]. Drawing on rideshare activity data from the non-profit Shared Streets, Washington, D.C., has adopted a strategic approach to placing 25 TNC pick-up and drop-off zones throughout the city [Perez et al. 2019].

2.6. Research Gaps

The rapid growth in curbside demand, along with a dearth of data, have led to several gaps in research. First, more research is needed into shared mobility operators at the curb. Little information exists on the parking behavior of dockless bike and scooter riders, for instance. Organizations such as Shared Streets and the Los Angeles Department of Transportation (LADOT) have made strides toward this goal by promoting standardized methods of data collection and encoding, although these have been resisted by rideshare operators. Until shared mobility operators such as Uber and Lyft are willing to share their data with municipalities and researchers, it will be difficult to conduct large-scale studies on this topic.

Existing studies reveal a desire on the part of policymakers to better understand novel curbside management technologies [ITF-OECD 2018], yet current research has not fully satiated this appetite. Through a series of pilot projects and academic evaluations, DDOT staff have made one of the most significant attempts to understand these tools. They uncovered several limitations to existing parking sensor technology, including prohibitive cost and a considerable number of false positives [Dey et al.2018]. While acknowledging that many contemporary computer vision techniques advertised for the curb have flaws, the researchers made use of predictive modeling to strategically deploy parking assets where they were most needed [Dey et al. 2016, Dey et al.

2017]. Additional research into this “asset lite” approach could illuminate a practical middle-ground for cities seeking to innovate amid shrinking budgets.

Policymakers have also said that obtaining curb data is a top priority, yet few studies have addressed best practices for data sharing. Case studies of cities that have successfully legislated data-sharing agreements with private operators could inform future curb management practices. Surveys or interviews that reveal attitudes about Mobility Data Specification (MDS) or other emerging standards would also be helpful. Such studies could inquire into the most useful formats for curb data, the variables that should be collected, and ways to make this process productive for both cities and operators.

On-demand delivery is another promising avenue for further research. Existing studies lag behind the rampant growth in services such as Uber Eats, DoorDash, and Uber Freight. A lack of publicly available data has made it difficult to study these curb users. Without large-scale data, observational studies or interviews with drivers or customers could provide insight into how these services use the curb.

Finally, better productivity metrics are needed to measure curb demand. Most cities still use traditional measures of parking demand, such as occupancy, turnover, and meter revenue. These have failed to capture new and varied ways of using the curb, focusing on passive vehicle storage rather than the active flow of passengers and goods. While Fehr and Peers established the first measure of curb productivity, to our knowledge, only a few cities—including Boston, San Francisco, and Cincinnati—have put it into practice [Boston Mayor’s Office n.d.]. Accurate, data-driven evaluations of curbside demand will lay the foundation for future innovation.

CHAPTER 3. CURBSIDE MANAGEMENT POLICY ASSESSMENT

By nature, the curb encourages experimentation. Nothing more than paint and signage can transform a simple 6-inch strip of concrete into a tableau of loading zones, bus lanes, bike facilities, or passenger pick-up zones. As pressures mount for scarce curb space, cities have embraced this ability to experiment. Recent years have seen a number of innovative strategies to meet rising on-demand delivery, ridehailing, and transit demands at the curb in cities.

For this report, the Urban Freight Lab research team reviewed existing regulatory structures, overarching policy frameworks and codes related to curbside management. Our research built upon several recent curbside management studies from the Institute of Transportation Engineers (ITE), the National Association of Transportation Officials (NACTO), and transportation consulting firm Fehr and Peers [ITE 2018, Fehr and Peers 2018, NACTO 2017]. We updated these findings with strategies and pilot programs launched in the past year, and expanded upon the geographic range and diversity of interviewees in these studies. We also provided a deeper exploration of the evaluation metrics and technologies used in curb management programs.

For this study, we interviewed 22 staff iin 14 cities and three regional metropolitan planning organizations (MPOs), listed in table 3.1. Interviewees held a diverse mix of job titles including curb access manager, transportation planner, director of freight mobility, code compliance officer, parking division operations manager, parking strategist, and curbside management operations planning manager. The study included municipalities from every census region of the United States, ranging from the Pacific Northwest and California to the Midwest, South, and Northeast, as shown in figure 3.1.

This chapter is divided into four sections. In Section 3.1, an overview is provided of the trend from incremental, reactive curb management structures to a holistic, framework approach. In Section 3.2, we examine how this shift has brought about changes in regulatory structures. Section 3.3 describes current challenges in curbside management. Section 3.4 catalogues recent policy experiments and pilot programs launched in response to these challenges, along with results and lessons learned.

Table 3.1 Demographics of Interviewees

City/MPO	Population	Position Title	Division Name
New York City	8,398,748	Director	Office of Freight Mobility
Los Angeles	3,990,000	LADOT staff	Department of Transportation
Houston	2,326,000	Division Operations Manager	Park Houston, administration and regulatory affairs department
Phoenix	1,660,000	Parking Strategist	Street Transportation Department
San Diego Association of Governments (SANDAG)	1,426,000	Associate Transportation Planner, Director of Integrated Transportation Planning, Mobility Hub Expert	San Diego Association of Governments
Columbus	892,533	Assistant Director for Parking Services	Department of Public Service
San Francisco	883,305	Senior Transportation Planner, Curb Access Manager	SFMTA, Sustainable Streets Division Parking and Curb Management team
Seattle	744,955	Parking Strategist	Department of Transportation
Washington, D.C.	702,445	Curbside management operations planning manager	Parking and Ground Transportation Division, DDOT
Boston	695,926	New mobility planner, co-chair, director	Department of Transportation, Office of New Urban Mechanics
Omaha	468,262	City Parking and Mobility Manager	Parking Department
Minneapolis	425,403	FUSE Executive Advisor, founder - Civic Ideation	Department of Public Works
Boise	228,790	Code Compliance & Community Resources Manager	Department of Finance and Administration
Spokane	219,190	Community Programs Coordinator	Parking Services
Bellevue	147,599	Traffic Engineering Manager	Department of Transportation
Southern California Association of Governments (SCAG)	NA	Senior Regional Planner	Southern California Association of Governments
Chicago Metropolitan Agency for Planning (CMAP)	NA	Multimodal transportation and parking	Local planning

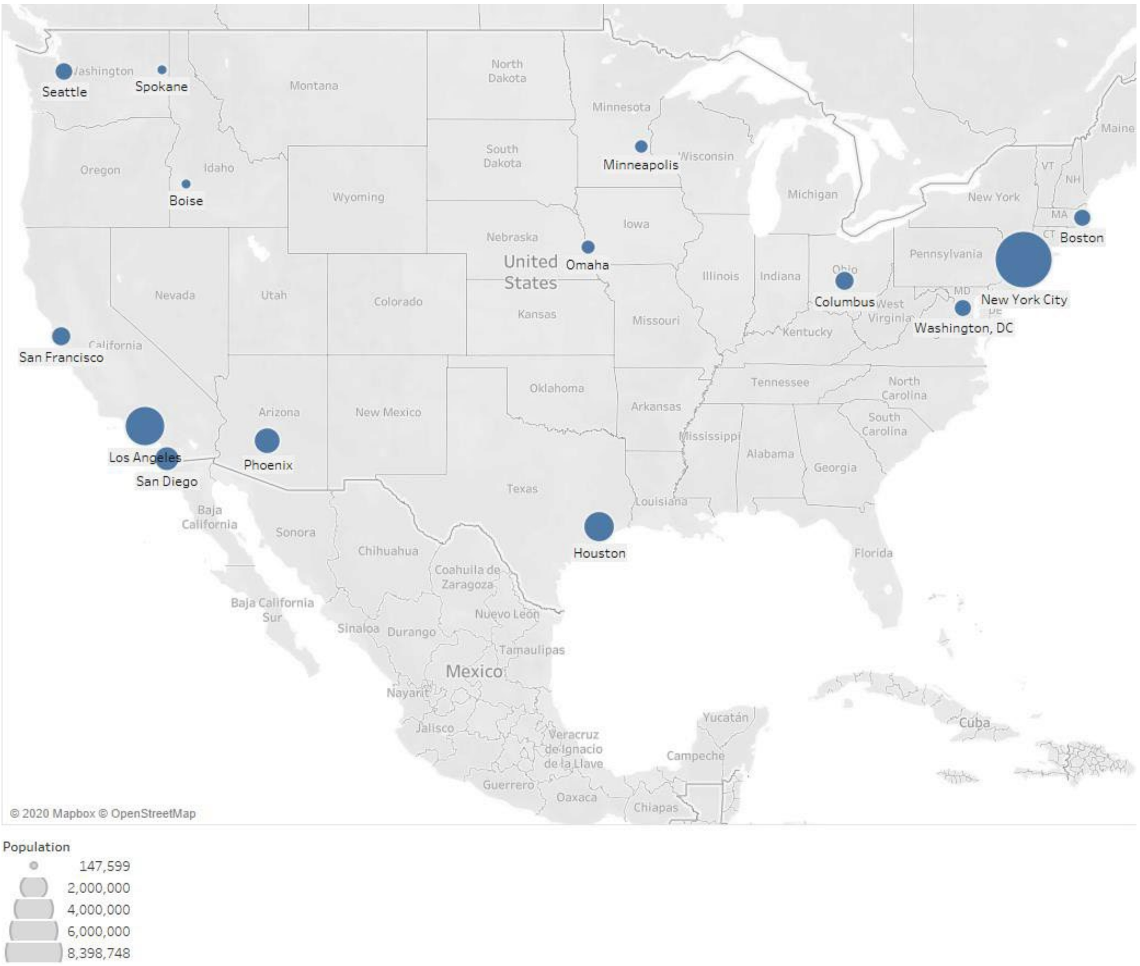

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Figure 3.1 Geographic Representation of Interviewees

3.1. Policy Frameworks

Currently, curb regulations in most cities favor parking for passenger vehicles above all other functions. Following an "incremental model," in most cities policies change retroactively, when residents or businesses complain [Zalewski et al. 2012]. Cities tolerate illegal activity until it becomes so big a problem that it cannot be ignored. In interviews, staff at cities nationwide described their curb management processes as "disjointed," "decentralized," "ad hoc," "reactive," and replete with "competing interests" and "tension."

The emergence of new mobility and the rise of on-demand delivery, however, has shifted this way of thinking to a proactive and holistic "framework model" [Zalewski et al. 2012]. Columbus plans to "rip apart" its current reactive process for allocating loading zones and replace it with a "data-driven" system that identifies hotspots by using ridehailing and delivery data. For the first time, Minneapolis' current draft Transportation Action Plan includes sections on freight and advanced mobility. An executive advisor in the public works department at the City of Minneapolis said that the plan would weave curbside management recommendations throughout each section and would link curb demand to the city's land-use goals, such as increasing density and banning single-family zoning. She highlighted a tension between pursuing overarching curb management goals and tailoring policies to fit the needs of individual blocks. "We can't fully standardize this because there are too many factors," she said. For instance, drivers of trucks, cars, and people with disabilities are willing to walk different distances from curb parking to their destination. "Every little detail like that—how prescriptive do you get, knowing we need a certain level of flexibility?"

To our knowledge, Seattle, San Francisco, and Washington, D.C., have adopted comprehensive, citywide curb management strategies. Boston, as of this writing, hoped to publish a similar strategy later in 2020, and Minneapolis was considering its own plan. These models, distinct from narrower parking plans, prioritize a wide range of curb functions according to land use. In industrial areas, for instance, businesses need storage for large vehicles and loading zones to pick up and receive goods. A downtown civic area might benefit more from a loading / unloading zone or a parklet.

Seattle and San Francisco have developed similar curb management frameworks to integrate transportation and land use. Both cities have published a matrix that plots land use against an ordered list of curb functions. "It's not a prioritized list," says a parking strategist at the Seattle Department of Transportation (SDOT). "We have to do all of these things." Seattle simplified its land-use categories into residential, commercial and mixed-use, and industrial [SDOT n.d.]. Each city emphasizes mobility in every land use and places access for people and goods within the top three spots of the list. As both cities prioritize transit over private vehicles in their modal master plans, mobility includes efforts to speed bus and light rail travel times. San Francisco's unique "major attractor" label foregrounds civic institutions by emphasizing access for people and public spaces and services over goods access [SFMTA 2020]. Table 3.2 summarizes differences between the two frameworks in greater detail.

Table 3.2 Curb Strategy Comparison of Seattle, Washington, and San Francisco, California

Seattle	**San Francisco**	**Key Aspects**
Access for People	Access for People	Both mention passenger loading
Access for Commerce	Access for Goods	SF explicitly defines a wider range of deliveries, such as passenger vehicles dropping off goods, or people picking up goods at the curb
Activation	Public Space and Services	SF is more focused on physical assets such as fire hydrants or wide sidewalks, while Seattle emphasizes public life—food trucks, streateries, festivals, and public art
Storage	Storage	SF includes bicycle and electric vehicle storage
Mobility	Movement	Both include multimodal priorities such as bike racks, bus lanes, carshare parking
Greening	N/A	Seattle includes an additional category for rain gardens, planters, and bioswales

The (Washington D.C.) District Department of Transportation's (DDOT) curb management strategy, adopted in 2014, also adjusts policies according to geography. The plan outlines three citywide goals: preserve access to residential areas, prioritize commercial vehicle access in commercial areas, and ensure safety of all users. The authors identified four curb management models to apply to different neighborhoods, based on feedback from resident surveys: "Local amenity support" stresses walking access to destinations such as schools and parks. "Equitable access" aims to provide all district residents with equal access to goods and services. "Resident priority" places the access needs of residents above those of all other users. "Managed availability" does not differentiate between users but seeks to balance all modes and needs with demand-based pricing strategies [Nelson / Nygaard 2014]. The District does not make clear in its strategy which policy framework it is currently pursuing in each neighborhood.

3.2. Governance Structures

Complexity defines the curb management governance structures at many local jurisdictions. In Washington, D.C., three divisions within the department of transportation govern the use of public curb space. The public works department assumes the primary role for enforcement. The Department of Consumer and Regulatory Affairs issues business licenses for valet parking. The federal government owns some curbside space in front of buildings on the National Mall, and the Council of the District of Columbia retains authority to set meter rates. In Phoenix, one parking strategist described his city's curb management structure as a "disjointed" mix of government and industry groups. Police enforce policies, the Street Transportation Department sets rates, and a quasi-governmental economic development group works with businesses to identify curb issues. The Minneapolis advisor said that "the legacy of our organizational structure [for curb management] is based around systems from 50 to 100 years ago." Functions such as engineering, operations, planning, and enforcement reside with different divisions or agencies, which view the curb as simply street parking rather than a holistic system. As part of a Transportation for America (T4A) pilot project, the city is tackling this problem by pulling together staff from each group into one team.

With curb management experiencing a renaissance, some cities have entirely rebranded and repositioned these responsibilities. Curb management has taken on a broader meaning, encompassing not only parking but ridehailing, freight, and micromobility. The modern curb calls for a skilled workforce well-versed in new mobility, data analytics, computer visioning, user experience, and other emerging technologies. Public works departments have aimed to fill these gaps with new hires, revised job postings, and expanded professional development opportunities [DDOT 2020]. "We hire data scientists now," said an assistant director for parking services at the City of Columbus. "We work on contactless, permitless, technology-heavy solutions," a significant shift from three or four years ago. The City of Omaha has embraced innovative mapping tools, the city's Parking and Mobility Manager said. In this new structure, he said, "people who are good with maps and data are highly desired."

Boston has assembled a diverse team of curb strategists with backgrounds in engineering, urban planning, policy, and investment banking. The policy and planning division of the Boston Department of Transportation collaborates with the Mayor's Office of New Urban Mechanics, an agile engineering team tasked with developing technical solutions to pressing urban issues. In Washington, D.C., the policy branch of DDOT's Parking and Ground Transportation Division has taken an active role in piloting cutting- edge technologies. The department's Curbside Management Division is restructuring its training work plans and updating operating procedures with an eye toward "preserving flexibility for the unknown [Perez and Whetstone 2019]." The Seattle Department of Transportation houses curb management within the transit and mobility team in its policy, programs, and finance division. Fourteen of the 31 employees on the curbside team work in high-level design, strategy, and program management [SDOT 2020].

In spring 2018, San Francisco created a curb management team within its parking and curb management division. The team of policy managers and urban planners promoted a culture shift within the department from reactive, complaint-based allotment of loading zones to proactive management. This work culminated in the city's Curb Management Strategy, released in February 2020, the most comprehensive of its kind in the nation [SFMTA 2020]. San Francisco Municipal Transportation Agency (SFMTA) staff noted that curb management is now a required component of most major transportation projects. For example, a recent redesign of the Valencia Street bikeway linked reductions in double parking to faster travel times for cyclists.

Other cities have made modest shifts to their existing regulatory structures. Los Angeles kept curb management within the Bureau of Parking Management and the Bureau of District Operations while creating or expanding several teams within this department to address new mobility. New York City's two curb management divisions—Parking, and Traffic Control and Engineering—have adopted a similar multimodal philosophy regarding curb use. Bellevue, Washington, has not hired a dedicated staff member for curb management, but it has increased the hours that transportation planning and engineering staff spend on curb management. In 2019, Seattle's parking division was renamed curbside management, to emphasize a data-driven approach and acceptance of a variety of curb uses. Minneapolis is considering transforming the street parking team into a curbside mobility team.

Drawing upon organizational psychology, DDOT planners identified two broad strategies to guide municipalities adapting to new curb management demands [Perez and Whetstone 2019]. First, at least one branch of the organization must be able to continually improvise to respond to the experimental and fast-changing nature of the curb. Second, all branches should stay abreast of curbside management trends, shifting toward asset-lite solutions, those that achieve results with the smallest investment in infrastructure. Creating a deep, rather than flat, organizational structure and expanding mentoring opportunities will help ensure a talented workforce in curb management divisions of the future.

3.3. Curb Space Management Challenges

Major metropolitan areas face similar challenges as they experiment with innovative curb management strategies. These challenges—enforcement, cost, politics, regional and inter-agency coordination, and data management—are summarized in figure 3.2.

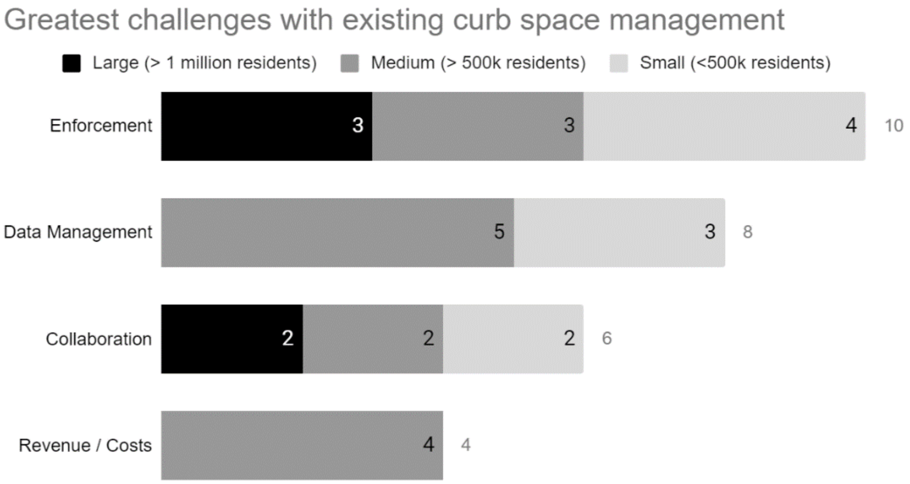


Figure 3.2 Challenges to Existing Curbside Management Practices

3.3.1. Enforcement

One of the greatest issues concerns enforcement, an expensive investment of staff time and resources. In Bellevue, Washington, the smallest city in this study, a single enforcement vehicle patrols every parking space citywide. Nationwide, the difficulty of communicating constant changes in curb rules to the public has limited the effectiveness of dynamic pricing programs and other policies.

At least two cities have taken novel approaches to this challenge. Los Angeles interviewed parking violators to learn where they most needed new loading zones. Then, the city built these zones and launched a marketing campaign to promote them. The city deployed “Tiger Teams” of 15 traffic control officers and ten tow trucks during the peak travel period, slashing the number of parking violations. Following the program, LA Metro Rapid buses on Ventura Boulevard improved speeds by 5 percent on average [Nelson / Nygaard 2014]. Washington, D.C., collected data on loading zones through ArcGIS Collector, mapped this information in an interactive, citywide truck and bus map, and required oversize/overweight vehicles to plot their route to obtain permits for loading within city boundaries. Companies initially pushed back but later welcomed the certainty that the program created [Nelson / Nygaard 2014].

Both of these stories demonstrate the importance of understanding reasons behind parking violations. Freight companies sometimes pay traffic tickets for their drivers, not out of blatant disregard for the law but because cities have not met their essential loading needs. New York City, for example, faced problems with drivers parking for three hours or longer in scarce loading zones.

According to an NBC News article, United Parcel Service (UPS), FedEx and other delivery companies paid the city $102 million in parking fines annually and averaged a combined 7,000 tickets per day [Associated Press 2006]. "They don't want to pollute and spend more on fuel," said the director of the city's freight mobility program. "They'd rather just park their vehicle there, so they'll eat up the ticket." For its T4A pilot, Minneapolis planned to redesign a stretch of 8th Street in downtown after observing trucks parking and double parking in no-stopping zones. The Minneapolis advisor said the city recognized that the street's physical design was contributing to the illegal behavior. "We haven't been ticketing because we partially have responsibility. It's a design failure." Future data collection, she said, will involve not only video monitoring but interviews with drivers to better understand their loading needs.

Smart loading zone regulations stem from conversations with drivers and operators, and understanding the driver experience is critical. "The diversity of operators is tremendous," the Columbus official said. "You can talk to UPS in D.C. but it's not the same UPS as in Columbus." Instead of simply enforcing inadequate regulations, cities should conduct more focus groups or surveys to understand how to reshape loading requirements. He stressed the importance of a citywide approach. For its curbFlow pilot, Columbus chose eight zones, but the city hoped to standardize how the rules of the pilot were enforced. "You're not going to see full acceptance unless all the zones are like that," he said. "You have to go in feet first and do the whole thing."

Some cities hope to resolve these issues through automated enforcement. The Columbus planner said that a key finding of the recent Columbus pilot project with technology company curbFlow was that cities need to completely automate the parking experience to make a demand management system useful for freight operators. He said that "using an app where the driver has to make a decision is not acceptable."

However, significant obstacles prevent cities from adopting this approach. Some, including Seattle, maintain surveillance ordinances against camera technology or license plate recognition (LPR). Citizens in most cities do not yet broadly agree on the use of computer vision techniques and may feel they are being "watched" or that cities can identify personal details as they monitor the curb. In 2007, the Minnesota Supreme Court ruled red light cameras unconstitutional, and the decision also blocked the city of Minneapolis from using LPR for curb enforcement. Without automated methods, the city struggles to deploy enough staff to enforce curb regulations. Another city noted that entrenched unions make it difficult to switch from manual enforcement to automated technologies.

3.3.2. Cost Concerns

High costs also limit cities' ability to experiment at the curb. The expense of placing more than one in-ground sensor per parking space and paying data charges made SF Park, a San Francisco demand-based pricing system, unsustainable in the long term. City officials hesitate to replace parking meters with loading zones, fearing a loss of revenue for public services. In Chicago, one regional planner commented that the city pays a private company an annual fee to run its meters, turning any curb policy that could jeopardize meter revenue into a political third rail. "They [City of Chicago] don't let anybody make changes to streets because they're worried payments will go up," she said. "They're not interested in being experimental or adding new meters." The Columbus staff member said that the city desperately needs to monetize pick-ups and drop-offs to avoid losing meter revenue, but it faces a prohibitively high cost to install automated infrastructure to achieve this task. Washington, D.C., has offered a model for working within budget constraints through an "asset-lite" curb management approach. This strategy deploys continuous sampling and data evaluation to distribute the minimum number of cameras or sensors where they are most needed [Dey et al. 2016].

3.3.3. Political Issues

Politics complicate attempts at curb reform. Taking away parking has always been a sure way to provoke ire from citizens. Houston's curb policies still largely revolve around installing meters and designating time limits. Omaha and Phoenix both named a strong car-oriented culture as a significant challenge to curbside innovation. "We're the fifth largest city in America," the Phoenix strategist said, "and we're still parking like we were in the 1970s and 1980s." As "edge cities," such as Bellevue, grow rapidly, they have tried to shift the culture around parking and the curbside. "Bellevue was known as the place you drive to and can park easily and for free," said a traffic engineering manager in Bellevue, "and you could avoid the hassle of driving and parking in Seattle." Established cities are not immune—in New York City some loading zone regulations have not changed since the 1970s.

3.3.4. Regional and Inter-Agency Coordination

Effective curb management requires regional collaboration, especially in large metropolitan areas. Staff at several agencies described their current management regimes as piecemeal, with regulations varying widely between neighboring jurisdictions, and even among different departments in the same city. The public works department, for instance, might have different priorities than the transportation agency. Planners at SFMTA said they continually navigate legal issues regarding where their jurisdiction falls for different sections of curb. Boise faces a highly unusual situation in which the county government owns all roads within the city, and curb managers must negotiate for county approval to install parking sensors or other technology. In Spokane, Washington, a community programs coordinator said that “getting everyone at the table and not working in a silo is one of the biggest challenges.” A parking strategist in Phoenix described a lack of coordination among agencies managing the curb, resulting in isolated or conflicting requests for curb space that do not follow an overall plan.

Regional coordination can also refer to effective communication between cities and private companies. Planners at the Southern California Association of Governments (SCAG), a metropolitan planning organization, noted that companies in their region sometimes launch their own curb pilot projects without coordinating with the city. Although this is not a requirement, sometimes the city is not aware of the work being done and how it fits into the existing regulatory structure. Effective public-private partnerships can bridge this gap and promote knowledge exchange.

3.3.5. Data Management

Every city we interviewed noted challenges with data collection and management. Few cities feel confident enough to entirely abandon manual data collection for digital techniques. Many of the manually collected data reside in uniquely formatted spreadsheets or GIS databases housed in different departments or agencies. Boise’s inventory is largely passed down through seasoned employees who know every parking meter in the city. Cities are searching for digital tools to consolidate these data and present them in a standard format to citizens and companies. In 2016, Los Angeles launched the broadest attempt nationwide to digitize more than 1 million curb signs and 37,000 parking meters through its “Code the Curb” effort [LADOT 2019]. Other municipalities, including Columbus and Omaha, have launched digital collection pilot projects with the company Coord.

In particular, cities have encountered barriers to accessing data from shared mobility operators. Parking managers in several cities we interviewed said they see services such as Uber and Lyft as major disruptors. The Phoenix parking strategist said they are “butting into a system” in which taxi drivers pay for medallions to use loading zones. In Chicago and San Diego, planners commented that Uber and Lyft drivers create congestion, double park, and block transit lanes. These operators use existing infrastructure such as loading zones but do not pay fees, as taxis do. In most cities, operators are not required to provide trip data. Numerous technology companies have approached Minneapolis with curb-related proposals, the advisor we spoke to said, but few have presented terms that are favorable to the city. “They want full ownership of the data, which is not acceptable,” she said, “while they also lean on the city to maintain the right-of-way and provide enforcement.”

Cities can overcome operators’ unwillingness to provide data by negotiating over space in the public right-of-way. Through a combination of offering more loading space and “arm twisting” over citations, Omaha, Nebraska, secured neighborhood-level, hexbin heat maps of pick-up and drop-off data from Uber and Lyft. The planner we spoke to said that Omaha’s small scale made the city a safer bet for the companies than releasing data in a major metro area. The companies were willing to trade data for loading zone availability. In a partnership with Coord announced in June 2020, the city plans to combine these data with delivery data to allocate “smart loading zones” throughout the city. Information on deliveries will come from usage data from the reservation app that Coord plans to develop. Likewise, when Uber and Lyft learned that Columbus would make pick-up zones available to them as part of its curbFlow pilot, they consented to sharing data through a trusted third party, the nonprofit Shared Streets. “If operators see that the city is willing to allocate space for their activities, they will share data,” the Columbus planner said. “We’ve been wanting those data for years, and wouldn’t even get a call back, until they found out we were allocating space for them.”

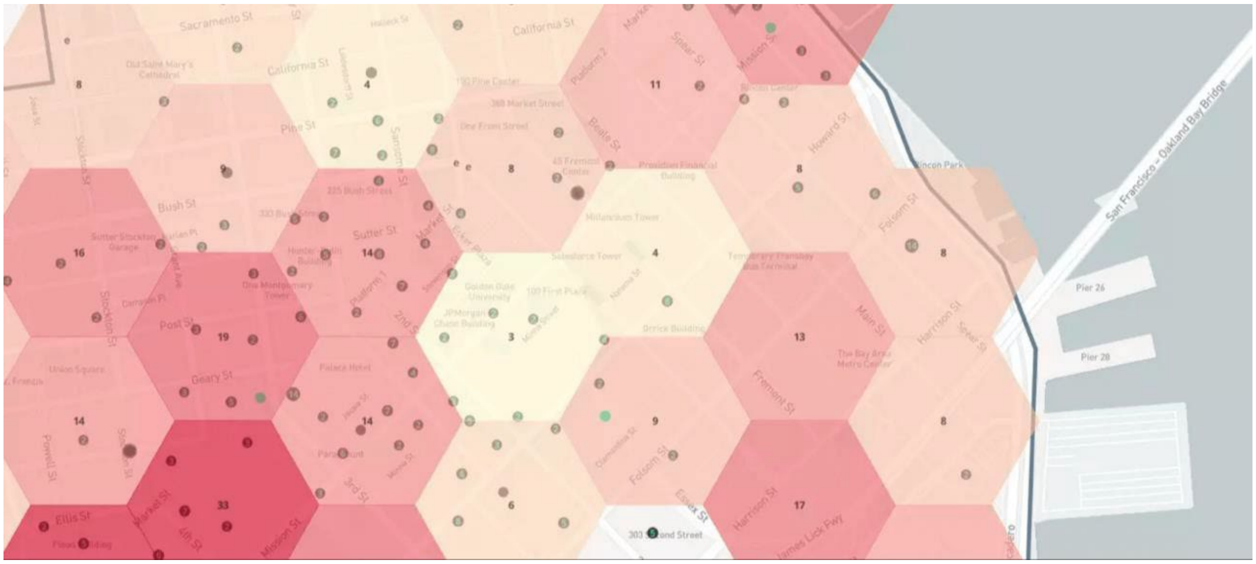


Figure 3.3 Hexbin Map of Uber JUMP bikes. (Credit: Uber Technologies)

3.4. Recent Policy Solutions

3.4.1. Pricing

3.4.1.1. Dynamic Pricing

Dynamic pricing schemes rationalize parking policy through simple principles of supply and demand. If prices are too high, parking spaces will sit empty and local businesses will suffer. If prices are too low, every space will fill up, and drivers will cruise for a spot, creating congestion and emissions. Cities can set dynamic prices to achieve the "goldilocks principle" of neither too much nor too little parking. Nearly every documented dynamic pricing program follows the recommendation of Donald Shoup, a professor of urban planning at the University of California Los Angeles (UCLA) and self-proclaimed "prince of parking," for a target occupancy rate of around 80 percent, or one empty space per block [Shoup 2007].

We reviewed dynamic pricing programs in ten U.S. cities. These programs generally succeed at reducing congestion and double parking if rates are varied enough, changes are incremental, and communication with the public is frequent and transparent. The most successful programs frequently change rates over a wide range of prices. The price elasticity of parking is low, so it takes significant rate increases to change behavior [Ghent 2018]. Although no city has successfully implemented a sustained real-time pricing program, cities have reaped benefits from periodic rate adjustments. Even smaller cities can take advantage of "lean demand management," infrequent adjustments that still provide more flexibility than a static model [Deakin 2018]. Seattle, for example, adjusts prices annually on the basis of a citywide parking survey. SDOT manually collects data on a Tuesday, Wednesday, and Thursday from 8:00 am to 8:00 pm to capture the percentage of occupied spaces on each blockface for typical weekdays. If occupancy falls between the target 70 to 85 percent, then the agency keeps rates the same, and if it falls above or below this, interval then rates are adjusted in $0.50 increments [SDOT 2020]. These programs rate well with the public, as they set prices in response to market forces instead of guesswork. As consumers recognize that the programs can force prices down as much as raise them, they could garner even more support. Public acceptance is more likely when raising revenue is a secondary goal to making more spaces available [Ghent 2018].

Two of the most ambitious performance pricing schemes took place in San Francisco and Los Angeles. In 2011, San Francisco launched "SF Park" for 28,000 parking spaces and 14 city garages, changing the previously static price several times a day. This effort expanded into a real-time pricing pilot that constantly changed prices in response to occupancy data from sensors. The city set target occupancy at 60 to 80 percent, and if it fell outside that range, then prices would go up or down by $0.25 per hour. In a 2014 evaluation, the program scored well on a range of metrics: Transit speeds improved, vehicle miles traveled declined, and consumers spent less time searching for spaces [SFMTA 2014]. However, that method proved too expensive to continue, and two years ago, the city moved back to semi-static pricing and settled on rate adjustments four times each year.

Figure 3.4 San Francisco, California, Parking Meter. (Credit: C. Pardo)

The Los Angeles Department of Transportation (LADOT) rates a similar program, LA Express Park, as one of its greatest successes. In 2012, the first year of the program, the city changed prices eight times on a scale from 0.50 cents to $8 for 6,300 spaces in the downtown area. Despite low public awareness and limited communication and signage, the program met its three stated goals to reduce congestion, encourage use of modes other than driving, and create more parking availability [Ghent 2018]. After a successful downtown pilot, the city expanded the program to the Westwood (near the UCLA campus), Hollywood, Venice, and (soon) Exposition Park (near the University of Southern California campus) neighborhoods, with prices changing three times a year [Ghent 2018].

A complete list of performance pricing programs and evaluation measures is included in the Appendix.

3.4.1.2 Discounts for Small and Clean Cars

Shoup suggested a novel approach to pricing the curb: discounts for small, fuel efficient cars [Shoup 2018]. Cities can award these discounts by classifying license plates by car length (table 3.3). Calgary, Canada, gives a 25 percent discount to cars that are 3.8 meters (12.5 feet) long. By incentivizing people to drive smaller vehicles, this policy could free up curb space for passenger or freight loading. This policy creates a parking price structure similar to that used to sell the cars. Shoup wrote that “most people who can afford to buy a longer car can afford to pay more to park it” [Shoup 2018].

Table 3.3 Shoup Vehicle Discount Structure

Vehicle	Length (feet)	Fuel Efficiency (MPG)	CO2 Emissions (grams / mile)	Discount from full meter price (%)
Rolls Royce Phantom	20	14	637	0
Lincoln MKS	17.2	22	400	14
Scion IQ	10	37	238	50
Smart Car	8	36	243	56

Smaller cars also tend to be more fuel efficient, reducing energy consumption and emissions. Cities can link license plate records to emissions data provided by car manufacturers or required smog tests, allowing them to charge parking rates on the basis of vehicle emissions. Madrid, Spain, links its parking meters to a motor vehicle database. The city records parking transactions by plate numbers and sets prices on the basis of fuel and emissions data for specific vehicles [Perez and Dahal 2018]. The city charges 20 percent less for parking for low-pollution cars and 20 percent more for high-pollution cars.

3.4.1.3. Event-Based Pricing

Major traffic generators, such as baseball games, concerts, or festivals, can sabotage a city’s otherwise well-oiled zone-based parking mechanism. At least three cities have responded through event-based pricing. Sacramento, California, switches to a tiered-pricing scheme within three blocks of Golden Arena One when an event’s attendance exceeds 15,000 (figure 3.5). Drivers can park for $1.75 for the first hour, after which the rate escalates to a maximum of $18.75. San Francisco defines an event zone within walking distance of AT&T Park. On event days, the hourly rate increases to $7 from the regular curbside rates of $0.50 to $8 an hour. In this case the fee applies for the entire day, from 9:00 am to 10:00 pm on weekdays and 9:00 am to 6:00 pm on weekends. At the start of the 2017 Washington Nationals Baseball season, the District switched to progressive event-based pricing. On ordinary days, drivers paid $2.30 per hour. On the 80 game days that season, they paid $8 per hour from the second hour onward [Perez and Dahal

2018]. An extensive two-year evaluation of the program showed that parking meter revenue increased, while transactions and average duration of stay decreased. However, this trend applied to both game and non-game days. Findings on multimodal transportation effects were inconclusive, the authors wrote, because of a lack of analysis on the effects of transportation network companies (TNCs) on transit [Perez and Dahal 2018].

Figure 3.5 Sacramento, California, Event-Based Pricing Scheme (Credit: City of Sacramento)

3.4.1.4. Pricing Commercial Vehicle Loading Zones (CVLZs)

In many cities, delivery vehicles park in commercial vehicle loading zones (CVLZs) for free. Several cities are managing the rapid demand that free parking creates by pricing these zones. In Chicago, CVLZs cost $3.50 per 15 minutes. Responding to emerging modes of on-demand delivery, the city allows passenger vehicles with commercial license plates, logos on the vehicle, or a non-commercial loading zone permit [City of Chicago 2020]. Seattle offers a $250 transferable permit for every ten non-transferable permits purchased by commercial vehicles fleets of ten or more. The city enforces a 30-minute time limit for CVLZs from 7:00 AM to 8:00 PM, Monday through Saturday, and it issues 4,000 CVLZ permits per year [SDOT 2020]. New York City designed a tiered pricing approach for newly designated CVLZs in 2009 —$2.00 for one hour, $5.00 for two hours, and $9.00 for three hours. This incentivizes shorter stays while providing the option to stay longer. After this pricing program went into effect, the percentage of occupied curb space in New York City dropped from an average of 140 percent (accounting for double parking) to 95 percent percent, average occupancy times decreased from 160 minutes to 45 minutes, and only about 25 percent of commercial vehicles occupied spaces for more than one hour [FHWA 2009]. After Washington, D.C., enacted a loading zone pricing program at $2 per hour (or $323 annual permit) in January 2015, violations for double parking and non-trucks parked in loading zones dropped by 50 percent [ITE 2018].

Companies initially pushed back but later proved willing to pay for added reliability and availability of loading zones. Shoup suggested that in future programs, cities should price loading zones according to vehicle length. For example, a 50-foot truck would pay five times more per minute than a 10-foot cargo bike. This plan, Shoup noted, could incentivize operators to switch to smaller, more efficient vehicles for urban deliveries [Shoup 2020].

3.4.1.5. Residential Parking Programs

This policy can raise revenue while garnering favor with the public. In Miami Beach, residents pay $1 an hour for metered on-street parking, while non-residents pay $4. Similarly, Washington, D.C.'s, Residential Parking Permits, available by petition, reserve up to 50 percent of spaces on each block adjacent to schools, parks, or other traffic generators for residents [Shoup 2018]. Pay by license plate technology enables this bifurcated system. Drivers enter their plate number into a meter or pay by phone.

These policies are similar to hotel taxes or other widely accepted sources of tourism revenue. They are also popular with businesses because they encourage residents to shop locally [Shoup 2018].

3.4.1.6. Pricing PUDO Zones

Several cities have seen success with designated passenger pick-up / drop-off (PUDO) zones, so a question for future pilot programs is how to price these zones. So far, some cities have converted parking to PUDO zones (see section 3.4.3.4), but they have not found a way to charge for these activities. Until they do, sacrificing metered parking for loading zones will often generate political tension, as meter revenue supports many essential public programs. Staff in cities including Seattle and Columbus expressed a need to monetize pick-ups and drop-offs to properly price valuable curbside real estate and reduce congestion. However, they noted challenges with getting companies to support these proposals and finding affordable automated technology for enforcement.

One proposal is a "curb-kiss fee," which could be digitally triggered every time a vehicle stops in any type of curb space [Howell et al. 2019]. Variables such as occupancy, type of services, time of day, and location would determine the fee. Cities could use fees to incentivize good behavior: for example, charging higher fees for vehicles with more passengers. However, the ability to charge such a fee would depend on digital infrastructure, regulatory language, compliance and enforcement regimes, and data standards, so this policy remains a distant future goal [Howell et al. 2019].

3.4.2. Move, Lengthen, or Merge Loading Zones

On some high-traffic corridors, cities may attempt to do too much with too little curb. An Institute of Transportation Engineers (ITE) whitepaper on curbside management tools suggested moving loading zones on congested corridors around the corner from their destinations. This tactic would allow transit vehicles and cyclists to move uninterrupted through the corridor and would offer delivery drivers a less congested and more reliable loading zone. ITE wrote that delivery drivers would prefer this legal, reliable access to hazardous or illegal loading, even if it put them a few steps further from their destination [ITE 2018].

Many loading zones are not long enough to allow delivery vehicles to maneuver into a space, especially with cars parked on either side. An Urban Freight Lab (UFL) study found that current loading zones in Seattle, for instance, accommodate standard truck lengths but not the extension of ramps, staging of packages or other activities in the vehicle “envelope” [McCormack et al. n.d.]. Moving the zones adjacent to intersections or driveways enables drivers to pull into a space in those situations instead of double parking. Transportation consulting firm Fehr & Peers identified this strategy in its report on San Francisco curb management strategies [Fehr and Peers 2018]. In its latest curbside management plan, San Francisco encouraged loading across driveways as an alternative to double parking in areas where drivers have no other options [SFMTA 2020]. In a pilot project with the UFL, the Seattle Department of Transportation (SDOT) in January 2020 installed design changes to 29 CVLZs in Belltown, a bustling neighborhood adjoining the central business district. The agency moved loading zones in front of driveways or intersections to make it easier to pull in or out, grouped nearby loading zones together, and enacted a minimum CVLZ length of 35 feet [Urban Freight Lab 2020].

SDOT also implemented Fehr & Peers’ recommendation to relocate CVLZs next to passenger loading zones (PLZs). This gives drivers more space to maneuver when one or the other zone is unoccupied. Another recent UFL study suggested that drivers use curb space fluidly—passenger vehicles accounted for more than half of vehicles parked in CVLZs (52 percent), while more than a quarter (26 percent) of delivery drivers parked in PLZs [Goodchild et al. 2019].

Combining these two zones facilitates drivers' natural behavior while keeping the same restrictions in place on each block.

3.4.3. Time Management

3.4.3.1. Add Evening and Weekend Parking Restrictions

Traditionally, cities have regulated parking mainly during the day, fitting with the paradigm of the curb as a place to store vehicles during the workday. Recently, however, ridehailing activity and mode shift to transit has increased demand for curb space on evenings and weekends.

In San Francisco, the vast majority of curb regulations end at 6:00 pm and do not apply on Sundays. At these times, loading zones revert to free, unlimited parking. However, in some nightlife hotspots, such as Valencia Street, curb demand in evenings is nearly twice that during the day. Some commercial corridors exhibit near 100 percent occupancy rates after 6:00 pm. So, in its latest curb management plan, released in 2020, the city recommended extending meter hours to evenings and Sundays in high-demand areas. The plan stressed that meter changes must be coupled with increased enforcement. Houston is also considering expanding metered parking from 6:00 pm through midnight to better manage demand around downtown restaurants.

3.4.3.2. Shorten Time Periods

Many cities allow hours of free or cheap parking outside businesses that cater mainly to pick-ups and drop-offs. However, commercial vehicle dwell times are often much shorter than the legal limits. Recent UFL research showed that at five locations in downtown Seattle, more than half (54 percent) of commercial vehicles parked at the curb for 15 minutes or less. Seventy-two percent parked for less than 30 minutes [Urban Freight Lab 2019]. Shrinking parking time limits is therefore a cost-effective way to ensure higher turnover at the curb.

San Francisco is confronting this challenge through reforms to its green zones, spaces for short-term, metered or unmetered loading of 15 to 30 minutes. In its Curbside Management Strategy, SFMTA proposes to standardize these zones at 15 minutes to ensure higher turnover, clamp down on abuse of other peoples' disabled permits, which allow 72-hour stays, and extend time limits to evenings and weekends. The agency also plans to take a more proactive approach to placing the zones outside businesses, such as dry cleaners, that cater mainly to pick-ups and drop-offs [SFMTA 2020].

3.4.3.3. Encourage Off-Peak Delivery

Regulating temporal shifts in deliveries has largely proved ineffective. In 2018, New York City tested a ban on deliveries during peak hours through its Clear Curbs program [Schaller Consulting 2015]. On some congested commercial streets in Midtown Manhattan, Queens, and Brooklyn, the city blocked commercial loading during the morning (7:00 to 10:00 am) and afternoon (4:00 to 7:00 pm) rush hours. The affected streets saw a high rate of violations, rendering the project ineffective [Schaller Consulting 2015]. A City College of New York study found that one area where clear curbs was implemented experienced a 73.3 percent increase in monthly parking violations in comparison with 18.6 percent in the surrounding neighborhood [Zhang et al. n.d.]. The pilot ended five weeks earlier than scheduled after many local business owners complained that the pilot was hurting business due to their inability to receive curbside deliveries and because it was off-putting to customers [FHWA 2009]. Similarly, when the UFL considered a late-night delivery pilot program to reduce congestion in Seattle alleyways, member businesses provided feedback that constraints such as labor contracts and tight air-freight schedules would render this approach impractical [Urban Freight Lab 2019].

A 2009 program achieved better results by changing behavior through incentives, as opposed to regulations. Back then, the NYC Department of Transportation offered delivery companies cash incentives to shift some of the city's 110,000 daily curbside deliveries to off-peak hours. Eight delivery companies and 25 of their clients volunteered for the pilot program, which aimed to reduce double parking, congestion, and illegal loading [Nelson / Nygaard 2014]. Carriers looked more favorably on that program. Scheduling at off-peak hours allowed them to cut average time spent loading and unloading trucks from about 100 to 30 minutes, save on fuel costs, and improve travel speeds by 75 percent. Companies incurred new expenses for staffing during off-peak hours, but they benefited from focusing peak-hour staff time on customer service rather than receiving and processing deliveries.

3.4.3.4. Create/Extend PUDO Zones and Geofencing

The increasing popularity of ridehailing as a means of travel to and from bars, clubs, and other nightlife destinations has created spikes in curb demand on evenings and weekends. Several cities have responded with time-limited PUDO zones that serve other functions during off-peak hours. For example, San Francisco currently offers some "dual-use" zones, usually marked with yellow paint, that change from commercial loading in the day to passenger loading in the evening. Expanding these zones could help accommodate variable demand throughout the day. Often, PUDO zones are “geofenced,” a practice of restricting ridehailing users' choice with the app to specific locations [Boston Mayor’s Office n.d.]. In some cases, Uber and Lyft do not restrict drop-offs, saying drivers are more likely to ignore the restrictions and follow riders’ directions.

In a ridehailing study of the highly congested South Lake Union neighborhood of Seattle, UFL researchers found that adding around 254 total curb feet of passenger loading zones and geofencing these areas cut the share of pick-ups in the travel lane from 20 percent to 14 percent [Goodchild et al. 2019]. Passengers were satisfied with the new measures: 79 percent rated their pick-up as satisfactory, and 100 percent said their drop-off was satisfactory, in comparison to 72 percent and 89 percent, respectively, before the new measures went into effect. Researchers found that the combination of geofencing and PLZs improved traffic conditions more than PLZs alone.

In 2018, the city of West Hollywood launched “The Drop,” a time-limited PUDO zone program. The city designated 12 zones with a high volume of ridehailing use as passenger loading zones from 6:00 pm to 3:00 am. The city has no evaluation metrics, but it plans to install new parking meters with vehicle detection sensors to record occupancy and turnover by the end of 2020. Boise replaced taxicab-only meters for 20 spaces across two blocks with evening ridehailing PUDO zones. At other times, these areas served as parking or commercial loading zones. Boise evaluated the pilot with time-lapse photography and conversations with local businesses, and it found that with consistent enforcement, traffic flow improved and restaurants reported safer and easier access for customers. Fort Lauderdale, Florida launched a similar pilot in 2018, creating three ridehailing zones during prime nightlife hours from Thursday to Monday, and the evaluation showed that the zones improved traffic flow and reduced delays along the corridor [Nelson / Nygaard 2014].

In March 2019, The Boston Transportation Department, Office of New Urban Mechanics, and Department of Innovation and Technology collaborated on a PUDO pilot on two westbound blocks of Boylston Street in the Fenway neighborhood (figure 3.6). They designated two adjacent parking spaces on each block as PUDO zones, with 5-minute time limits, from 5:00 pm to 8:00 am. In accordance with the city’s “red top meter” program, the meters in these zones received red caps to indicate time-specific restrictions. Uber and Lyft geofenced the zones. Boston received encouraging results on its pilot study from Waze data on traffic jams and speeds, field observations, and parking citations. On one block, the share of pick-ups and drop-offs in the travel lane plummeted from 67.9 percent to 31 percent. Average vehicle turnover per hour increased from three to 14 on one block, and from two to nine on the other, a combined 350 percent increase in curb productivity. Parking citations fell by 8 percent. Local businesses responded favorably in a survey, and neither Uber nor Lyft reported any customer complaints or safety concerns associated with the pilot. For future pilot studies, the city recommended painting the curb and establishing more visible signage to reduce violations, and expanding the zones to 60 feet or more to allow vehicles to nose-in to spaces. It also noted that geofencing in ridehailing apps should refer to specific businesses near the zones, not just a whole block [Boston Mayor's Office n.d.]. The city also expressed a desire to tailor future pick-up zones to the needs of the adjacent local business.

Figure 3.6 Boston, Mass., PUDO Zone (Credit: Boston Herald)

Washington, D.C., launched the most extensive pilot study in this area, after chaotic loading in Dupont Circle, a popular nightlife destination with nearly 100 venues in a three-block radius, led to persistent double and triple parking. Low meter rates of $2.30 an hour until 10:00 pm and free until 7:00 am resulted in nearly 100 percent occupancy, and pedestrian counts recorded around 1,000 people per hour [Perez et al. 2019]. The city partnered with the Golden Triangle Business Improvement District, the Alcohol and Beverage Regulation Administration, and other private and public stakeholders to design the pilot. Beginning in October 2017, officials transformed 45 parking spaces into PUDO zones from 11:00 pm to 7:00 am Thursday through Monday. The city had to modify four regulatory ordinances to make the pilot study possible, and it initially struggled to guide drivers to the zones and enforce violations. The three types of restrictions over a 24-hour period, along with atypical hours and days of enforcement, confused drivers. With added towing enforcement and cones to direct drivers, the pilot has generally been seen as a success and is supported by local businesses and ridehailing companies. Using 12 time-lapse cameras, the city observed 0.55 PUDO actions at the curb every 15 minutes during nightlife hours, and 0.62 in the roadway [Perez et al. 2019]. The success prompted the district to work with the non-profit Shared Streets to gather Uber and Lyft data and identify hot spots for PUDO zones across the city.

Encouraged by the Washington, D.C., pilot, in November 2019 Seattle developed its own late night PUDO program, dubbed "catch your ride." The Seattle police and fire departments reported difficulty routing emergency vehicles through raucous nightlife hotspots in the Pike / Pine district in Capitol Hill. SDOT, coordinating with police and the Seattle Office of Film and Music, collaborated with Uber and Lyft to geofence areas with a large number of pick-ups and drop-offs. They designated four block faces with daytime parking within a six-block radius as PUDO zones from 12:00 am to 3:00 am. SDOT marked the zones with permanent, bright orange signs. The parking strategist we spoke to said that while business response to the pilot was mixed, and wayfinding and "ongoing education" for riders could be a challenge, Uber and Lyft were pleased with the program. Seattle Police also reported that people left the area more quickly, allowing emergency vehicles to travel more easily through the corridor.

3.4.4. Converting Existing Uses

3.4.4.1. Create Delivery Vehicle Waiting Zones

As e-commerce activity increases, some researchers have suggested that freight operators will see an increasing need for urban distribution hubs [Nisenson 2020]. In the absence of these facilities, delivery drivers sometimes sort large volumes of packages in the curb lane. In its 2017 curbside management plan, Toronto, Canada, suggested establishing staging zones for delivery vehicles waiting in line to access elevators at high-demand downtown office buildings. This policy aimed to reduce double parking or circling around the block [City of Toronto 2017]. Policies like these would legalize what delivery drivers do instinctively at the curbside.

3.4.4.2. Create Permanent PUDO Zones

Encouraged by the success of its time-limited PUDO zone pilot study in the Golden Triangle, Washington, D.C., expanded these zones citywide. To simplify regulations for confused drivers, the city made the zones permanent. In December 2018, the city launched PUDO zones at 14th and U Streets serving ridehailing, freight, and on-demand delivery vehicles. The District partnered with the non-profit Shared Streets to use aggregated Uber and Lyft data to identify the

100 most active blocks. Combining these data with heat maps of police-reported crash data, taxicab trips, and meter payments yielded 12 candidate zones [Perez et al. 2019]. The District also factored in access to transit stops, local land use, and site observations to determine where it could remove parking. As of June 2020, according to its online map, the District has installed 28 permanent PUDO zones.

DDOT evaluated the pilot through a range of metrics, including traffic counts, TNC and taxi activity, vehicle turnover, average speed of cars, crash data, transit ridership, and parking citations. The department generally rated the pilot as a success. However, it noted challenges with communication and enforcement. Some of the evaluation challenges included difficulty in determining whether delivery drivers were loading or merely parked, and that the Shared Streets data could not specify individual trips, referred to imperfect geographies, and covered only 8:00 am to 8:00 pm. Accessibility advocates also raised issues with Americans with Disabilities Act (ADA) compliance [Perez et al. 2019]. The District hopes to collaborate with Shared Streets to refine the data for future pilots and to address the ADA issues.

San Francisco partnered with Lyft on a three-month pilot from March to June 2018 aimed at improving curb safety along Valencia Street, a hotspot in the city's Vision Zero high injury network (figure 3.7). Lyft examined ride activity in a 30-block stretch from Market Street to Cesar Chavez and identified three blocks that accounted for 27 percent of rides [Schrimmer 2018]. The company conducted an A/B test, geofencing these three blocks for 50 percent of riders, while the other 50 percent used the app in the same way as before. Despite a time imbalance of twice as many observed loading events between 7:00 pm and 9:00 pm as between 9:00 am and 11:00 am, the company chose to simplify the restrictions to 24 hours a day to avoid confusion. Lyft released only limited findings from the Valencia pilot, but it found that loading time increased slightly from 25 to 28 seconds, indicating that the pilot had no positive effect. The company noted that geofencing cannot solve curb congestion issues on its own and recommended that the city dramatically expand loading zone capacity and provide better wayfinding and signage [Schrimmer 2018].

Figure 3.7 Cyclist Conditions on Valencia Street (Credit: San Francisco Examiner)

In another variation on PUDO zones, Toronto recommended in its 2017 curbside management plan that curbs adjacent to fire hydrants double as taxicab stands. Under the proposal, the city would allow taxi activity provided that drivers stayed with the vehicles at all times and immediately left if an emergency vehicle approached the space [City of Toronto 2017].

A live experiment in a related type of loading zone is ongoing as a result of the coronavirus pandemic. Following the closure of restaurants to facilitate social distancing, several cities transformed parking spaces into loading zones for food pick-up [Mutasa 2020]. Seattle created three-minute loading zones marked with blue-and-white signs for takeout customers (figure 3.8). SDOT installed more than 400 of these zones outside local businesses. The agency plans to make some of these permanent and to work with technology companies on navigation apps to guide customers to them. Austin deployed a similar strategy and displayed its food pick-up zones on an interactive, online map. Evaluations of the effects of these temporary spaces on traffic flow and curbside productivity could inform the development of future loading zones.

Figure 3.8 Temporary Food Pick-up Zone in Seattle, Washington (Credit: Seattle DOT)

3.4.4.3. Create Green Loading Zones

Green loading zones (GLZs) designate curb space for fuel-efficient or zero-emission vehicles. Seeking to encourage commercial companies to adopt electric truck fleets, New York City piloted green loading zones reserved for electric commercial vehicles (figure 3.9). A study of GLZs in New York concluded that the program proved more effective than cash subsidies for fleet electrification [WXY Studio 2014]. In addition, fleet managers interviewed said that GLZs could lower operating costs by reducing parking fines, providing time-based delivery assurances, and reducing truck cruising time for parking.

Figure 3.9 Green Loading Zone in New York City (Credit: WXY Studios)

Cities can also allow already fuel efficient transportation modes to use existing loading infrastructure. In 2019, New York City launched a pilot study that allows electric cargo bikes to use commercial loading zones. Such programs could significantly reduce emissions, double parking, and congestion in loading zones; UPS delivers more than 413,000 packages in New York City each day using 6,400 trucks [Colon and Kuntzman 2019]. The pilot is small scale, with only around 100 bikes in comparison to the thousands of trucks operating in the city, and no evaluations have been announced.

3.4.4.4. Reduce ADA Parking Exemptions

Americans with Disabilities Act (ADA) parking placards pose a problem for cities of all sizes. While these are necessary to allow people with disabilities to access destinations, many jurisdictions expressed that their current systems allow too many exceptions and are rife with abuse. State laws in California and Idaho allow drivers with an ADA permit to park in any space for free, forever. In San Francisco, green loading zones have 15- to 30-min time limits, but people with ADA placards can park there for up to 72 hours. The city's curbside management plan recommends pursuing state legislation to remove this exemption [SFMTA 2020]. This would free up parking space for others, including those with disabilities who need short-term parking.

In Boise, the city parking manager reported residents using placards from drivers who had passed away, or eligible drivers receiving two placards and distributing them to friends. Moreover, health care specialists from chiropractors to nurse practitioners can hand out placards for conditions as mild as a sprained ankle. Within the Los Angeles Express Park target zones, 35 percent of parkers displayed these placards, curtailing the program's effectiveness in setting prices according to demand. A study of 13 neighborhoods in Los Angeles found that fewer than 50 percent of drivers in occupied spaces paid the required amount, and 27 percent displayed ADA placards. The placard-holders consumed a stunning 40 percent of all meter hours, in comparison to just 8 percent from lawbreakers. For this reason, the researchers, including Shoup, recommended eliminating free parking for ADA placards [Manville and Williams n.d.]. As an alternative solution, Shoup proposed using the increased meter revenue on subsidies for paratransit or other services for people with disabilities who lack access to a vehicle.

3.4.4.5. Improve Bus Lane Infrastructure

Apart from dedicating an entire block to a bus-only lane, cities can make spot improvements along the curb that require only a few parking spaces. Queue Jump lanes combine a short, dedicated bus lane section with transit signal priority, giving buses the green light to enter an intersection before other vehicles. Modeling shows that this treatment can result in a 3 to 17 percent reduction in bus delay [NACTO 2013]. One standard for Queue Jump implementation is when traffic volumes exceed 500 vehicles per hour in the curb lane.

Bus bulbs extend the curb outward to the edge of the travel lane, allowing the bus to load without pulling over. NACTO recommends a length of 140 feet (or two articulated buses) on high-demand routes and 30 feet for routes with less frequent service for bus bulbs [NACTO 2013]. It recommends that curbside bike lanes should not be dropped but instead be safely routed between the sidewalk and bus bulb.

Transit facilities can become flexible during off-peak hours, adding benefits for freight, on-demand delivery, and ridehailing companies. San Francisco designates some bus zones as parking spaces outside of bus operating hours, marking them with alternating red and black paint. The SFMTA curb management strategy mentions opening these zones to commercial and loading purposes on a case-by-case basis.

3.4.4.6. Turn Parking into Shared Mobility Storage Space

Washington, D.C., and Seattle have taken similar approaches to managing car-share storage at the curb. Beginning in 2011, DDOT required operators to pay a fee for these spaces. In

2014, the District maintained 84 car-share spaces, reserved 24 hours a day. A second permit allowed “point-to-point” car sharing, in which vehicles can park in any space. Similarly, in 2013, Seattle began to issue two types of car-share permits: free-floating ($1,230 annually) and designated space ($300 for an unmetered space and $3,000 for a metered space). The free-floating permit allows users to park in any city space for free, with no time limit [SDOT 2020]. After a pilot study with 350 free-floating spaces, the city expanded the number to 3,000.

A Seattle City Council resolution adopted in 2019 recommended adding 3,000 shared bike and scooter corrals (figure 3.10) by the end of 2020 and imposing fines for users who did not comply with the regulations [Nickelsburg 2019]. Funding would come from the $250,000 annual permit fee charged to shared bike and scooter operators. Placing these corrals along the curb next to intersections would solve two problems at once: bike and scooter clutter, and illegal parking that blocks sightlines near intersections. If there was no space near an intersection, the resolution recommended turning parking spaces into that use. Arlington, Virginia, has already created on-street scooter parking corrals in the curb lane, based on heat maps of historic scooter parking events supplied by the transportation data startup Populus. The Los Angeles Climate and Equity plan recommended converting parking spaces to bike corrals or dedicated car-share parking [NRDC and Nutter Consulting 2018]. Toronto established 36 motorcycle and scooter parking zones in a pilot study and found that 24 of them were heavily used, especially in good weather from April through October [City of Toronto 2017].

Figure 3.10 Scooter Parking in Santa Monica, California (Credit: Transportation 4 America)

Most cities currently charge scooter companies per ride or per scooter, but the city of Omaha is piloting a fee structure based on parking sessions. In collaboration with the digital payments company Passport, the city will set parking rates based on geographic area. The proposal involves geofencing curb parking areas on three levels. In “green” areas, the city will provide incentives for companies to drop off scooters. In “yellow zones” it will require devices to be moved within two or three hours. “Red Zones,” including unsafe areas such as cobblestone streets in the Old Market Arts and Entertainment District, will be auto-enforced, with significant fees for violations.

3.4.4.7. Allow Private Shuttles to Use Bus Stops or Other Restricted Curb Space

In 2014, SFMTA observed dramatic demand for privately operated commuter shuttles. These vehicles crowded the curb and violated existing regulations, slotting into white passenger loading zones, red zones, or wherever they could fit. In response, the city adapted its curb regulations to make way for these vehicles while using the opportunity to earn revenue from their operations. SFMTA conducted an 18-month pilot from August 2014 to January 2016. In the first year of the program, the city earned $4.5 million from permit fees [SFMTA 2019]. Funds mostly went back to the program’s administration and enforcement. Data from the first year showed a reduction in illegal loading behavior, despite a 15 percent increase in ridership. Illegal stops in Muni bus zones fell from 72 percent of all private shuttle stops to 57 percent. The program also shielded residential streets from loading and unloading activity, with a decrease in stops on non-arterial streets from 26 percent to 9 percent. Global Positioning System (GPS) tracking allowed the city to easily find and stop shuttles that drove down restricted streets, cutting this behavior to nearly zero. Undoubtedly, vigorous enforcement contributed to the program’s success. In the first month of the pilot alone, parking control officers issued 2,267 citations worth a total of $360,895 [SFMTA 2019].

In 2017 the pilot study was approved as a permanent program, establishing a network of 125 stops. Some stops are shared with public buses and others are dedicated solely to private shuttles. Service providers pay an annual permit and a fee of $7.75 each time they load or unload. Data-sharing is built into the agreement as well, and providers must transmit real-time GPS tracking information for all vehicles [SFMTA 2016]. Bellevue, Washington, a high-tech hub that sees numerous private shuttles from Microsoft, Amazon, and other large employers, has expressed interest in adopting a similar leasing framework for charging these vehicles for curbside access.

Seattle has a permit-based system in place for the shuttles, which staff say are becoming more popular.

CHAPTER 4. CURB MANAGEMENT TECHNOLOGY

As cities confront new and competing demands for curb space, they aim to collect data, track users, and gain insights into efficient curb space management. For this report, the Urban Freight Lab research team reviewed emerging technologies in this sector. To evaluate the potential use cases and effectiveness of emerging products, we conducted interviews with city planners, curb space managers, and technology company representatives at nine companies and four public agencies. (More information on companies and contacts can be found in the Appendix). In addition, we reviewed marketing materials, case studies, and existing pilot project evaluations.

This report classifies companies on the basis of four broad uses of curb management technology, namely data collection technologies, data-sharing platforms that allow cities to communicate curb regulations, third-party platforms for communicating company data to cities, and automated parking reservation and enforcement tools. Section 4.1 discusses data collection and includes technologies that inventory curb assets or gather real-time information on curb users. In Section 4.2, platforms that enable cities to publically share clean, complete, and machine-readable curb data are described. Section 4.3 examines companies that serve as trusted third parties for communicating curb data to cities without revealing sensitive information. Section 4.4 explores automated parking reservation and enforcement systems. Many of the companies we examined have developed business models that encompass several of these categories.

Pilot evaluations of these products are still under way, and many firms are still positioning themselves in the market, making it difficult for city officials to compare products. However, initial findings reveal a desire on behalf of both public and private actors to change city procurement practices, fill gaps in data from urban freight and emerging on-demand delivery systems, and agree upon a common data standard to facilitate information sharing between cities and operators. We hope that this research will help cities and companies identify areas of mutual interest and explore opportunities to collaborate on efficient curb management solutions.

4.1. Data Collection

Any successful curb management technology rests on a foundation of accurate data. However, cities have identified major challenges to curb inventory. Various agencies hold competing or incomplete data sets, collection efforts require a vast mobilization of staff time and resources, and regulations constantly change.

A fast-growing spectrum of technologies seeks to provide cities with better data. In 2017, researchers identified a range of data collection technologies, including GPS-enabled cameras, time-lapse cameras, license plate recognition devices, traditional manual collection and in-ground sensors [Dey et al. 2017]. We identified specific companies marketing these products and reviewed advances in their methods. In the few years since the release of that paper, technology companies have grown more ambitious in their approach, seeking to construct a complete digital representation of the physical curb that cities can update in, or close to, real time. Advances in machine learning have allowed companies to market enhanced collection products. However, many of the limitations the original authors identified still exist. In the following sections, we discuss the advantages and limitations of the primary curb data collection technologies on the market.

4.1.1. GPS-Enabled Cameras for Digital Imaging

Pittsburgh-based startup Allvision markets a GPS-enabled sensor mounted atop cars [Allvision 2020]. The sensor combines photographic collection with LiDAR (light detection and ranging), a method of bouncing lasers off objects to form three-dimensional images. The company piloted its technology in 2019 in Pittsburgh's strip district, one of the city's most congested neighborhoods (figure 4.1). In a first pass, vehicles recorded the locations of curb cuts, fire hydrants, signs, and other assets. The vehicles looped several more times around the neighborhood on both weekends and weekdays to capture the numbers and type of vehicles (commercial or private). A machine learning algorithm classified vehicles on the basis of shape (i.e., passenger car vs. delivery truck) but was unable to identify moving traffic. Allvision produced a heat map of parking activity, revealing the types and frequencies of violations—for example, whether a private vehicle was parked in a load zone. The company also compared the numbers of vehicles parked in metered spaces before and after construction to estimate the effects of construction on revenue.

Figure 4.1 Allvision Sensor in Pittsburgh, Pennsylvania (Credit: Lidar News)

While Allvision demonstrated that it could inventory an entire neighborhood in a matter of days, this technique proved capital intensive and difficult to scale. In addition, deep "urban canyons" disrupted GPS signals, making the technology unsuitable for the foot-by-foot accuracy needed to pinpoint locations along a blockface. Parked cars could also obscure signs, leading to gaps in the data. Moreover, curb regulations changed so frequently that up-to-date data collection would require numerous passes with the survey vehicles. Allvision hopes to ultimately hand off this task to public works vehicles such as buses or street cleaners and solely manage the platform that interprets the data.

4.1.2. Real-Time Data Collection (Sensors and Cameras)

Commercially available real-time collection methods range from sensors sunk to grade in parking spaces, to dome sensors mounted on parking meters, to cameras affixed to nearby buildings or light poles. Numina, a Brooklyn-based startup founded in 2016, has installed cameras equipped with machine-learning capabilities in 20 cities around the U.S., Canada, and Europe, and it has completed a pilot with the City of Jacksonville, Florida (figure 4.2) [Numina n.d.]. The cameras record counts and shapes and then plot these to image coordinates. For curb research, Numina can measure dwell times for passengers and freight, and the company can track multimodal traffic and navigation around obstructions, aiding in before and after studies of new construction or other interventions. Numina is participating in the 2020 Transit Tech lab challenge sponsored by the New York City Port Authority, New York City Department of Transportation, and New York Metropolitan Transit Authority, with the goal of better understanding pedestrian movements around bus stops and car parks.

Figure 4.2 Numina Sensor on a Light Pole (Credit: Numina)

Cleverciti, a sensor technology company with installations in 200 cities worldwide, has recently entered the U.S. market in eight cities. Cleverciti sensors attach to light poles, drawing power at night and storing it in batteries for daytime use. Cameras record parking events, process information about dwell times and vehicle lengths onboard the device, and broadcast it to dynamic messaging signs, online dashboards, or mobile apps through either a cellular network or wi-fi connection. The company claims a 98 percent accuracy rate, based on manual audits, for determining occupancy, and notes that the sensors operate in nearly any climate conditions from Dubai to Banff, Canada. Sensors classify all vehicles 22 feet long or below as passenger vehicles; anything above this length is classified as a commercial vehicle. The company cannot currently identify passenger vehicles being used for commercial purposes, but it is developing machine learning algorithms to identify company logos on the sides of vehicles.

Verizon launched a similar video-based “parking optimization platform.” Video cameras record cars parking or pulling away from curb and send data to the cloud via wi-fi for real-time analytics. The devices collect volumes, turnover, revenue, dwell times, violations, and occupancy data. Verizon maintains an application programming interface (API) for integrating with navigation apps, reservation apps, or smart meters, and sells dynamic messaging signs [Verizon 2019]. The company has conducted two pilots, in Kansas City and Washington, D.C., using the MapQuest application to display available parking spots.

Many cities are still hesitant to partner with real-time data collection companies because of the limited accuracy and high cost of their methods. Unexpected situations such as passing streetcars (in San Francisco) and heavy snowfall (in Boston) easily confound most in-ground sensors, while battery life plummets in cold conditions [Dey et al. 2017]. Some cities, such as Seattle, prohibit companies from drawing power from light poles, forcing them to use batteries that must be manually recharged. Camera-based sensors generally have difficulty distinguishing double parking events from ordinary in-lane stops (for example, at a traffic light), passenger vehicles being used for commerce, and vehicles parked in unmarked spaces. In one pilot, Boston planners said every two parking spaces required its own sensor to achieve the required accuracy. In Washington, D.C., the District Department of Transportation estimated the cost of sensors for its 18,000 metered parking spaces to fall between $2.25 million and $4.8 million, with added annual operating costs of between $1 million and $3.2 million [Dey et al. 2017]. Likewise, San Francisco curb managers deemed the 11,917 real-time sensors (1.45 per parking space) pilot tested in SF Park too expensive for long-term use.

Surveillance ordinances in some cities also limit the use of sensors and cameras. Citizens do not yet broadly agree on the use of computer visioning techniques, and they may feel they are being “watched” or that cities can identify personal details as they monitor the curb. Seattle, for example, maintains surveillance ordinances against camera technology or license plate recognition (LPR), unless information is processed onboard the sensor unit. In 2007, the Minnesota Supreme Court ruled red light cameras unconstitutional, and the decision also blocked the city of Minneapolis from using LPR for curb enforcement. Cleverciti says it avoids collecting any information about pedestrians in loading zones, even though this information might help distinguish double parking or other behaviors, to ensure that it complies with strict privacy standards.

Boston planners have evaluated a range of camera and sensor technologies, and they have concluded that it is still cheaper to task interns with manual on-street data collection. They noted that every company struggles to record dwell time and double-parking events, especially for unmarked spaces. In 2013, the Mayor’s Office of New Urban Mechanics in Boston installed 330 sensors from the parking software company Streetline in the city’s innovation district. The city planned to use real-time data to adjust parking policies and make the data available to researchers [Boston Mayor’s Office 2017]. Planners noted the sensors were difficult to install, incurred prohibitively expensive data charges of $14 per hour per space, and yielded data that were not accurate enough for public consumption.

4.1.3. Enhanced Manual Collection

The most market-ready technologies appear to be enhancements to the manual collection process. Coord, a San Francisco-based curb technology subsidiary of Alphabet, deploys an army of human data collectors equipped with “Collector,” the company’s augmented reality smartphone app (figure 4.3) [Coord n.d.]. The app, free for anyone to download and use, collects images of curb assets including freight loading and passenger pick-up/drop-off zones, street parking signs, bus stops, taxi stations, fire hydrants, and more. The device automatically references the position of these objects along the curb. Coord can also read license plates to determine whether vehicles are following regulations, for example, finding a commercial vehicle parked in a passenger loading zone (some cities prohibit this practice through surveillance ordinances). Coord customizes the app to respond to individual cities’ methods for communicating curb rules. Firms or agencies can send the data they collect to Coord, where a proprietary “rules engine” interprets features such as parking signs, fire hydrants, and paint and determines which regulations apply. As of March 2020, Coord’s inventory includes 15 cities, with a goal of reaching 100 by 2021.

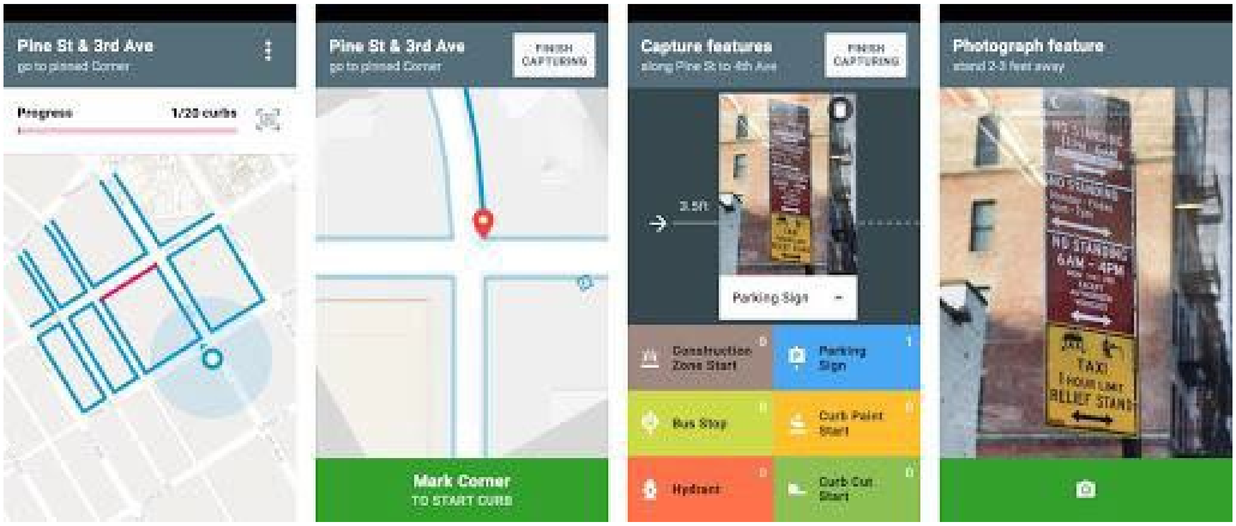


Figure 4.3 Coord’s Collector App (Credit: Coord)

Another organization, the non-profit Shared Streets, aims to improve the efficiency and accuracy of curb data collection. The nonprofit is pilot testing technological improvements to the manual data collection process in San Francisco and Seattle. The method involves measuring curbs with an iPhone camera and a small computer called a Raspberry Pi affixed to a measuring wheel (figure 4.4). The parts cost around $100 and are designed to be easily assembled. The computer and iPhone sync via a wi-fi connection to automatically match photos to measurements. The system still requires manual data entry; the data collector must view the photos and, with the help of Shared Streets' interface, enter attributes for each feature [Shared Streets 2020].

The Coord and SharedStreets systems provide a high degree of accuracy and can still be completed relatively quickly; Coord can survey 0.9 miles of curb per field collector hour. Using the "surveyor" app developed by Coord, a five-person team from the engineering firm AECOM collected data on 101 miles of Philadelphia curbs over seven days [Coord 2019]. However, the Coord and Shared Streets systems cannot capture moving vehicles or pedestrians, nor can they provide real-time data.

More information about common variables that cities collect on the curb can be found in the Appendix.

Figure 4.4 Shared Streets Curb Wheel (Credit: Shared Streets)

4.1.4. Data Integration and Processing

All of the companies can integrate the information they collect with data from city geographic information systems (GIS) databases or spreadsheets. They also partner with large engineering firms such as AECOM, Kimley-Horn, and Stantec, as well as older companies such as Quality Counts, that conduct manual curb inventories.

Many emerging companies classify their data through machine learning algorithms. Numina runs its algorithm onboard the sensor and uniquely trains each device on the environment in which it is installed. The machine recognizes the major axes of an object and its contrast with surroundings, placing it into one of several categories. The algorithm can currently differentiate bicycles, people, cars, trucks, and dogs. This process is extremely energy-intensive and requires a hard connection to a power source. As a newer company, Numina lacks data on the effectiveness of its visioning techniques.

Current computer vision techniques and algorithms are still largely inadequate for categorizing the data. To the best of our knowledge, no company has fully automated curb data collection and processing to date. The algorithms still demand continuous fine-tuning to overcome obstructions, high winds, or other disruptions [Dey et al. 2017]. While they are developing AI and machine learning approaches to measure to the curb, parking consultant IDAX Data Solutions [IDAX 2020], based in Renton, Washington, says that manual reduction of video recordings is still more reliable than the automated methods.

With rapid advances in machine learning technology, however, these limitations could soon be overcome. Washington, D.C., saw encouraging results in a Penn Quarter and Chinatown pilot study using an “asset-lite” approach to parking [Dey et al. 2016]. The city sought to deploy the minimum number of sensors possible to reduce costs, filling in gaps with predictive modeling. Six trailers with up to four cameras each circled the study area every week, identifying unusual patterns in occupancy and informing the best locations to place sensors. Data scientists measured the effectiveness of the sensors by the correlation between sensor-recorded occupancy and meter payments. They used the historical gap between average daily occupancy and meter payments to predict future demand for June and July 2015, with root mean squared errors (RMSE) of 6.3 percent and 3.9 percent for their two study areas [Dey et al. 2016].

4.2. Standards and Applications for Communicating City Data to Operators

Most cities are eager to publicize the data they collect but lack the technical expertise to do it. Cities hope to better communicate their curb data sets, stored in various formats with different agencies, to private sector mobility companies and delivery services. Many of these companies operate across the country, encountering different regulations and data formats in every city. This heterogeneity leads to confusion and lawbreaking.

Nonprofits such as the Open Transport Partnership (OTP) and the Open Mobility Foundation (OMF) hope to make digital curb data open source, free, standardized, and widely accessible to the public [Open Mobility Foundation 2020]. A core mission of the public-private partnership Mobility Data Collaborative (MDC), whose members include Uber, Lyft, and Spin, is to promote standardized definitions for micro mobility data [Mobility Data Collaborative n.d.]. Coord contributed toward this goal with its “open curbs” map, launched in 2019. Cities can publish their data on Open Curbs, while retaining ownership rights to data that consultants collect [Coord 2020]. Such technologies not only promote government transparency but support the business models of curb management startups, many of whom ingest data from a variety of sources [ITF-OECD 2018].

Two leading formats have emerged for data standardization at the curb. The Los Angeles Department of Transportation championed the Mobility Data Specification (MDS), a standardized method for encoding and communicating information about shared mobility systems. MDS currently allows cities and companies to exchange data on shared devices such as dockless bikes and scooters, but it is designed to expand to cover TNCs, autonomous vehicles, and other emerging modes of transportation. More than 80 cities, including Los Angeles, Austin, Santa Monica, Seattle, and San Francisco, use components of MDS. The nonprofit Open Mobility Foundation (OMF), which includes 26 member cities, oversees this standard [Open Mobility Foundation 2019].

Modeled off the General Transit Feed Specification (GTFS) and General Bike Feed Specification (GBFS), common languages for publicly sharing city data about transit and bicycle trips, MDS consists of three APIs for both governments and mobility providers. The Provider API allows government agencies to query data from mobility companies, while the Agency and Policy APIs encode information about rules and regulations that agencies wish to distribute to companies. Cities can query the MDS Provider API to find where bikes and scooters tend to cluster on different blockfaces. MDS communicates the coordinates from GPS systems inside the shared mobility devices [Open Mobility Foundation 2020]. As mentioned previously, GPS signals cannot achieve the foot-by-foot accuracy needed to make useful determinations about curb use within a particular block, especially in downtown urban canyons. Through the Policy API, cities can communicate scooter speed limits, restrictions on riding in specific areas, and other regulations. While cities can attach these rules to specific geographies, most features are polygons for areas larger than a parking space (for example communicating to users that they cannot ride within a park or special district). Lacuna Technologies, a Palo Alto-based company, is exploring curb-specific use cases for the policy and geography APIs to allow cities to continually broadcast curb regulations in machine-readable format [Lacuna Technologies n.d.]. Shared mobility devices, ridehailing vehicles, and smartphone applications could then query the API for these rules and respond to real-time changes in parking availability or time limits. Lacuna staff name three components of a successful curb API:

- Represents physical assets
- Communicates policies
- Provides occupancy and reservation data to users.

In 2019, the Open Transport Partnership's geographic data-referencing project Shared Streets launched CurbLR, which provides another standard format in which cities can publish their curb data. Funded by Bloomberg Philanthropies and maintained by the National Association of City Transportation Officials (NACTO) and Open Transport Partnership, the Shared Streets system is open source [Open Transport Partnership 2018]. It works through "linear referencing," generating line segments that represent streets and points that represent intersections (figure 4.5). This creates a level of abstraction on top of the original data, allowing companies and cities to protect their proprietary base maps [Shared Streets 2018]. Another advantage of linear referencing is the ability to refer to more specific segments of curb, measured by feet from an intersection.

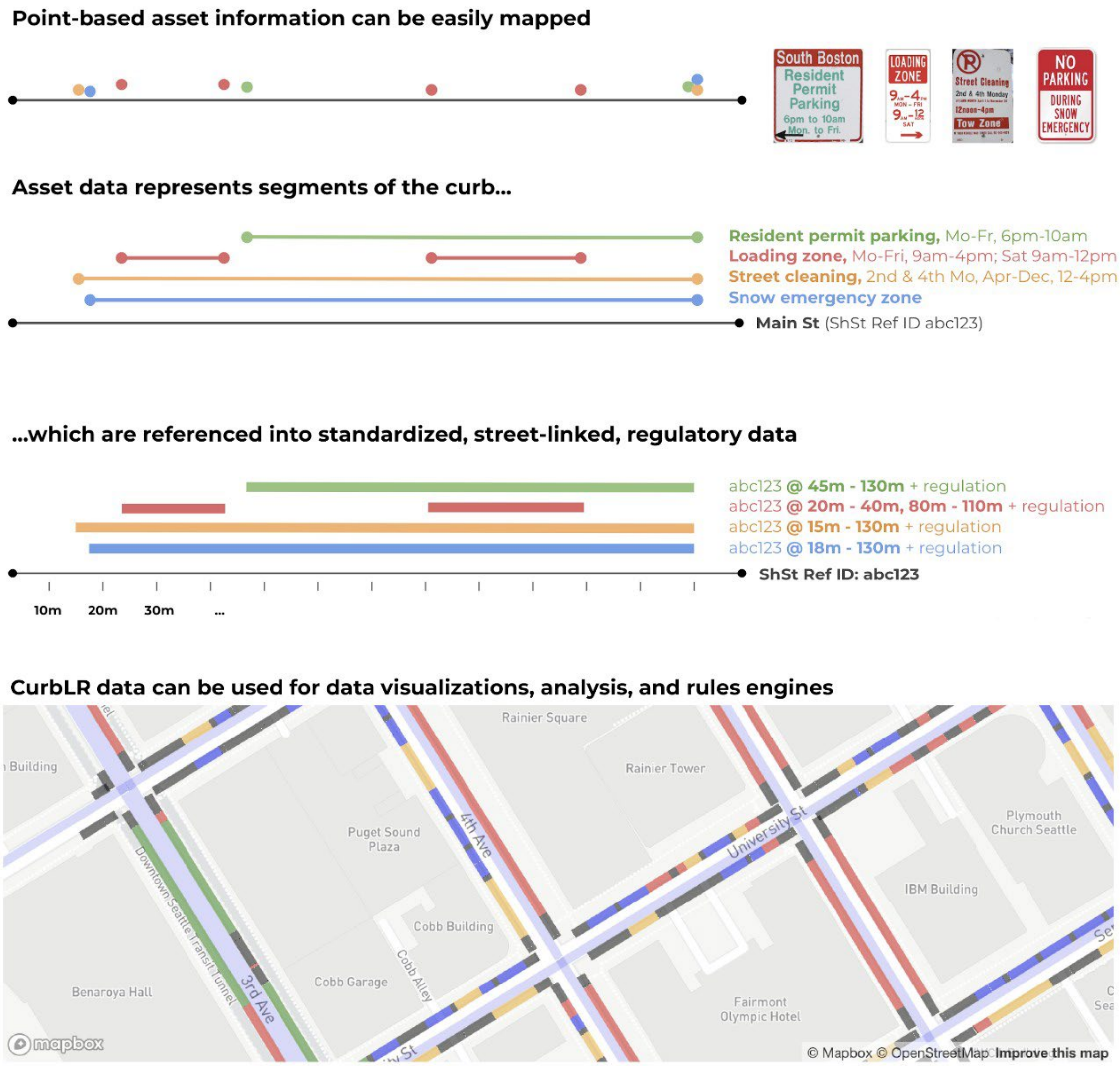


Figure 4.5 CurbLR Linear Referencing System (Credit: Shared Streets)

CurbLR supplements the Shared Streets segments with another layer of information, a standardized list of curb regulations. CurbLR fields store data on allowed uses, physical characteristics, and pricing. Currently, the pricing data structure can store flat or tiered prices (such as $1 for 1 hour, $2 for 2), and conditions (vehicle type, permit, or other variable that affects price), but not enough information to facilitate dynamic pricing models. Another field assigns a “priority” to overlapping curb functions. If a segment of curb serves multiple functions at the same time, this field assigns a number indicating which one takes precedence. For example, a space that functions mainly as a commercial loading zone but allows passenger pick-ups during limited hours could have a priority of four for the first rule and two for the second, where a larger priority level takes precedence. Proposed improvements to CurbLR include adding more priority levels to make the data more legible and including a “status” field to highlight where a regulation sits in the regulatory process, such as “proposed,” “pending,” or “active [Shared Streets 2019].”

Some technology companies are already standardizing existing city curb data. IDAX has worked with the Seattle Department of Transportation to convert two years of citywide sensor data on parking occupancy and events in Seattle into CurbLR. Coord maintains its own Open Assets Curb Specification, a standard data format with rules for storing information about physical assets, such as fire hydrants, bike racks, and signs, in the curb lane or sidewalk. Like CurbLR, this format includes linear references for each curb segment. Consultants have collected curb data in this format for 15 cities. After cities collect the data, Coord can work with them to publish the results in CurbLR, which adds information about spatial and temporal regulations for particular stretches of curb.

Other companies market additional platforms to help cities communicate standardized, machine-readable data to operators. Originally designed to translate city regulations for autonomous vehicles (AVs), INRIX “curb rules” provide a platform to which cities can upload their data in any format, for free [INRIX 2020]. If cities have incomplete curb data sets, they can contract with INRIX for manual collection to fill in the gaps. INRIX earns its revenue from selling custom reports of the aggregated city data and add-on services. INRIX converts these data into CurbLR and makes them available via a free API for operators to integrate into apps or messages to drivers or users. TNCs, AV startups, and car manufacturers including Jaguar Land Rover access the data to research rules in various cities before they conduct pilot projects.

In a similar fashion, Coord Analytics helps shared mobility companies avoid parking citations by importing citation data from cities and adjusting vehicle routing accordingly. The Curbs API allows companies to build their own applications for this purpose. For example, a shared mobility company in New York City gets a reminder from Coord every time the city changes a parking regulation. Taxi and transportation network companies can alert their drivers if they idle for too long in a load zone. Future plans for Coord’s Curbs API include bike share integration and automated access to tolling and parking prices.

4.3. Third-Party Data Sharing from Operators to Cities

Curb communication is a two-way street, and most platforms that contract with cities to standardize and communicate curb rules also help municipalities collect curb-use data from transportation network companies (TNCs) and other shared mobility operators. Cities have struggled to capture the vast streams of data from mobility-as-a-service providers because those companies want to protect their proprietary base maps or identifiable user data. Moreover, many curb users, such as on-demand delivery services and parcel delivery companies, do not have to provide data. By aggregating and anonymizing proprietary data, this segment of the mobility technology industry serves as a trusted third-party broker of curb information.

Shared Streets and a growing cluster of for-profit companies reformat data from mobility companies and furnish them to cities in a user-friendly format. San Francisco-based startup Remix collects data from TNCs such as Uber and Lyft and displays them to city staff on user-friendly dashboards [Remix 2020]. Another San Francisco company, Populus, is adapting its mobility manager platform, which ingests and displays data on shared bikes, scooters, and cars, for curb data [Populus 2020]. The company hopes to acquire anonymized data from Uber on pick-ups and drop-offs, dwell times, and routes to the curb. One possible application of these data could be to merge them with digitized curb maps, such as those created by Coord, to map the Uber data to curb assets. This would show where operators are complying with regulations. Lacuna provides technical support and security features for cities using open source systems such as the Mobility Data Specification (MDS) or CurbLR.

Mobility providers require these platforms to anonymize and aggregate curb data to protect user data and proprietary information. In pilot tests with Toronto, Washington D.C., Minneapolis, Pittsburgh, and Los Angeles, Shared Streets merged Uber and Lyft pick-up and drop-off data before encoding them in CurbLR. This protected user data and allowed Shared Streets to provide more detailed information—pick-ups and drop-offs down to 10-meter segments of curb—than cities could request on their own. Some cities are investigating uses for the Shared Streets curb data, but they are concerned that the data currently describe a patchwork of hotspots, rather than a complete picture of their curbs.

4.4. Smart Parking Reservation

Smart parking reservation technologies allow drivers of trucks and passenger, on-demand delivery, and rideshare vehicles to find and reserve available parking spaces through an app or website. Parking prediction and reservation technologies help save time, reduce double parking, and curtail cruising for parking and consequently vehicle miles traveled (VMT) and associated emissions [Shoup 2007].

CurbFlow, a San Francisco-based company that describes itself as “air traffic control for the curbside,” [curbFlow n.d.] has established an app-based loading zone reservation system for commercial vehicles or passenger vehicles used for commerce. Part of the company’s vision, according to staff, is to replace parking spaces with commercial loading spaces to help cities adapt to growing loading needs. DDOT tested the system in its "Next Innovation in Curbside Management Program." The city removed parking for 12 weeks at nine locations to create flexible curbFlow loading zones. Delivery trucks or private vehicles "acting in a commercial manner" registered with curbFlow to use the app for free. They could reserve curb space 30 minutes in advance by checking in or out of a mobile app. The pilot evaluation focused on four metrics: safety, utilization, productivity, and equitable access [District DOT 2019]. The report found that the number of vehicles double parked in the study area dropped by 64 percent [Pyzyck 2019], and 85 percent of drivers rated their satisfaction with the system at least a 9 of 10.

In a 12-month Columbus pilot completed in June 2020, curbFlow collected freight operator data and partnered with the city to designate eight loading zones in delivery hotspots. The pilot focused on on-demand delivery with around 90 percent of drivers working for services such as DoorDash or GrubHub. Of participating drivers, 83 percent reported saving at least 2 minutes per pick-up or drop-off. The majority of drivers said they would have illegally or double parked without curbFlow's zones, indicating that the pilot prevented an estimated 9,700 illegal parking events [curbFlow 2020].

The company still faces challenges with enforcement and access to infrastructure in the public right-of- way, such as light poles. Currently, the reservation system relies on the city for enforcement, making it financially difficult for cities to partner with it. curbFlow has made attempts at addressing this issue by deploying human "ambassadors" at the curb near spaces in its D.C. pilot to inform curb users of regulations (figure 4.6). However, city officials are concerned about how this solution will scale beyond a few blocks. curbFlow representatives acknowledged that higher fines and stricter enforcement would enhance the value of the reservation system for operators. The company said it is not possible right now to take on a broader enforcement role but suggested that better signage, ground markings, branded barricades, and bollards could enhance the visibility and authority of loading zones. The company also developed an enforcement app for Columbus that alerts police officers if the wrong vehicle parks in a curbFlow space.

Figure 4.6 curbFlow Pilot in Washington, D.C. (Credit: curbFlow)

Recently, other technology companies have launched competing reservation services. In May 2020, Lacuna launched a digital platform that allows cities to remotely allocate reservable curb space. Cleverciti debuted its sensor-based smart parking system for 770 parking spaces in Cologne, Germany, as part of a Smart City initiative aimed at reducing transportation emissions. Drivers receive occupancy information and directions to the nearest open space from dynamic messaging signs and a mobile app. In June 2020, Coord chose four cities—Aspen, Colorado; Omaha, Nebraska; Nashville, Tennessee, and West Palm Beach, Florida—to participate in a “smart zones” pilot test of a reservable, app-based commercial vehicle loading zone program. One of the factors the company considered in selecting the cities was their willingness to charge fleets for using the zones, a means of internalizing the underpriced real estate along the curb [Musulin 2020].

Some companies, including Bosch, Conduent, and Streetline, are employing machine learning algorithms to predict parking space availability [Conduent 2020, Streetline 2020]. In Bosch’s “community-based parking” model, ultrasonic sensors placed on the vehicle identify open spaces [Bosch Global 2020]. The sensors transmit these data to the cloud, where artificial intelligence draws upon past data such as weather readings, historical curb occupancy, and regulations to determine whether a space will be free when a driver arrives. The system communicates these data back to vehicles looking for a space. Through Streetline's Parker app, users can access information on pricing, hours, time limits, and payment methods. On Streetline's ParkSight platform, cities can view occupancy reports at the block level, number of citations in a given neighborhood, and hourly parking space occupancy [Schwartz 2012]. Conduent's "Merge" platform uses machine learning to maximize parking revenue based on data collected by the company's sensors. The platform can provide trip planning and parking guidance to consumers, using a predictive approach based on samples of historical parking data [Conduent 2019]. While intriguing, few of these technologies have proved to work over the long term. Boston DOT, NYC DOT, and District DOT attempted pilot tests using sensor data and prediction algorithms, and all three agencies reported excessive glitches and false positives that made the products unsuitable for the public [Dey et al. 2018].

With further refinement, smart reservation systems could also make more efficient use of other curb functions, such as transit and freight loading. Lacuna Technologies is working on extending the use of GTFS to better predict bus arrivals at stops, so that bus stops can serve other curb functions when not in use. Lacuna hopes to pilot this approach this summer in Los Angeles' Arts District. Improvements in curb reservation technologies could also simplify routing and cut expenses for time and fuel for transit agencies and freight companies. The Urban Freight Lab (UFL), in partnership with Pacific Northwest National Laboratory (PNNL), is developing a parking prediction app designed to help delivery drivers find available curb spaces in dense urban areas.

Reservation technologies could also provide a massive new revenue stream for cities. Passport (2020) has ongoing pilot tests in Charlotte, North Carolina, Detroit, Michigan, and Omaha, Nebraska. These cities plan to use the platform to charge all micromobility modes for using curb space. In addition to overseeing curbside pricing and payments, Passport will collect data on scooter supply, demand, distribution, and use [Pyzyk 2019]. On its website, Passport envisions a future in which commercial delivery vehicles, including emerging on-demand delivery services that provide service in smaller vehicles, such as AmazonPrime vans, could seamlessly reserve and pay for curb space through an app.

A further extension of smart reservation systems could be autonomous parking. Working with Daimler, Bosch has pilot tested automated valet parking for Mercedes Benz vehicles in garages. German regulators approved tests that make this feature the world's first driverless parking technology to achieve Level 4 automation, meaning it can operate on its own with a human supervisor as a backup, although it will likely be some time before this technology could move onto the street and happen safely [Korosec 2019].

4.5. Automated Enforcement

By improving data collection, standardization, and dashboards for cities and consumers, some companies are seeking the highest level of technological efficiency for the curb: fully automated enforcement. Instead of customers paying a meter, sensors or license plate readers could immediately charge vehicles for parking. These technologies automate revenue collection and rapid policy changes, enabling dynamic pricing pilot tests such as those conducted in San Francisco and Los Angeles [Ghent 2018].

With $58.5 million in funding from five investors, including Bain Capital, MK Capital, Grotech Ventures, NEST-TN and Relevance Capital, Passport is a leader in this business [Hicks 2019]. The company claims that 16.7 percent of commuters use apps built into their vehicles for everyday tasks, such as buying coffee or paying for gas, and that parking payments should integrate into apps consumers use in the vehicle. The company aims to create an environment in which "a driver can find, park, and pay for a parking space directly through their connected vehicle powered by an end-to-end platform that manages rules, rates and restrictions of individual cities" [Passport 2020]. This vision remains unfulfilled at this point.

In the "Merge" platform that enables reservations, Conduent aggregates information on meter numbers, zone numbers, vehicle registration markings, locations, payment methods, time purchased, overtime parking, and amounts paid, and presents the data to cities in a dashboard. Parking managers can set hourly rates or policies for individual spaces from within the system and can communicate the changes on the street through dynamic messaging signs. The Merge system powered LAExpress Park and ParkDC [Ghent 2018], two of the largest dynamic pricing pilots [Conduent 2019].

Cleverciti has developed the "Cleverciti Card," a battery-powered, credit card-sized device that freight operators can obtain when they register for permits to use loading zones. The device sits dormant on a vehicle's dashboard. When the driver stops, the card activates and transmits credentials (such as license plate number, driver name, and carrier) to a city database. Cities can charge for parking by the minute to the card, or check for time-of-day or zone-based restrictions on the vehicle's parking privileges. Sensors can flag vehicles over 22ft without a card and transmit this information to parking enforcement officers via apps or their handheld devices. This system has limited potential for on-demand delivery drivers, however, because they often use passenger vehicles and have brief dwell times.

A highly speculative, but intriguing, approach to automated curbside management comes from Sidewalk Labs, the Alphabet subsidiary that developed the Coord platform [Sidewalk Labs 2020]. The company's Street Design Guidelines, drafted as part of a plan for a smart urban neighborhood in Toronto (since cancelled because of economic uncertainty during the COVID-19 pandemic), include a step beyond dynamic messaging signs: dynamic curb markings [Ng et al. 2019]. The proposal does away with paint, signage, and raised curbs in favor of light emitting diode (LED) tiles that can change colors to signal different uses. With the "flick of a switch," the curb could become a transit lane during rush hour, a public space during off-peak hours, and a loading zone at other times of day (figure 4.7). This proposal provides the ideal degree of flexibility many cities seek for their curbs but would require major investments in infrastructure.

Figure 4.7 Sidewalk Labs Street Design Principles Schematic (Credit: Sidewalk Labs)

To date, no cities have successfully implemented real-time parking management over the long term using these technologies. Those that have tried, such as San Francisco and Los Angeles, have eventually moved to periodic price adjustments throughout the year [Ghent 2018, SFMTA

2014]. Cities struggle to implement automated enforcement because of political issues around privacy and surveillance, as well as entrenched parking management unions. Companies are seeking ways to improve their data collection technology to maintain privacy, by, for example, blurring video feeds to obscure faces. As sensor technology improves and more companies enter the market, costs could drop, making real-time management more feasible. Standardized methods for anonymizing data, such as the CurbLR feed described in Section 4.2, could also change the public perception of these methods.

4.6. Key Takeaways

Free and open curb data benefit both cities and companies. Many startups' business models depend on aggregating information from a variety of curb studies and then adding analytics capabilities. Currently, however, many private mobility operators and TNCs are reluctant to share data, citing concerns about user privacy and proprietary information. Agreeing on a common data standard will help businesses to build stronger platforms and cities to communicate public information to their citizens and operators who use the curb [Dey et al. 2016]. Open source code will allow cities and companies to log issues with the data they receive and assist each other in developing more usable formats. The ultimate vision of nonprofits and public-private partnerships in this area is to make curb data easily accessible and free for members of the public.

The existing business models of curb technology companies are highly speculative and unproven. Their clients at municipalities have noted a number of technical issues, including incomplete or inaccurate data, unexpected events that easily fool machine learning algorithms, and data processing inefficiency. Officials at some cities commented that many curb management startups approach them, but most propose contracts that do not give cities enough ownership over the data or satisfy their legal and procurement requirements. Small startups often do not meet city procurement requirements for partnering with minority or other disadvantaged businesses. In addition, public concerns over surveillance and privacy, as well as entrenched public employee unions, block attempts at automated enforcement. Some cities have estimated that it will take at least several years for companies to overcome these concerns. Technology competitions and accelerators, such as Transit Lab's curbside management challenge in New York City, aim to shorten this timeline by closely aligning city goals with company proposals.

Urban freight represents a significant gap in available curb data. Cities have no way to track small, on-demand food or beverage delivery services such as DoorDash or UberEats, Amazon vans, UPS, FedEx or other freight companies. Yet cities need those data to make accurate decisions about curb management. Isolated pilot tests, such as the Columbus curbFlow loading zone pilot and the Urban Freight Lab's Belltown delivery pilots, have attempted to capture dwell times and vehicle information through cameras, in-ground sensors, or app-based reservation systems. However, these have not been scaled up to a citywide approach. In one attempt to solve this issue, Shared Streets hopes to expand its partnerships, which currently cover only TNCs, to freight companies. The non-profit already provides a platform for aggregated, street-linked data about curbside pick-ups and drop-offs for ride-hailing and it is considering launching a similar tool for freight. Such a platform could allow freight operators to more efficiently route their vehicles.

Many technologies exist to inventory curb assets, but it is technically difficult to track curb users and raise tracking privacy concerns. Digital license plate technology provides a way to track users, but it raises privacy concerns and runs afoul of surveillance ordinances in many cities. Sophisticated data collection technologies such as those developed by Coord or Allvision have difficulty identifying moving vehicles. Other technologies, such as parking occupancy sensors, can do this, but they are difficult to deploy on a large scale. Linking users to information about their permissions and payment of fees would help cities better manage the curb in real time.

In the current climate, for cities to gain complete pictures of their curbs, they must collect data frequently by using both digital and analog methods. Curb data collection requires a higher level of precision and frequency than surveys of other city assets. No technology can currently provide accurate foot-by-foot measurements without relying on human data collectors. However, digital tools can help these people cover more ground and conduct more frequent surveys to continually update ever-changing curb regulations.

While most cities are still working on data collection, planning and operating the curb promises to be the next frontier of competition among technology companies. Most companies are seeking to move away from data collection and position themselves as platforms for communicating information between cities and operators.

The ultimate technological vision of the curb is the "self-coordinating" or "self-communicating" curb. Cities interact with too many mobility operators and change their regulations too frequently for staff to communicate new curb rules to representatives of each company. Technology companies envision a city in which curbs send information about their rules to drivers or autonomous vehicles, and those users automatically adjust their behavior. For example, the MDS Provider API allows cities to dynamically communicate curb rules to shared mobility operators. Coord, Passport, and other companies have developed platforms and apps that are moving in this direction. However, full automation of the curb remains a distant reality, as it will depend on fully developed automated payment systems, digitized curb maps, and accurate sensor technology.

CHAPTER 5. POLICY RECOMMENDATIONS

This study completed a review of emerging urban policies developed in response to growth and of existing curb management policies and regulations. The results suggest that agency goals and daily enforcement practices broadly vary from city to city. Many agencies would be well-served to examine these current policies with the emergence of new mobility and on-demand delivery, and advances in technology and data collection. In this section, two versions of a conceptual curb management policy framework based on best practices are described. The first framework provides general agency guidance while the second framework details guidance pertaining to the use of evolving technologies.

The authors of this study recognize that the format and content of each agency's policy statement will vary and depend on local practices and preferences. For this reason, these recommendations aim to shepherd each agency through the policy development process by providing specific questions and guidelines for each policy component.

5.1. Policy Recommendations (General)

The policy recommendations presented here include the components of policy purpose, scope, policy statement, responsibilities, procedures, and evaluation or measurement of success (figure 5.1). These broad categories are common in policy guidance documents and supporting literature [UCSC 1994, Tunny 2021, University of Bath 2021, CQUniversity n.d.]. While each agency will tailor a policy to fit its individual needs, these broad aspects should serve as the foundational pieces of any policy statement.

Table 5.1 Policy Content Components

PURPOSE	Defines the overall outcome of the policy.
SCOPE	Identifies to whom and to which parts of the agency the policy applies.
POLICY STATEMENT	Defines broad principles of expected action and standards.
RESPONSIBILITIES	Establishes actions and positions responsible for ensuring policy is implemented and reviewed to evaluate its effectiveness
PROCEDURES	Addresses how the policy is to be implemented.
EVALUATION / SUCCESS MEASUREMENT	Describes repercussions for when policy violations occur.

5.1.1. Purpose

A purpose statement will identify the outcome or outcomes that the policy intends to achieve. For example, the purpose in the context of this study may be to establish a *"fair and enforceable curb management system."*

Questions to consider:

- What outcome does this curb management policy seek to achieve?
- What is the main reason for this policy within the agency?

Guidance:

- Describe the overarching purpose in one or two sentences.
- The content should be easily understood to a lay audience.
- Consider linking this purpose to the agency's transportation or land-use goals.

5.1.2. Scope

The scope will identify to whom and to which parts of the agency the policy applies. For larger agencies with multiple departments, the scope should be expected to be more complex, given the multitude of parties involved and their respective interests.

Questions to consider:

- To whom does this curb management policy apply (i.e., agency and/or users)?
- Who is / would be impacted by changes to how the curb is managed?

Guidance:

- Potential users include, but are not limited to, the general public, delivery drivers, transit operators, business owners, homeowners, parking license issuers, and law enforcement.

5.1.3. Policy Statement

A policy statement will identify the principles of expected action and standards and will establish the framework for decision-making.

Questions to consider:

- What are the expected agency actions based on this curb management policy?
- What are the standards of this curb management policy?
- How long will this curb management policy be in effect?

Guidance:

- Recognize that curb management means different things (i.e., parking, ridesharing, freight, transit, micromobility, parklets) to different people.
- Consider how curb management needs vary depending on location (i.e., residential areas, business districts, industrial areas).
- Group common topics together, as needed.

5.1.4. Responsibilities

In the policy, a section focused on responsibility will be used to identify the positions accountable for ensuring that the policy is being administered and list the appropriate actions to be taken.

Questions to consider:

- Who are responsible for the policy aspects?
- What are the responsibilities of each entity?
- How will potential conflicts be resolved?

Guidance:

- Potential policy developers include, but are not limited to, the department of transportation, public works, law enforcement, elected officials, IT, general public, delivery drivers, business owners, parking license issuers, economic development, and transit planning.
- Consider the creation of a “deep,” rather than “flat,” organizational structure to deliver efficiencies in the decision-making process.

5.1.5. Procedures

In the procedures section, the content provided will address how policy standards are to be implemented.

Questions to consider:

- How will the curb management policies be implemented?
- How will enforcement practices of new loading areas or experimental locations be handled?
- What engagement practices should be used to deal with parking violators?
- How will advancements in technology be implemented?
- How will curb management pricing be determined (i.e., price, effective for how long)?
- How will usage (i.e., location and time duration) be determined?
- How frequently will the curb management policy be reviewed?
- How will requests for modifications or changes be handled?

Guidance:

- Provide clear communication to the public early and often.
- Administer focus groups and surveys with users to gauge common practices.
- Develop a systematic method to handle dynamic pricing.

5.1.6. Evaluation / Success Measurement

In the policy evaluation and/or success management section, the repercussions for those found in violation of policy will be described.

Questions to consider:

- How frequently should usage be monitored?
- What metrics will be used to evaluate curb management effectiveness?
- How will the effectiveness of non-compliance procedures be determined?

Guidance:

- Strive to match the ability to make changes with any public expectations.

In addition to the policy aspects described above, each agency would be well-served to consider separate policy sections to define any uncommon terms, answer frequently asked questions, and provide forms that may be needed as part of the agency process.

5.2. Policy Recommendations (Implementing New Technology)

As described earlier, evolving technologies are likely to play an increasing role in curb management. While there is some apprehension about using technology because of its reliability and cost, agencies will be more amenable to considering these tools when a proven track record has been established.

Three specific sections of any curb management policy should be updated to address adoption of new technology. Specific questions to consider and guidance for a recommended framework that focuses on new technology are provided in the following sections.

5.2.1. Responsibilities

Questions to consider:

- Who sets the agency's common data standards?
- Who will provide oversight of the vendor?
- Which department(s) will provide the technical oversight of any applications used?

Guidance:

- Coordinate between IT and transportation department staff.
- Identify data compatibility needs with existing agency needs.
- Determine whether the employment of an outside vendor would be in conflict with any public employee union regulations.
- Meet minority / disadvantaged business owner requirements.

5.2.2. Procedures

Questions to consider:

- What types of curb management technology will be tested and utilized?
- What are the current agency procurement processes?
- How will the technology be validated?
- Who will have ownership of the data?
- How will the collected data be managed?
- How will the collected data be stored?
- Are there privacy laws or surveillance ordinances to be aware of?
- What open-source curb technology should be considered?
- How will proprietary data be handled?

Guidance:

- Determine staffing levels and needs as they pertain to knowledge of transportation, data analytics, computer visioning, user experience, and emerging technology.

- Differentiate among data collection technologies and data-sharing platforms, and third-party platforms for communicating company data to cities, automated parking reservation tools, and enforcement tools.
    - Establish a common data standard to facilitate data sharing.
    - Surveillance ordinances may limit the use of sensor or camera technology.
- Explore how the agency would provide digital curb data that are open-source, free, standardized, and widely accessible.
- Consider future infrastructure maintenance needs to ensure that technology is reliably operational (for automated curbside management).

5.2.3. Evaluation / Success Measurement

Questions to consider:

- What happens if the vendor fails to meet its contractual obligations?
- What are the consequences if the data collected are incomplete?
- What are the consequences if the data collected are inaccurate?

Guidance:

- Determine how to communicate impacts with vendors if agency regulations change.
- Establish penalties if delivery of any service provided fails to meet expectations.
- Determine contract termination protocols.

5.3. Thematic Components of Successful Policies

The public and private sector staff interviewed for this study shared a common set of themes that defined successful curbside management pilots and policies:

- Continuous and aggressive enforcement of new loading zones or experimental uses. Clear communication to the public should occur early and frequently.
- Provision of exclusive loading spaces can encourage changes in operations. Cities reported success in obtaining data from operators in exchange for additional loading space. Reserving space for low-emission vehicles or other priority uses can be as valuable to operators as cash subsidies, and prompt them to make changes to their fleets accordingly.
- Adoption of open-source curb technologies. A consistent, nationwide standard for publicizing the ever-changing rules and locations of curb assets would benefit both public agencies and the private sector. Open-source technologies allow cities and companies to log issues and collaborate on solutions.

- Engagement with parking violators. Illegal behavior is often symptomatic of operational or regulatory failures at the curb. Agencies that engaged parking violators through focus groups and surveys, and adjusted their regulations in response, often saw the greatest improvements to curbside issues.
- Automated systems to enforce and monetize passenger/goods pick-up and drop-off. This approach would recover revenues at the curb, save staff hours, and ensure that operators have up-to-date information on regulations.

The curb is a dynamic space that encourages experimentation. Emerging technologies and data standards offer more consistency among cities, yet no single approach works for every municipality. Gaining a better understanding of public and private sector challenges and capabilities in this space will encourage collaboration and innovative technology and policy solutions that result in mutual benefits and more efficient curb management.

CHAPTER 6. SIMULATING CURB MANAGEMENT ACTIVITIES

Cities and municipalities are working to revise their curb management plans to better manage their limited resources and to test multiple strategies through pilots. Simulation technologies offer the opportunity to test different curb management strategies without requiring many resources.

In this study, a microscopic agent-based traffic simulation was used to simulate curb blockface activity under different traffic demand levels and different policy frameworks.

6.1. Microsimulation Platform (VISSIM)

For this study, we selected VISSIM as the micro-scale simulation tool. VISSIM is a traffic microsimulation software by the PTV Group, and it is widely used by transportation planners, public agencies, and academic research.

Each simulation software has its own strengths and weaknesses with respect to traffic modeling and simulation activities. In terms of modeling the road network, VISSIM and SimTraffic are easier to use than software like AIMSUN, ARCHISIM, and SUMO, which require heavier coding [Saidallah et al. 2016]. A study comparing the microsimulation software TRANSIMS, SUMO, and VISSIM reported that VISSIM is preferable for users at every experience level and has a very user-friendly and intuitive graphical user interface [Maciejewski 2010]. VISSIM also enables the highest level of detail and precision in traffic modeling, which contributes to more realistic results than TRANSIMS and SUMO [Maciejewski 2010]. SUMO and TRANSIMS are open-source software that allow developers to access and contribute/modify the code. VISSIM, on the other hand, is a commercial software, but it has a component object model (COM) API integration, which sets it apart from other microsimulation software. The COM interface enables inter-process communication between software that allows users to manipulate functions and parameters originally provided by the graphical user interface (GUI) dynamically [Tettamanti and Horvath 2020]. It can be programmed in computer programming languages such as C++, Python, or MATLAB, and it is generally used for project automation, which has proved to reduce errors when complex simulation frameworks are implemented [Fellendorf and Vortisch 2010]. VISSIM is also capable of obtaining detailed state variable information with better than second-by-second accuracy on every vehicle and time scale [Gettman and Head 2003].

Along with all its advantages, VISSIM has some limitations for curbside modeling. However, given its flexibility for customization for specific model needs, the research team was able to address those limitations by modifying some built-in classes and functions and by writing supplemental codes to create VISSIM's required inputs or to post-process its default outputs.

Moreover, VISSIM has been used by researchers to effectively model activities in the curb lane [Kilbert 2011, ITF/OECD 2018, Savrasovs et al. 2018, Overtoom et al. 2020] because of its built-in feature—such as on-street and off-street parking, passenger pick-up/drop-off zones, public transportation stops—and also its flexibility for customization for specific model needs.

6.2. Modeled Study Area

An urban arterial street network in the South Lake Union (SLU) area of Seattle, Washington, was chosen as the study area (figure 6.1). The study area consisted of two blocks of Boren Avenue N between John and Harrison Streets. The intersection of Boren Avenue N and Thomas Street had stop signs in all directions. Three blockfaces (1, 2, and 4) had curb spaces available for parking. In the study area, there were 11 parking lots containing one or multiple (up to four) parking spaces each.

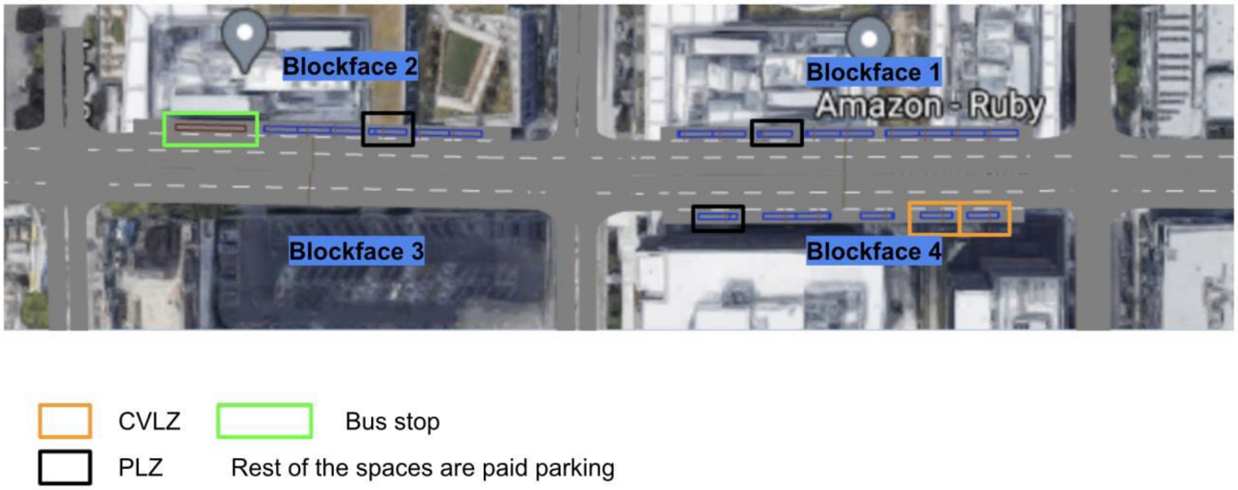


Figure 6.1 Study Network Modeled in VISSIM

Four different curb allocation types were modeled in this study: bus stop, commercial vehicle load zone (CVLZ), passenger load zone (PLZ), and paid parking. CVLZs were restricted to commercial goods and services delivery access, permitted to freight vehicles such as heavy goods vehicles, trucks, and work vans. PLZs were restricted for quick passenger drop-off and pick-ups performed while the driver remained in the vehicle. PLZs had a time limit of 3 minutes and could be used by TNC vehicles, taxis, or private passenger cars. These curb allocations were adapted from the City of Seattle's current rules.

While the curb management strategies are in place, their actual impact on overall traffic is determined by the road users' compliance to the rules. Therefore, in this study we modeled different driver behaviors with respect to compliance to curb management rules. For example, TNC vehicles might be more likely to make stops in the travel lane because of their typically lower dwell times in comparison to commercial vehicles.

6.3. Simulation Settings

6.3.1. Vehicle Composition and Speed

Five vehicle types were implemented in the simulation model: private car, TNC vehicle, heavy goods vehicle (HGV), bus, and work van. Data collected from a cordon count study in Seattle [Giron-Valderrama and Goodchild 2021] were used to find the vehicle composition (specifically, data were used from the intersection of Mercer Street and Westlake Avenue N, which was the closest location to the study area in cordon counts).

In the cordon study, TNC vehicles were included in the passenger car category. So we used another dataset collected from a previous curb management study in SLU [Goodchild et al. 2019] to derive the percentage of TNCs. According to that study, 55.7 percent of passenger cars using the curb were TNC vehicles.) Using this ratio, the passenger car category was then broken down into private cars and TNC vehicles. Table 6.1 shows the resulting calculated vehicle composition used in the simulation model. The desired speed distribution for each vehicle type was assumed to be compliant with the urban arterial speed limit of 25 mph (40.2 km/h) and vehicle types.

Table 6.1 Vehicle Composition and Speed in the Simulation Model

Vehicle Type	Desired Speed (km/h)	Composition (% of total vehicles)
Passenger car	40	39.5
HGV	30	2.7
Bus	30	3.8
TNC	40	49.6
Work Van	30	3.8

6.3.2. Traffic Volume and Turning Movements

Traffic volume was set to enter from four directions into the network toward the center of the study area, the Boren Ave N and Thomas St intersection. The volume input was defined at each entrance link using flow rates equal to the number of vehicles per hour. Volume inputs coming from north and south directions on Boren Ave N had varying flow rates throughout the simulation time to demonstrate different traffic conditions, such as severe congestion, flow at capacity, and free flow. This was necessary to create complete speed-flow diagrams, capturing the whole spectrum of traffic flow conditions.

Table 6.2 Volume Inputs for the Simulation Model

From North		From South		From West		From East	
Time Interval (s)	Volume rate (veh/hr)	Time Interval (s)	Volume rate (veh/hr)	Time Interval (s)	Volume rate (veh/hr)	Time Interval (s)	Volume rate (veh/hr)
0-1800	600	0-1800	700	0-1800	100	0-1800	200
1800-3600	500	1800-3600	600	1800-3600	100	1800-3600	200
3600-5400	400	3600-5400	500	3600-5400	100	3600-5400	200
5400-7200	400	5400-7200	500	5400-7200	100	5400-7200	200
7200-9000	300	7200-9000	400	7200-9000	100	7200-9000	200
9000-10800	200	9000-10800	300	9000-10800	100	9000-10800	200

Turning movements were defined as the ratio of vehicles traveling to the right, left, or straight directions (figure 6.2). They were defined for the four volume inputs coming from all directions into an intersection. Turning movement ratios were calculated by using counts from a previous curb study in SLU [Goodchild et al. 2019]. Those turning movement counts were conducted by the Seattle Department of Transportation at the Boren Ave N & Thomas St intersection between December 3 and 7, 2018 [Goodchild et al. 2019].

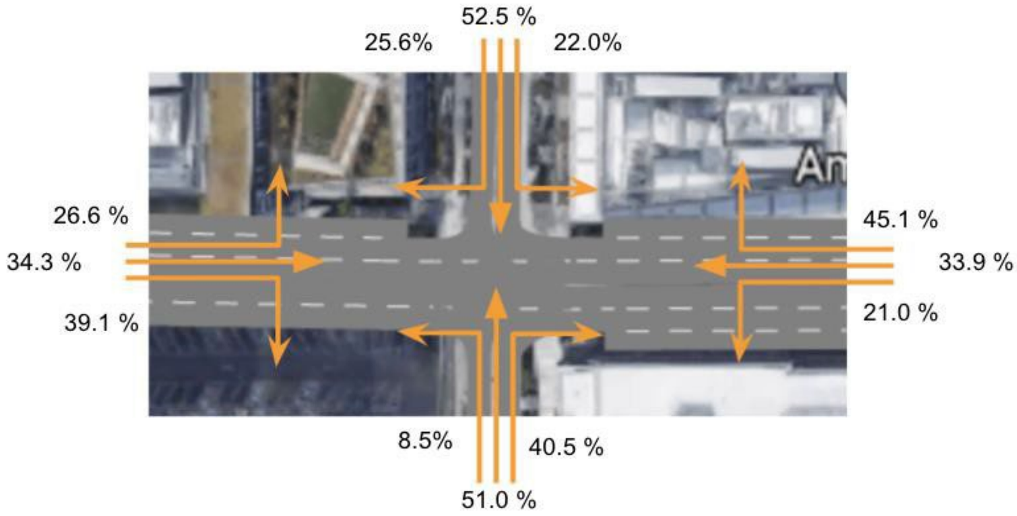


Figure 6.2 Turning Movement Ratios for the Simulation Model

6.3.3. Parking Behaviors

We built a baseline network in which different curb allocations and driver behaviors were developed and implemented.

The curb allocation in the baseline scenario reflected the existing allocation at the study area and consisted of one bus stop, three PLZ spaces, two CVLZ spaces, and 16 paid parking spaces, shown in figure 6.1. Each parking space was about 20 feet long (one vehicle capacity).

The flow rate of buses was found to be eight buses per hour from the aforementioned cordon data. Therefore, buses were scheduled to arrive every 7.5 minutes. The dwell time for buses was assumed to be 60 seconds, as advised by the Transit Capacity and Quality Service Manual, when field data were unavailable for a bus stop [TCQSM 2013]. Dwell time for different vehicle types were calculated using the field data collected from a previous curb study in SLU [Goodchild et al. 2019]. Dwell time distributions are listed in table 6.3.

Table 6.3 Dwell Time Distributions for Different Vehicle Types in the Simulation

Vehicle Type	**Dwell Time Distribution**		
	Type	**Mean (sec)**	**Std. Dev. (sec)**
Passenger car	Normal	350	80
HGV	Normal	850	200
Bus	Normal	60	10
TNC	Normal	50	10
Work Van	Normal	850	200

The parking routing decisions could be set at a location on the road segment (e.g., an intersection) for any vehicle type destined to a group of parking lots. These decisions created the candidate pool of parking spaces available for specific vehicle types and determined the percentage of vehicles attempting to park (should there be an available parking space). In the simulation model, parking routing decisions were set at the entrances of blockfaces 1, 2 and 4.

In the baseline scenario, all vehicle groups were assumed to comply with the curb allocation rules; i.e., passenger cars used paid parking, TNC vehicles used PLZ, work vans and HGVs used CVLZ spaces. Those behaviors were set to be different in other scenarios to evaluate the impacts of different policies on roadway traffic conditions and performance of the curb.

6.3.4. Simulation Period

The simulation time period was set to three hours, with a 15-minute warm-up periods, after which the traffic network was assumed to be in a stable state. Each scenario was run for 30 trials using different random seeds.

6.4. Outputs and Performance Metrics

Upon completion of a simulation run, data were collected from VISSIM either as data collection points or as a direct output.

Data collection points were used to measure the traffic flow and speed at given points on a road segment. Using these data, speed-flow diagrams were built to investigate the impacts of different curb management rules and driver behaviors on traffic flow. A speed-flow diagram, commonly referred to as a fundamental diagram, was one of the primary tools used to describe the roadway's traffic flow condition. In this study, these diagrams were produced by using the 15-minute interval data collected at the midpoint of each blockface in the study area. Flow was measured as the number of vehicles passing through the point in a 15-minute time interval, and the speed was the arithmetic mean of speed of all vehicles passing through that point during the interval.

VISSIM also produced vehicle records data as a direct output. The file contained the locations, parking information, and types of all vehicles in the network, every 6 minutes. The raw vehicle records data were used to extract curb usage information.

For each simulated scenario, curb performance was also studied in terms of failed parking rate and occupancy rate:

- Failed parking rate is the share of vehicles that failed to park out of those that attempted to park. The failed parking rate was calculated for each vehicle type i and indicated how much of the parking demand was satisfied for each vehicle type.

$$\text{Failed parking rate}_i = \frac{\text{Number of vehicles of type}_i\text{ that failed to park}}{\text{Total number of vehicles of type}_i\text{ that attempted to park}}$$

- Occupancy rate is introduced to assess the utilization of the curb lane and was calculated as the percentage of time that the curb space was occupied. First, the occupancy rate was calculated for each one-vehicle parking space, as a unit of curb space (e.g., a heavy goods vehicle that was twice as long as a passenger car occupied two parking spaces at once when parked at the curb). Then, the average occupancy rate across all parking spaces was calculated per vehicle type. The average occupancy rate per vehicle type i was calculated as follows, where n is the total number of one-vehicle parking spaces indexed by j.

$$\text{Occupancy rate}_i = \frac{1}{n}\sum_j \left(\frac{\text{Time during the curb space}_j\text{ was occupied by vehicle type}_i}{\text{Total simulation duration}}\right)$$

Each metric was calculated for each simulation run and then averaged over these 30 trial runs.

6.5. Results and Discussion

6.5.1. Scenarios

We simulated four different scenarios with different curb allocation/parking behaviors to evaluate the impacts of different policies on roadway traffic conditions and performance of the curb. The scenarios are listed in table 6.4.

Table 6.4 Simulated Scenarios

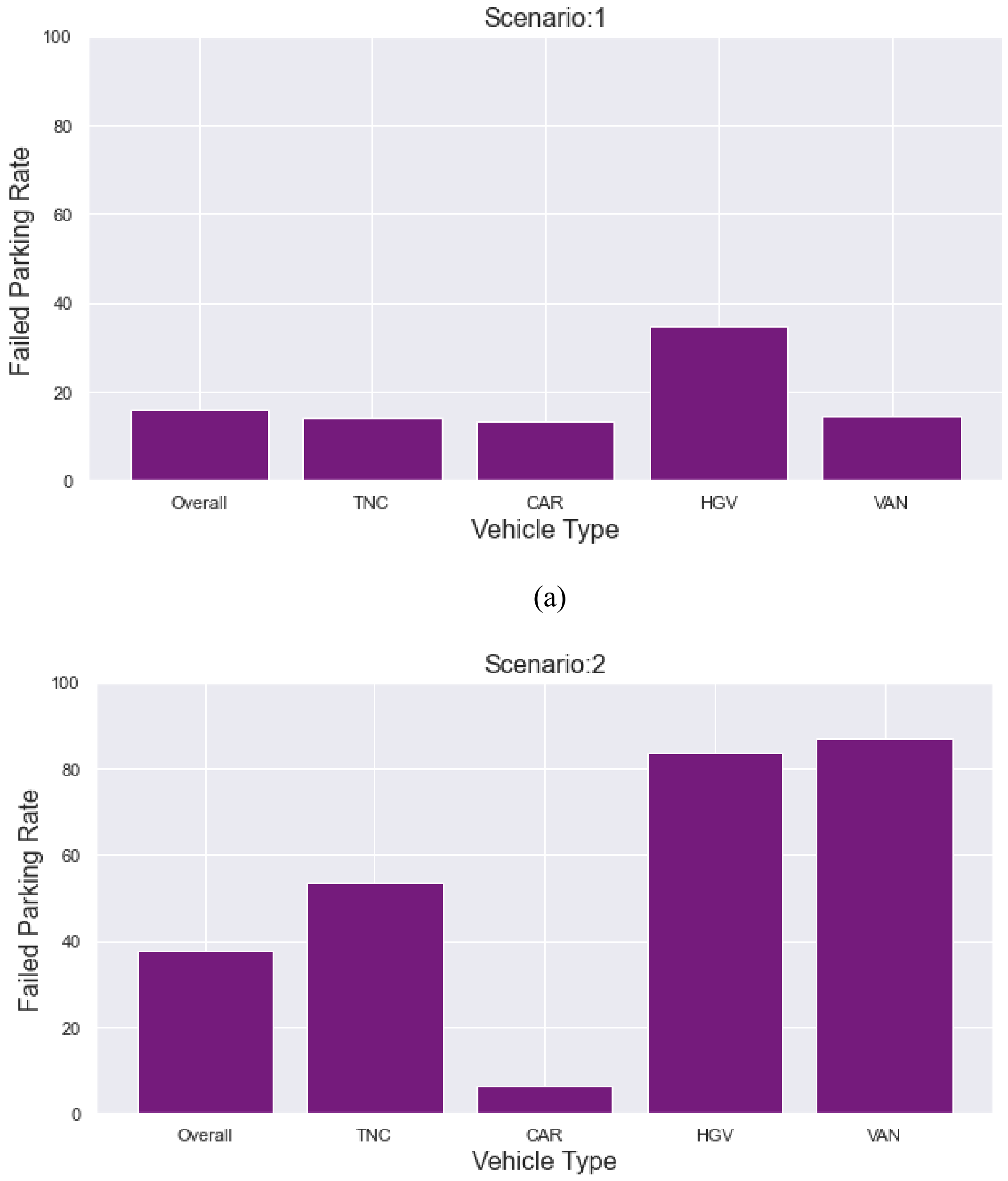
	Scenario	**Description**
	No curb rules (Baseline)	There are no vehicle type-specific curb allocations. Any vehicle can park in any parking space available.
	Strict vehicle-specific curb rules	Passenger cars use paid parking, TNC vehicles use PLZ, work vans and HGVs use CVLZ spaces.
	No curb rules – TNC stop in travel lane	Same as scenario 2, plus half of TNC vehicles park (stop for pick- up/drop-off) in the travel lane
	Flexible curb rule for non-passenger vehicles	Passenger cars only park in paid parking spaces. TNCs, HGVs, and work vans park in any space available.

6.5.2. Impacts on Curb Performance

6.5.2.1. What if there are curb allocation rules in place for all vehicles?

The impact of imposing curb allocation rules for every vehicle type was observed by comparing Scenario 2 with the baseline scenario. Figures 6.3 and 6.4 show failed parking rates and occupancy rates calculated for both scenarios.

The overall failed parking rate increased from 17 percent to 37 percent when every vehicle type was restricted to a specific curb allocation, preventing it from using other available curb spaces. The failed parking rate increased drastically from Scenario 1 to 2 for all vehicle types except for passenger cars. For vehicle types TNC, HGV, and work van, the failed parking rate was 2.8, 1.4, and 5.0 times higher, respectively, than that of Scenario 2 with the baseline. That is because paid parking spaces had the largest vehicle capacity in comparison to PLZ and CVLZ spaces, and they were restricted to passenger cars only in Scenario 2. Passenger cars composed the largest share of vehicles in the vehicle composition; therefore, their failed parking rate decreased by about half (from 14 percent to 6 percent) in Scenario 2, in which more spaces were allocated to them.



(a)

(b)

Figure 6.3 Failed Parking Rate (Overall and for Each Vehicle Type) for a) Baseline Scenario and b) Scenario 2

Figure 6.4 shows the breakdown of occupancy rates by vehicle type in Scenarios 1 and 2. The average occupancy rate at the curb dropped from 50 percent to 37 percent, when specific curb allocation rules were imposed. In looking at specific vehicle types, the occupancy rates for passenger cars and TNC vehicles did not change much, but the occupancy rates for commercial vehicles and work vans/HGVs dropped by 87 percent and 91 percent, respectively.

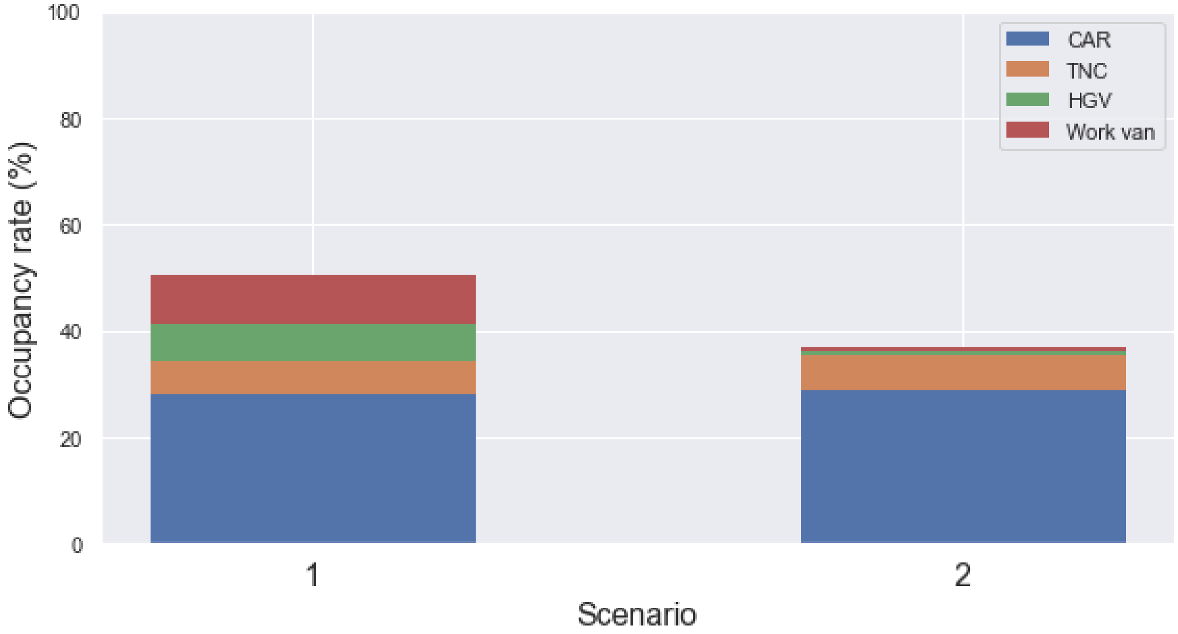
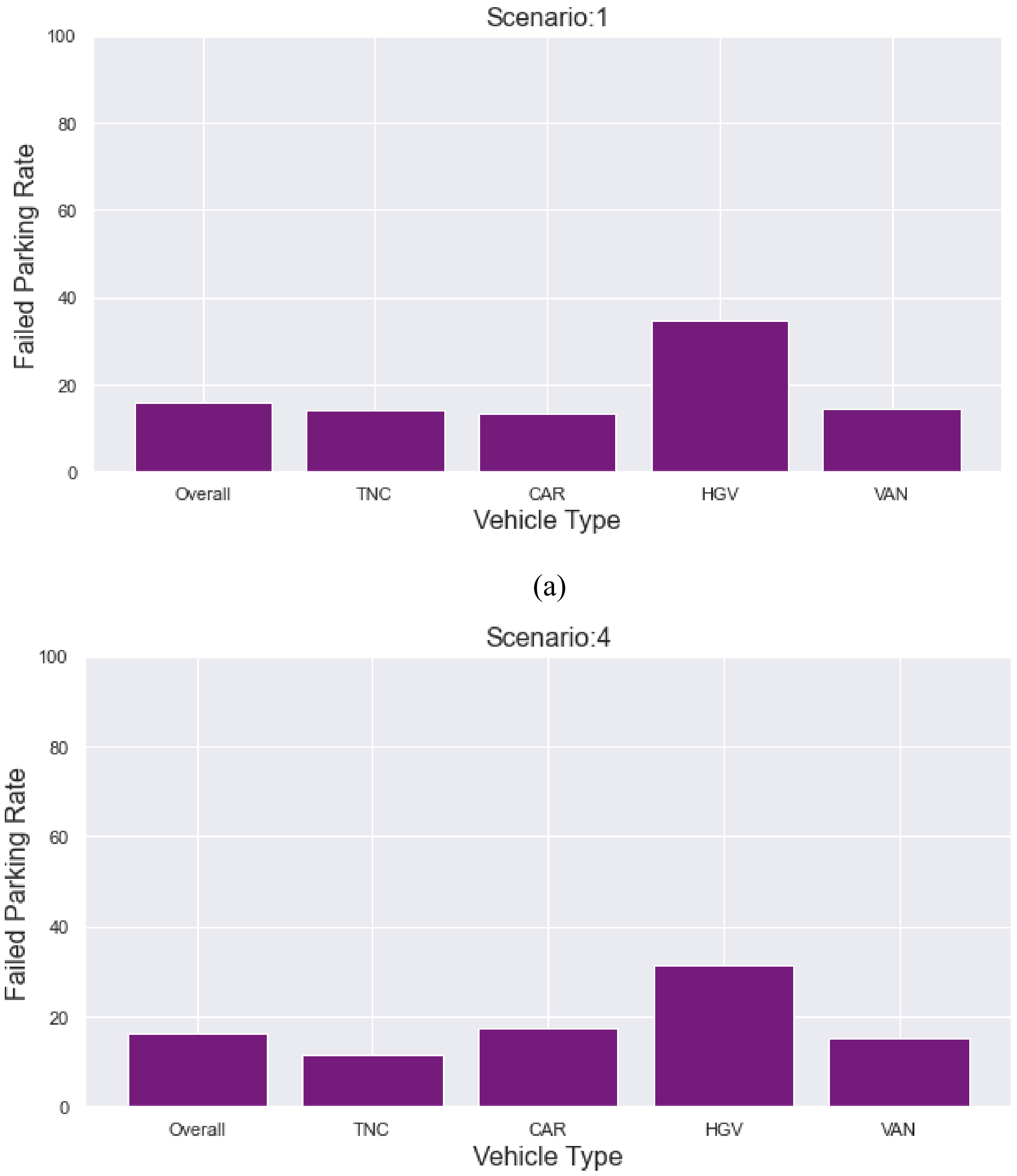


Figure 6.4 Occupancy Rate Breakdown by Vehicle Type for Scenarios 1 and 2

6.5.2.2. What if only passenger cars had specific curb allocation rules, but other vehicles could park wherever available?

Under Scenario 4, only passenger cars were assigned a curb allocation, being restricted to parking only in paid parking spaces. To investigate the impact of applying such a policy, Scenario 4 was compared with the baseline scenario. Figures 6.5 and 6.6 show failed parking rates and occupancy rates calculated for both scenarios.

The overall failed parking rate changed only slightly (from 17 percent in the baseline scenario to 14 percent in Scenario 4) when passenger cars were restricted to using the paid parking spots. This was reflected in fewer passenger cars (2 percent) successfully finding a place to park, while more TNCs and HGVs could park, showing decreased failed parking rates of 18 percent and 10 percent for TNCs and HGVs, respectively. This is because TNCs and HGVs no longer needed to compete with passenger cars for CVLZ and PLZ spaces in Scenario 4. Passenger cars composed a high share in the vehicle composition, and preventing them from using non- paid parking spaces freed up more parking capacity in CVLZ and PLZ spaces for other vehicle types.



(a)

(b)

Figure 6.5 Failed Parking Rate (Overall and for Each Vehicle Type) for a) Baseline Scenario and b) Scenario 4

The occupancy rates did not see much of a change when passenger cars were restricted to using paid parking spaces. The occupancy rate for TNC vehicles increased from 6.4 percent in the baseline scenario to 8.0 percent in Scenario 4, but occupancy rates for all vehicle types remained about the same between the two scenarios.

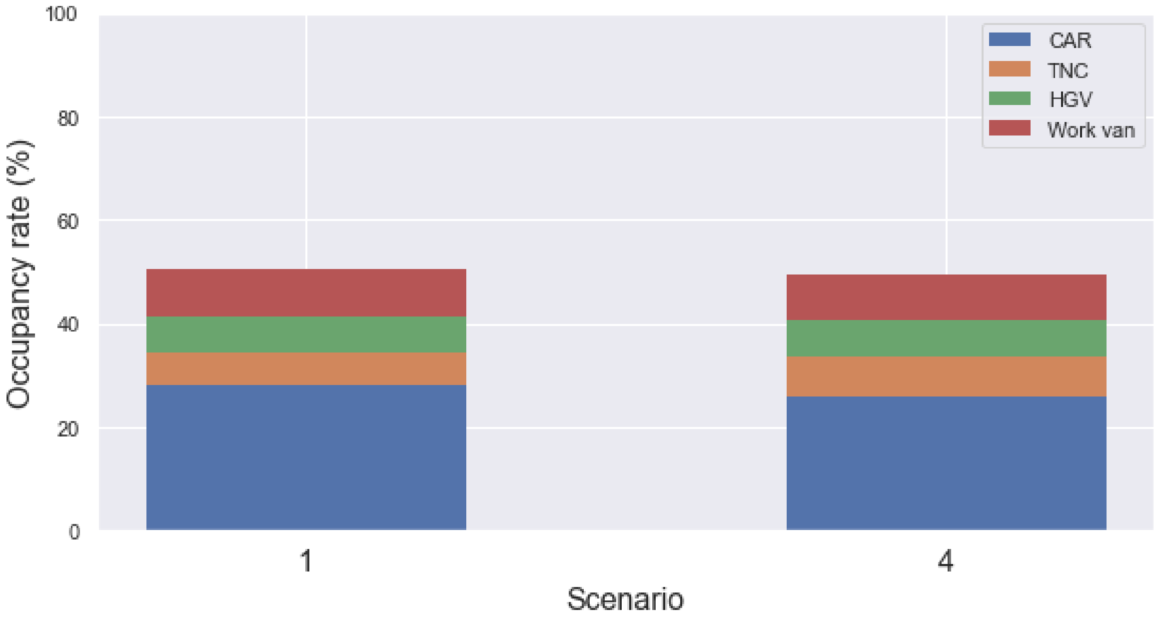


Figure 6.6 Occupancy Rate Breakdown by Vehicle Type for Scenarios 1 and 4

6.5.3. Impacts on Traffic

Figure 6.7 shows the speed-flow diagrams for Blockface 1, and as can be seen, the simulated curb policy scenarios did not cause a significant difference in traffic conditions.

The results for the other blockfaces did not show a noticeable different either, but Blockface 1 was selected here because it was closer to the study area volume entrance and showed more of a fundamental diagram parabolic shape (indicating both free-flow and congestion states)

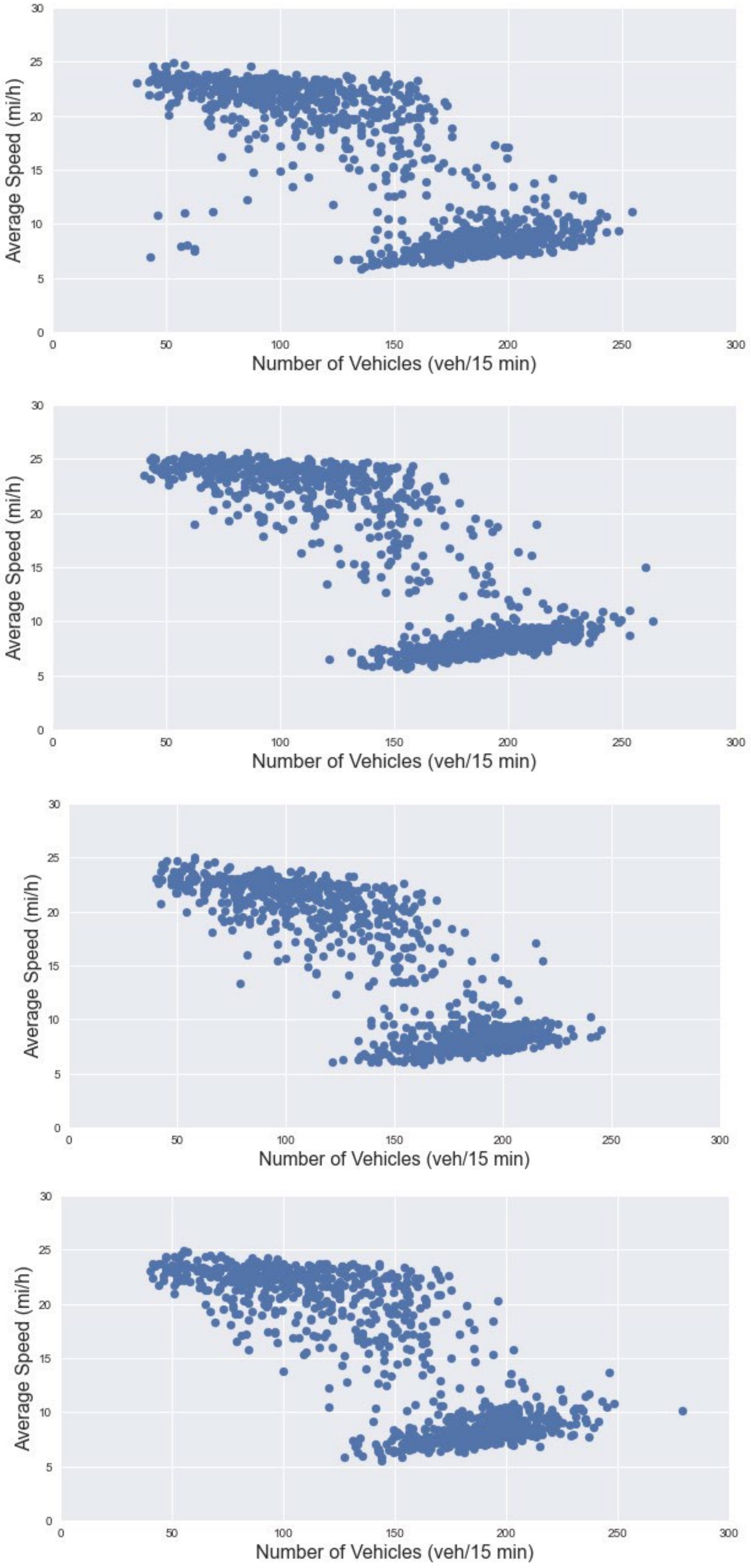


Figure 6.7 Speed-Flow Diagrams for Blockface 1 under Scenarios 1, 2, 3, and 4

CHAPTER 7. CONCLUSIONS

The rapid rise of on-demand transportation and e-commerce goods deliveries, as well as increased cycling rates and transit use, is increasing demand for curb space. This demand has resulted in competition among modes, failed good deliveries, roadway and curbside congestion, and illegal parking. This research increased the understanding of existing curb usage and provided new solutions to officials, planners, and engineers responsible for managing this scarce resource in the future. The research team worked with local agencies to ensure the study's relevance to their needs, and that the results would be broadly applicable for other cities. This research allowed for the development of innovative curb space designs that will ensure that our urban streets operate more efficiently, safely, and reliably for both goods and people.

The research study elements included conducting a thorough scan and documenting previous studies that have examined curb space management, identifying emerging urban policies developed in response to growth, reviewing existing curb management policies and regulations, developing a conceptual curb use policy framework, reviewing existing and emerging technologies that support flexible curb space management, and evaluating curb use policy frameworks by collecting curb utilization data and simulating curb performance.

A detailed literature review highlighted studies across five broad topics, namely dynamic pricing, travel behavior, regulatory structures, urban freight, and new mobility. As noted earlier, the rapid growth in curbside demand, combined with a lack of data, have contributed to several research gaps. More research is needed into shared mobility at the curb, such as the parking behavior of dockless bicycles and scooter riders. Policy makers desire to better understand novel curbside management technologies and to obtain curb data, but both activities remain works in progress. Research gaps also remain with regard to on-demand delivery (such as Uber Eats and DoorDash) and to developing better productivity metrics such as the active flow of passengers and goods to measure actual curb demand. Most cities still use traditional measures of parking demand such as occupancy, turnover, and meter revenue. By focusing on passive vehicle storage rather than the active flow of passengers and goods, these measures fail to capture new and varied ways of using the curb. Accurate, data-driven evaluations of curbside demand will lay the foundation for future innovation.

Existing regulatory structures and overarching policy frameworks and codes related to curbside management were also reviewed as part of this study. Curb regulations in most cities currently favor parking for passenger vehicles above all other functions. Many issues exist, including enforcement capabilities, equipment and infrastructure costs along with additional costs to maintain existing hardware, political repercussions associated with any parking policy changes, challenges associated with regional and interagency coordination, and data management. Existing curb management policies do not change quickly, and sometimes only incrementally when public outcry reaches a tipping point. Part of the problem can be associated with the complexities that define curb management governance structure at many local jurisdictions. In interviews, staff at cities nationwide described their curb management processes as “disjointed” and “decentralized,” and with “competing interests” across departments. With these challenges exposed, and with the emergence of new mobility and the rise of on-demand delivery, some cities have entirely rebranded and repositioned these responsibilities. Out-of-the-box solutions that include dynamic pricing, modifications to loading zones, flexibility with time restrictions, and converting existing uses for other purposes are being explored. On the basis of this understanding, recent strategies and new pilot programs were identified, and the geographic range and diversity of interviewees from previous studies were expanded. A deeper exploration of the evaluation metrics and technologies used in curb management programs was also provided.

As various forms of curb management technology continue to emerge, this study identified several key takeaways. While many agencies are working on how to collect and manage data, the planning and operating of available curb space promises to be the next frontier of competition among technology companies. This is a challenging endeavor, as it remains difficult to track curb users while managing privacy regulations and concerns. However, for cities to gain complete pictures of their curbs, frequently collected data are required. The existing business models of curb technology companies remain speculative and unproven, but initial findings reveal a desire on behalf of both public and private actors to change city procurement practices, fill gaps in data from urban freight and emerging on-demand delivery systems, and agree upon a common data standard to facilitate information sharing between cities and operators.

Given the evolving nature of curb management policies and regulations, this study reviewed emerging urban policies that have been developed in response to these changes. The results indicated that agency goals and daily enforcement practices vary broadly from city to city, and many agencies would be well-served to examine current policies, given the emergence of new mobility and on-demand delivery, and advances in technology and data collection. Two versions of a conceptual curb management policy framework based on best practices were described, with the first framework providing general agency guidance and the second framework detailing guidance pertaining to the use of evolving technologies.

As cities and municipalities work to revise their curb management plans to better manage their limited resources, different curb management strategies can be tested with traffic simulation models. On the basis of the outcomes identified from the other sections of this study, a microscopic, agent-based simulation model was developed and used to simulate curb blockface activity under different traffic demand levels and different policy frameworks. Four different scenarios with different curb allocation and parking behaviors were used to evaluate the impacts of different policies on roadway traffic conditions and performance of the curb. The scenarios included the following:

- An initial baseline model with no curb rules in which there were no vehicle type-specific curb allocations, and any vehicle could park in any parking space available.
- A second model with strict vehicle-specific curb rules in which passenger cars used paid parking, transportation network company (TNC) vehicles used passenger load zones (PLZ), and work vans and heavy goods vehicles (HGV) used commercial vehicle loading zone (CVLZ) spaces/
- A third model with no curb rules, and TNC vehicles stopped in the travel lane.
- A fourth model that featured a flexible curb rule for non-passenger vehicles; in this last model, passenger cars could park only in paid parking spaces, while TNCs, HGVs, and work vans could park in any space available.

The simulation results indicated that the failed parking rate and average occupancy rate at the curb would be impacted depending on the curb allocation rule. A significant change in traffic conditions, however, would not be as likely, given the different simulated curb policy scenarios.

In summary, managing increasing demand for curb space in the city of the future, and doing it effectively, will depend on agencies recognizing the changing travel dynamics of their citizens and users, policy makers developing and regularly reviewing rules that balance the limited availability of curb space with a constantly changing user demographic, and planners and engineers relying on increasing amounts of data and new methods of collecting those data to make informed decisions as to how this curb space should be allocated. The policy recommendations from this study, along with the approaches taken to develop the simulation models, reflect the ever-changing landscape of curb space management. As a very recent example, the COVID-19 pandemic caused traffic volumes and curb space usage to significantly decrease at the outset, but these measures have been slowly returning to pre-pandemic levels over time. In fact, the only constant along the curb space seems to be continuous change. The researchers from this project hope that this study will help cities and companies to identify areas of mutual interest, and to explore opportunities to collaborate on efficient curb management solutions moving forward.

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APPENDIXES

A. GROWTH MANAGEMENT POLICIES

Puget Sound Region Growth Management Policies

Seattle and Bellevue regulate growth through Washington state standards, primarily the Growth Management Act (GMA). The GMA, adopted in 1990, has been the subject of fierce debate. Critics argue that compact urban growth does not solve the problems the GMA intends to address, while supporters say the legislation protects critical areas and open space. Here, we give an overview of the GMA and tangential growth management legislation in Washington state, explain the key controversies over these laws, and review academic studies of their effectiveness.

In the decades before the adoption of the GMA, comprehensive planning for growth was optional. Amid a heightened environmental consciousness nationwide, the state of Washington passed several landmark environmental laws in the 1970s, including the Shoreline Management Act (1972). These laws somewhat limited development in critical areas, but urban sprawl continued unchecked.

Finally, in the 1980s, an economic boom in Seattle resulted in rampant population growth, degradation of pristine farm and forest land, and some of the worst traffic congestion in the nation. These developments inspired residents to pass the Seattle CAP initiative, which limited heights and set floor area quotas for downtown buildings. Several years later, in 1989, voters demanded statewide growth management legislation [Lloyd and Kisielius 2007]. In 1995, the state legislature adopted the Shoreline Management Act as an addition to the GMA. This act has three broad goals: control pollution along the shoreline, protect coastal natural resources, and preserve public access to the coast. The enthusiasm over these measures coincided with a national trend toward "smart growth." Advocates of this approach advance ten principles oriented toward mixed-use communities, access to transit, environmental conservation, and concentrating development in existing neighborhoods.

The GMA includes 13 goals [RCW 2002]. The first two lay out the overarching goal of the legislation:

- "Encourage development in urban areas where adequate public facilities exist."
- "Reduce the inappropriate conversion of undeveloped land into sprawling, low-density development."

The remaining goals chart a course for achieving these aims. They direct cities to provide "efficient multimodal transportation systems," make affordable housing available to "all economic segments," and promote economic development to support "disadvantaged and unemployed persons." Another subset of goals relates to protecting reserves of key resources such as timber, open space, wildlife habitat, historic sites, and air and water quality. Cities and counties must establish level of service standards for public facilities and ensure they meet these needs. The final three goals relate to the process for upholding these responsibilities. They state that private property cannot be taken without "just compensation," require that local governments process building permits in a "fair and timely manner," and encourage citizen involvement in the planning process [Lloyd and Kisielius 2007].

Two factors determine whether a county is required to plan under the GMA: current population, and population growth. Counties with a population of 50,000 or more must plan if their population increased by more than 10 percent in the ten years before 1995, or by 17 percent in the ten years after 1995. Counties with growth of more than 20 percent in any ten-year period must plan, regardless of population. Other counties can choose whether to opt into the requirements. As of 2020, 18 counties in Washington must fully plan, and another 11 have opted in (one, however is in the process of opting out). These counties account for about 95 percent of the state's total population [MRSC 2020].

The GMA mandates three primary requirements for counties: comprehensive plans, development regulations, and public participation. Comprehensive plans guide a region's development goals and must include maps that designate urban growth areas, rural areas, critical areas, and agricultural or forest lands. If the comprehensive plan is the blueprint for a county's growth, development regulations are the tools for carrying out the plan. A key change after the adoption of the GMA was that regulations must be consistent with the stated goals in the comprehensive plan. Finally, the GMA requires "early and continuous" public participation. Cities must provide opportunities for public hearings and written comments on their comprehensive plans. Planners must respond to comments, but do not have to act on them [Lloyd and Kisielius 2007].

Comprehensive Plans under Washington's GMA

Under the GMA, every city in fully planning counties in Washington must write and adopt a Comprehensive Plan. These plans form the backbone of the GMA. They must articulate broad goals and more specific policies for the eight required elements below. Cities can choose to add sections on recreation, conservation, or local subarea plans. The land-use element plays the most significant role in shaping the urban form of the community. Cities must include a policy-focused land-use map depicting where certain uses will be allowed. This corresponds to a zoning map used to implement the policies. Cities must update their comprehensive plans every eight years, with the option of making annual revisions. Three quasi-judicial Growth Management Hearings Boards resolve challenges to city and county plans.

The required elements of comprehensive plans are as follows [MRSC 2020]:

- Land Use
- Housing
- Capital Facilities Plan
- Utilities
- Rural Development (counties only)
- Transportation
- Economic Development
- Parks and Recreation
- Ports (mandatory for cities with annual maritime port revenues exceeding $60 million, RCW 36.70A.085)

Based on the Oregon system of state-enforced Urban Growth Boundaries, the Urban Growth Areas provision of the GMA seeks to concentrate population growth in urban centers. Counties can use one of three projections (high, mid, or low) provided by the state Office of Financial Management (OFM) to forecast growth. Much debate has occurred on what densities constitute "urban growth." The GMA hearings board at one time ruled densities as low as four dwelling units per acre as urban [Settle and Gavigan 1993]. The hearings boards have continually revised the density standards for both urban and rural areas.

The Puget Sound Regional Council's (PSRC's) Vision 2050 plan governs growth planning for Seattle, Bellevue, and 80 other cities in the Puget Sound region [Miller 2017]. The plan designates 21 urban centers targeted for future population and employment growth. These locations account for only 2 percent of the land area within the urban growth areas but are meant to accommodate 31.8 percent of all employment and 16 percent of population growth by 2020. Through a policy called transfer of development rights, King County and the City of Seattle have allowed owners of farm and forest land to sell development credits to developers building in designated urban centers. The city and county have also purchased conservation easements using a $50 million bond approved by voters.

Another key policy change under the GMA was transportation concurrency. The GMA required cities and counties to deny development permits if new construction would degrade transportation levels of service in the surrounding area below the community's adopted standards. To allow new development, a city or county must demonstrate a financial commitment to concurrent transportation improvements that can be completed within six years [MRSC 2019]. This requirement has faced criticism from many quarters. Developers worried that it would slow permit applications, while environmentalists argued the standards would encourage more car-oriented facilities [Trohimovich 2001]. To overcome the latter criticism, some cities, including Bellevue, have developed multi-modal concurrency standards [MRSC 2019]. A 2003 PSRC report recommended improving the concurrency standard by including multimodal investments, requiring coordination across jurisdictions, and providing exemptions for high-capacity transit facilities [PSRC 2003].

Since its adoption, the GMA has come under repeated scrutiny in the courts. Urban growth areas (UGAs) face criticism over the levels of density required. Some say the UGA provisions unintentionally encourage sprawl by requiring lower densities in rural areas [Robinson et al. 2005]. Others debate the definition of "rural character," and when and where exceptions to the act's rural growth restrictions should be allowed [Parker 2015]. The provision to protect critical areas comes under frequent litigation. Parties dispute the definition of "best available" science, and what it means to "include" that science in development regulations. Citizens have also protested the power of countywide growth regulations over individual cities. Critics argue that countywide planning policies give residents of major population centers more voting power than people in rural areas [Lloyd and Kisielius 2007]. Some cities have challenged the requirement to use the OFM's population forecasting models for growth planning, rather than their own local projections. Other authors have argued that smart growth policies, by directing intensive development toward highly localized areas, can lead to gentrification and displacement [Kushner 2002].

Scholars have attempted to quantify smart growth policies in the Puget Sound region through various methods, including land cover classification, density estimates, and building approval records. In 2004, a comparison of growth-managed states and unregulated states revealed that the growth-managed states saw higher densities, but that state growth management programs did not have a statistically significant effect in curbing sprawl [Anthony 2004]. A 2005 study suggested that Growth Management policies may have the unintended consequence of promoting suburban or "exurban" development. The authors of a land cover classification analysis found that housing density increased within urban growth boundaries, but that sprawling, low-density housing in rural areas accounted for about 72 percent of the growth observed in the study area [Robinson et al. 2005]. Interior forest habitat in wildland areas decreased by 41 percent, as these regions were converted to low-density, single-family housing developments. A 2007 study of six counties in the Puget Sound area found that urban areas increased more rapidly outside the urban growth boundaries than within them, suggesting that growth management policies were ineffective. Urban sprawl, measured by urban land area per capita, also increased [Cymerman et al. 2011]. A 2013 examination of building permit data declared Puget Sound growth policies generally successful in containing urban growth but found concomitant increases in social inequality and segregation [Dierwechter 2014].

Other studies have cast the Puget Sound growth management regime in a largely positive light. Tromovich noted that in the decade following the adoption of the GMA, Seattle reversed a 30-year decline in growth [Trohimovich 2001]. Urban centers in Seattle and Bellevue captured the bulk of the new growth. Real estate firms in 2001 noted that a deliberate and constrained development strategy in Bellevue transformed it into a "24-hour city" with a mix of commercial, residential, and retail spaces, making it an "attractive investment target" [Trohimovich 2001]. At the same time, rural populations of King County grew at a relatively low rate. Tromovich (2001) also noted that since the GMA's adoption, local governments streamlined permitting processes and improved cooperation with neighboring jurisdictions. Miller (2017) cited data showing that in 1998, only 6 percent of approved King County building permits fell outside the urban growth boundary. He argued that favoring incentive programs such as transfer of development rights over regulations can lead to greater acceptance of growth management.

Boise, Idaho, Area Growth Management Policies

Unlike Washington, Idaho does not truly have a statewide growth management act. In 1975, the state passed a bill that became the Idaho Local Land Use Planning Act (known as the Land Use Planning Act before 1995), which requires every city and county in the state to produce comprehensive plans that must be based on a set of specified components outlined in Title 67, Chapter 65, § 67-6508 of Idaho's State Code. Comprehensive plans consequently act as the primary source of growth management for communities in Idaho, which is similar to the intent of Washington's GMA. However, Idaho's Local Land Use Planning Act (LLUPA) has fewer regulations concerning the implementation of comprehensive plans than Washington's GMA; for example, the GMA requires cities to create development regulations that are consistent with their comprehensive plan, but the LLUPA has no such requirement. Required comprehensive plan components as outlined in the LLUPA, the applicability of which may vary based on locality, are as follows [Idaho State Code 2014]:

- Property Rights
- Population
- School Facilities and Transportation
- Economic Development
- Land Use
- Natural Resources
- Hazardous Areas
- Public Services, Facilities, and Utilities
- Transportation
- Recreation
- Special Areas or Sites
- Housing
- Community Design
- Agriculture
- Implementation
- National Interest Electric Transmission Corridors
- Public Airport Facilities.

Idaho's emphasis on local land-use planning poses several problems for the rapidly expanding Boise metropolitan area. Because of high rates of growth in the Treasure Valley, which includes Boise as well as surrounding cities such as Meridian, Nampa, and Caldwell, some community leaders are calling for more coordination in the realm of growth management. They hope that growth management on a regional level would help reduce sprawl in the area and ensure that adequate facilities are provided to accommodate the region's predicted future growth. The situation is especially troublesome in Ada County, the most populous county in Idaho and home to the cities of Boise, Garden City, Meridian, Eagle, Kuna, and Star. A single agency, the Ada County Highway District (ACHD), is responsible for transportation planning and road construction for the entire county. While a unified growth management plan would simplify the decision-making of the ACHD, achieving that level of coordination has proved difficult in the past [Talerico 2019].

The most obvious reason for this is the state of Idaho's reliance on local comprehensive planning; since every city in Ada County is required to have its own comprehensive plan with policies for managing growth, these policies often differ from one city to another, which can result in conflicting visions for the future. Additionally, the countywide comprehensive plan does not always reflect minor changes that the individual cities have made to their plans. However, urban planners in the region have long sought to create wider-reaching plans that would provide growth management for the entire area instead of a single city. The Treasure Valley Futures Project represented the first regional look at managing different growth scenarios and was led by representatives from several cities in the region [TVFP 2002]. However, the first concerted attempt to actually produce a multi-jurisdictional growth management plan for Ada County resulted in the Blueprint for Good Growth, whose first phase was introduced in 2006 [Ada County Consortium 2006]. The Blueprint for Good Growth's website reports that the Ada County Consortium, which was the name of the partnership of governments that created the plan, included representatives from Ada County, each of its cities, the ACHD, and the Idaho Transportation Department [Blue Print for Good Growth n.d.]. Both Boise and Meridian's current comprehensive plans refer to the effort, which was intended to "coordinate land use and public facility decisions" to improve growth in Ada County [City of Boise 2018]. One of the plan's major points of emphasis was that growth should occur only when adequate public facilities were available for the area of intended development, not before; this idea is similar to the concurrency requirement of Washington's GMA. Each city would have had to enact an ordinance to enforce the aforementioned policy, and it was this requirement that caused the member cities to balk, which effectively brought an end to the Blueprint for Good Growth [Talerico 2019]. Their reasons for doing so were varied; some cited the ordinance's lack of clarity, but others were concerned that if one of the cities in Ada County chose not to adopt the ordinance, that city would attract more new development. Not long after the issues surrounding the Blueprint for Good Growth halted Ada County's push for coordinated growth management, the recession of 2007 caused its cities to deprioritize the issue.

Several studies have been conducted to evaluate how well Idaho's planning policies function at the state, county, and local levels. In 2009, a group from the University of Idaho evaluated the compliance of city and county comprehensive plans across the state with the required elements identified in the LLUPA [Laninga et al. 2009]. Overall, the plans examined were not found to be highly congruent with the state statutes, as many of them contained goal and planning information but lacked the data that the state code required. Another analysis, conducted by Boise State University's Public Policy Center from 2009 to 2010, involved a survey of "local land use planners, public administrators, and others involved in the land use planning process" concerning the LLUPA [22]. One of its more relevant findings was that less than half of respondents believed the comprehensive plan "adequately anticipate[d] future conditions" [Witt et al. 2010]; while they generally approved of Idaho's local land use statute as a source of planning guidance, respondents were divided on whether there was an adequate level of support for planning. In summary, the survey found that while respondents generally agreed on the importance of comprehensive plans and the adequacy of Idaho's planning guidelines, there were many who felt that the state did not provide enough assistance to planners in developing and implementing a comprehensive plan, citing issues with cost and the availability of required data [Witt et al. 2010]. The issue of data availability was echoed by the data-related compliance problems identified in the University of Idaho study [Laninga et al. 2009].

The Treasure Valley's current solution to the issue of unified growth management comes from the Community Planning Association of Southwest Idaho (COMPASS). Much like the Ada County Consortium, COMPASS is a coalition of local government representatives "working together to plan for the future of the Treasure Valley" [Community Planning Association of Southwest Idaho 2018]. It functions as a metropolitan planning organization (MPO) for the Boise area, providing planning services and allocation of federal funding for transportation projects in the region. Unlike the Ada County Consortium, however, COMPASS's area of influence also includes Canyon County, home to cities such as Caldwell and Nampa that contribute to the Boise metropolitan area. COMPASS's unique position enables it to prioritize transportation projects that can benefit the entire region, which has led it to develop a series of regional long-term transportation plans called Communities in Motion. The current version, known as Communities in Motion 2040 2.0, is a plan for regional transportation projects until the year 2040, which makes it the Treasure Valley's most comprehensive source of growth management.

The creators of Communities in Motion 2040 2.0 applied several different growth models to the Treasure Valley to produce a reasonable prediction for population growth by 2040. A transportation plan for the region was then created using this predicted growth information. The plan emphasizes many smart growth principles, including the preservation of farmland and natural areas, increased walkability and encouragement of alternative modes of transportation, and compact growth for more efficient land use [24]. In determining which future projects to prioritize, COMPASS employed a "performance-based planning approach," combining the predicted quantifiable, traffic-related impacts of a project with its expected contribution to the different goal areas of the Communities in Motion initiative [COMPASS 2018]. Puget Sound's Vision 2050 plan targets specific urban centers for the bulk of predicted growth. While Communities in Motion 2040 2.0's primary concern is just to provide facilities to accommodate expected growth, it has the potential to encourage urban growth areas by concentrating transportation resources and multimodal transportation development in key parts of the region. The Communities in Motion goal areas include housing, land use, and community infrastructure [COMPASS 2018], so the prioritization of projects that improve these factors could result in the development of urban growth areas. COMPASS is currently updating the plan to accommodate projected growth to the year 2050. This process is expected to be completed by December 2022 [COMPASS 2019].

Comparison of Growth Management Approaches in Idaho and Washington

The above case studies of Washington and Idaho illustrate two related, but different, approaches to growth management. While both states require comprehensive plans and conduct long-term regional transportation and infrastructure planning, Washington follows a more top-down, state level approach. Idaho, to a greater extent, leaves it up to local jurisdictions to decide how to write and implement their comprehensive plans.

Washington's GMA defines specific standards for implementation, arguably lending more power to its regulations. Specifically, in the Puget Sound region, urban growth areas concentrate growth in designated centers. The Boise metro area, however, does not enforce similar geographic boundaries for growth. Washington also requires transportation concurrency, a notion that proved politically unpopular in the Boise region. However, studies on the effectiveness of Washington's additional regulations have reported mixed results.

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B. DYNAMIC PRICING APPROACHES

City	Program	Occupancy Target	Price Structure	Frequency of Adjustment	Neighborhood/ Number of Spaces	Results
San Francisco	SF Park	60 to 80%	$.25 and $6	real-time	Citywide program for all 28,000 parking spaces and 14 city garages	Time to achieve parking occupancy: 31% increase, compared to 6% for control. Amount of time it took to find parking: decreased 16% in target areas compared to 51% for control. Time to find a space: decreased 43% compared to 13% in control. 6.6 mph along corridors with reduced double parking, and it decreased 5.3 percent from 7.1 to 6.7 mph along corridors with increased double parking [SFMTA 2014].
New York	PARK Smart	85%	Binary: peak and off-peak rate, Depends on neighborhood	Daily switch between peak and off-peak hours	Upper East Side, Park Slope, Greenwich Village, Jackson Heights	Greenwich: 6% decrease in occupancy, residents supported rate increases to $3 and $5. Park Slope: Little change in occupancy rates (still around 90%), occupancy time dropped 17%-23%, 17-18% increase in unique vehicles, traffic volumes dropped 5-9%, community supports doubling the program area [Kazis 2010]. Upper East Side: Occupancy and turnover unchanged, community asked for end to program. Jackson Heights: 12% increase in drivers finding spaces, decreased occupancy rate and average duration of parking, shifted deliveries to morning, reducing conflict between shoppers and delivery trucks.

City	Program	Occupancy Target	Price Structure	Frequency of Adjustment	Neighborhood/ Number of Spaces	Results
Los Angeles	LA Express Park	70 to 90%	Varies by neighborhood, .5 to $3 in .5 increments, then $4-6 in $1 increments	Priced changed 8 times in 1st year, now 1-3 times per year. Three times of day: 8-11,11-3, and 3-8pm [Ghent 2018]	6,300 spaces in downtown area	Low public awareness of program: 25% award of Express Park and mobile apps. But broad public support: 76% willing to park in nearby cheaper blocks if they knew about it beforehand. Needs more communication, signage, outreach, etc [Zhao n.d.]. As of 2016: revenue up 2.5%, paid occupancy up 16%, average hourly rate down 11% "public acceptance of these programs is more likely when increasing revenue is not the primary goal" [Ghent 2018].
Berkeley	goBerkeley	65-85% (1 to 2 open spaces per block)	$2.25 in "premium zones" (2-hr limit) and $1.50 in value zones (8-hr limit)		Downtown Berkeley, Euclid/Hearst, North Shattuck, Southside/ Telegraph, and the Elmwood	2013 pilot program results: 41% increase in drivers saying finding a space is "very easy," "somewhat easy," or "neutral." Downtown, full blocks dropped by 12%, but 37 blocks still had occupancy rates greater than 85%. Fewer complaints from customers, city officials happy with increase in revenue with little capital investment. Drivers moved from parking in neighborhoods to using metered spaces [Clough 2014]. Revenue increase by 12% in first year, 4% in second year
Seattle	Performance-based parking pricing	70 to 85% (1 to 2 spaces per block)	.50 to $5	Annually	Citywide	Results from 2011: In four districts where rates increased, occupancy dropped to target of 1 to 2 spaces per block (80-90% occupancy). In seven districts, where rates remained the same, occupancy sometimes went up and sometimes went down. Rate reductions did not attract new parkers [City of Seattle 2020].

City	**Program**	**Occupancy Target**	**Price Structure**	**Frequency of Adjustment**	**Neighborhood/ Number of Spaces**	**Results**
Baltimore	Demand-based parking meter rate setting	75-85%	.50 to $3.50	Every 6 months	Citywide	Data showed that with every round of changes, more block faces reached the occupancy targets [City of Baltimore 2019]
Washington D.C.	ParkDC multimodal variable pricing pilot	1 open space per block	$1 to $5.50	Quarterly, different prices for 3 times of day on weekdays, and one price for Saturday	Pilot in Penn Quarter / Chinatown, also commercial loading zones	• Blockfaces that met target increased from 62% to 72%. • 7-min decline in time to find parking, 15% said parking regulations easier to understand, pilot was paired with launch of ParkDC App. • 43% decrease in amount of time vehicles were observed double parking. • Bikeshare and bus numbers remained stable or slightly increased. • 15% decrease in cruising time. • 17% increase in total revenue. • 10% reduction in occupancy time [Zhao n.d.]. • 5% decrease in congestion. • Businesses saw increases in sales and visitation numbers [Kittleson and Associates 2019].

City	Program	Occupancy Target	Price Structure	Frequency of Adjustment	Neighborhood/ Number of Spaces	Results
Boston	Boston performance parking pilot	60 to 80%	Zone-based static in Back Bay (increased from $1.25 to $3.75 for whole neighborhood) Dynamic in Seaport ($1 to $4)	Every two months	Back Bay, Seaport	Back Bay: • 11% increase in available spaces, 14% decrease in double parking. • 33% decrease in illegal parking in a loading zone. • Average meter time decreased by 14 min. • Seaport: Not successful, 1% increase in parking availability (not significant); on 29 of the 35 blockfaces there was actually an average increase of occupancy by 4.6%. City speculates this is because of a lack of price transparency and readily available information, maybe block-based pricing is too micro-level, making it difficult to understand. • 44% decrease in illegal parking in a loading zone. • 24% decline in double parking. Illegally parking in a resident spot decreased 12% in Back Bay and 35% in the Seaport. • Increase in revenue ($5.7 million and $350k respectively) [Boston DOT 2017].

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C. LIST OF STUDIED COMPANIES AND INTERVIEWEES (IF ANY)

Allvision

CEO

Bosch

Brisk Synergies

Conduent

Coord

Marketing Manager

curbFlow

Founder & CEO

IDAX

CEO

INRIX

Senior Director, Public Sector Services

Lacuna Technologies

Director of Ecosystems & Partnerships

Numina

Manager of Operations

Passport

Populus

Principal Product Manager

Remix

Shared Streets

Co-director
Public Sector Tech Lead

Streetline

D. METRICS AND DATA SOURCES IN USE FOR CURB EVALUATION

Table A: Curb Inventory Variables

Variables	**Collection methods/ data sources**	**Companies/ agencies that collect the data**	**Indications of success**
Price	Parking meter data	Coord, Passport, curbFlow	Price results in 70-90% occupancy (based on Shoup recommendation for 1 to 2 open spaces per block)
Length (in feet) of curb allocation	Measuring wheels, smartphone apps	Coord, Shared Streets	UFL study suggests 40 feet long by 14 feet wide. Should be located near intersections and driveways and connected to other loading zones when possible
	GPS/ LIDAR (limited accuracy)	Allvision	
Physical Assets (fire hydrants, signs, mailboxes, landscaping, scooter parking, bike racks)	Manual collection with smartphone app	Coord, Shared Streets	Matches the needs of nearby residents, businesses
	GPS/ Lidar	Allvision	

Table B: Curb Productivity Metrics

Curb Productivity	Dwell Time	Parking Occupancy Sensors (in-street or pole-mounted)	Streetline, Conduent	Dwell times match curb regulation times set by authorities
		Cameras	Numina, IDAX	
		TNC data	Populus, Remix	
	Parking Turnover	Cameras	Numina, IDAX	Turnover that results in 80% occupancy
		Parking Occupancy Sensors	Streetline, Conduent	
	Occupancy rate	Parking Occupancy Sensors	Streetline, Conduent	Around 80% occupancy (1 to 2 empty spaces per block at all times)
		Cameras (pole-mounted or smartphone app)	IDAX, Allvision, Coord	
	Economic data	Surveys, Economic census, Sales data from nearby businesses, pedestrian count	Census Bureau	Increase in foot traffic and/or sales at nearby businesses
	Vehicle type	Parking Occupancy Sensors	Streetline	Type matches curb regulations
		Cameras	Numina, Coord, Allvision	

	Number of passengers/ goods	TNC data, shared mobility operator data	Populus, Coord, Remix	Increase in number of people per hour, without violating regulations
		In-person observations	IDAX, public agencies	
Safety	Perceptions of safety	Survey of businesses	Transit agencies	Increased feelings of safety, based on surveys of business owners or transit riders
	Collisions/ near-crash instances along corridor	Transit agency collision data	Brisk Synergies, Numina	Fewer collisions than cities' vision zero targets or other goals
Compliance	Number and type of parking violations	Created by matching curb space allocation to vehicle types time limits to dwell times	Allvision, Coord, Passport	Fewer violations
	Double Parking/ Stopping in travel lane	Cameras	Numina	Fewer instances of double parking
		Citations	Police departments	
	Bus lane blockage	Cameras	Numina	Fewer violations
		Ticket Data	Police departments	

	Bike lane blockage	Cameras	Numina	Fewer violations
		Ticket Data	Police departments	
Mobility Along Corridor	Passenger throughput	Sensors, observational studies	Transit agencies	Increase in people moved per hour, including transit, bike lanes, and cars
	Corridor travel time	GPS data from navigation apps	Waze	Decrease in overall vehicle travel time
	Bus corridor travel time	GTFS (General Transit Feed Specification) data	Transit agencies	Decrease in bus travel time
	Pedestrian, bike and vehicle paths of movement	Cameras	Numina	People and vehicles can travel straight to destination without circling/ taking circuitous routes
		Crowdsourced data (i.e. Strava)	Strava Metro, Streetlight	
		Customer data from Rideshare or scooter apps	Populus, Shared Streets	