TPB REGIONAL CURBSIDE MANAGEMENT FORUM

Literature Review

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National Capital Region
Transportation Planning Board

TPB REGIONAL CURBSIDE MANAGEMENT FORUM LITERATURE REVIEW
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Editor: Fehr & Peers
Contributing Editors: Andrew Meese, Janie Nham, Michael Farrell
Design: TPB
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EXECUTIVE SUMMARY

This literature review discusses the role of curbside management in urban planning, tracing its development from basic parking regulations to technology-driven strategies. Curbside management addresses the growing and diverse demands on urban curb spaces, driven by transportation network companies (TNCs), shared micromobility options, e-commerce growth, and the impacts of the COVID-19 pandemic.

Key strategies for efficient curbside management include **integrating advanced technologies** such as real-time data collection and automated enforcement systems, which have the potential to improve compliance and optimize space utilization. The adoption **of dynamic pricing models, flexible allocation of curb spaces, and comprehensive digital inventories** have shown benefits in pilot programs across various cities. These strategies aim **to improve operational efficiency and increase mobility** at the curb but need to occur in lockstep with broader goals of equity, accessibility, sustainability, and safety.

The review highlights the need for **coordinated efforts among government agencies and stakeholders** to address implementation challenges and ensure cohesive curbside management policies. Emphasizing **community engagement and phased implementation** allows for refining strategies based on feedback and outcomes.

Emerging trends in curbside management include integrating **electric and autonomous vehicles, implementing sustainable initiatives, and focusing on multimodal transportation**. **Prioritizing equity and accessibility** aims to ensure that curbside management benefits all community members, particularly those from underserved or marginalized groups.

The future of curbside management depends on adaptability, innovation, and inclusivity. By adopting dynamic management practices and leveraging technological advancements, cities can transform curbside spaces into valuable urban assets that enhance mobility, reduce congestion, and promote sustainable and equitable urban environments.

INTRODUCTION

This literature review was conducted to support the Transportation Planning Board (TPB) Regional Curbside Management Forum by providing an overview of regional and national trends in curbside management. Its primary purpose was to identify and analyze best practices and innovative approaches implemented across the United States, highlighting case studies and examining challenges encountered in various regions. Building upon the insights gained from the policy scan conducted as a part of NCHRP 20-102(26) Dynamic Curbside Management, this review aimed to synthesize findings and offer lessons. Through this analysis, the review sought to equip forum participants with a foundation of knowledge, serving as a resource for the Curbside Management Forum event.

What is Curbside Management?

Curbside management is the systematic approach of organizing and regulating curb space usage. This space, serving as an interface between vehicular movement and pedestrian activity, accommodates various functions: passenger pick-up and drop-off, parking, loading and unloading of goods, and staging for services like taxis and ridehailing vehicles (International Transport Forum, 2018; Marsden et al., 2020). Unlike travel lanes that primarily facilitate vehicular movement, the curbside is inherently dynamic, supporting multiple activities that contribute to urban mobility and accessibility (International Transport Forum, 2018). **Figure 1** provides a graphic example of current curbside uses.

Figure 1: Curbside uses

Source: FHWA Curbside Inventory Report, 2021

The evolution of curbside management reflects the changing demands on urban spaces. From early parking regulations to today's data-driven approaches, the field has transformed in response to emerging technologies and evolving consumer preferences. This transformation underscores the growing importance of effective curbside strategies in creating efficient, equitable[1], and sustainable cities.

Brief History of Curbside Management

The beginnings of curbside management in the United States trace back to basic parking regulations. A key moment occurred in 1938 when Washington D.C. installed downtown curb meters, charging five cents per hour for parking (Pérez et al., 2021). This effort to control parking availability and induce turnover laid the foundation for future practices and remained the primary practice for several decades. In more recent decades, the District implemented additional static parking regulations, including dedicated loading zones, rush hour "no parking" zones, and residential parking permits (DDOT, 2024). These efforts were designed to balance the needs of commuters, residents, and businesses, particularly as car ownership increased significantly during this period.

A key moment occurred in 1938 when Washington D.C. installed downtown curb meters, charging five cents per hour for parking, which equates to $1.11 of today's (2024) money.

The dawn of the 21st Century signaled significant advancements as cities recognized the need for more comprehensive strategies. The framework model, exemplified by the Lower Manhattan Street Management Framework, emerged to categorize streets based on primary functions such as access, through traffic, and residential use (Lethco et al., 2009). This model enabled cities to prioritize curb functions according to surrounding land use and street type.

Another watershed development was the introduction of performance pricing models, which sought to align curb demand with supply through dynamic pricing. This approach gained momentum following Donald Shoup's seminal research on the negative impacts of cruising for parking, illuminating the benefits of demand-responsive pricing in mitigating congestion (Shoup, 2006).

Recent years have seen an accelerated shift towards dynamic curbside management, propelled by technological advancements and innovative pilot programs. The SFpark pilot in San Francisco (2011) marked a turning point by utilizing sensors and smart meters to adjust parking rates based on real-time demand (San Francisco Municipal Transportation Agency, 2014). Similar initiatives, such as the District Department of Transportation's parkDC pilot, have highlighted the potential of demand-responsive strategies to optimize curbside efficiency (District Department of Transportation et al., 2019).

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[1] Equity in this context can refer to equitable mode usage —the fair allocation and design of curbside spaces to ensure that all modes of transportation, such as walking, cycling, public transit, ride-sharing, and private vehicles (including AVs and EVs), are adequately and proportionately accommodated— or social economic equity —the fair and inclusive distribution of resources, services, and opportunities within a city or community.

Importance and Current Challenges

Curbside management is an important component in addressing the evolving demands on urban curb spaces. The proliferation of transportation network companies (TNCs), expansion of shared mobility options, and surge in e-commerce have significantly intensified curbside utilization (Institute of Transportation Engineers, 2018). The COVID-19 pandemic further underscored the need for adaptive curbside management, prompting cities to repurpose on-street parking for various community needs.

As cities deal with these changing dynamics, determining optimal curb allocation and decision-making processes presents a multifaceted challenge. This process often requires input from public and private stakeholders to ensure comprehensive consideration of diverse needs and preferences (Institute of Transportation Engineers, 2018). Beyond stakeholder engagement, implementation of demand management systems, such as dynamic pricing for curb usage, could signify substantial improvements, but can pose operational and economic challenges.

Addressing these challenges requires a multifaceted approach. Effective curb management relies heavily on physical infrastructure improvements, including signage installation and, in some cases, data collection and monitoring technologies (Federal Highway Administration, 2021). Additionally, cities must navigate the complexities of updating public regulatory codes and ensuring consistent enforcement. These enforcement efforts are resource-intensive and increasingly dependent on advanced technologies like automated license plate readers and video analytics that not all jurisdictions have access to (National Conference of State Legislatures, 2021).

Given the complexity of these interrelated issues, addressing curbside management challenges demands a coordinated approach and the adoption of context driven solutions. Implementing comprehensive solutions that involve stakeholder input, best satisfy infrastructure requirements, and apply strategies that are suitable for each jurisdiction, is the best way to confront the overarching challenges.

MAINTENANCE CHALLENGES

Curbside management faces some maintenance challenges, particularly with the infestation of invasive plant species such as **Wall Barley**. Wall Barley, a recent invader to the Mid-Atlantic, has been increasingly found in median strips and roadsides in the Washington Metropolitan area. This invasive grass poses significant risks to urban and suburban environments, especially to pets. Wall Barley seeds can embed in animal fur, causing severe health issues as the seeds migrate into the body, potentially reaching vital organs.

Strategies such as regular monitoring and coordinated efforts between city maintenance crews can help control and eradicate invasive species. Public awareness and community involvement are crucial, as timely reporting and responsive action can prevent the widespread establishment of such harmful plants. Ensuring curb spaces are safe and well-maintained not only preserves the aesthetic and functional value of urban environments but also protects the health of community pets and wildlife.

METHODOLOGY

This literature review employs a systematic approach, adapting the framework from the NCHRP report “Dynamic Curbside Management: Keeping Pace with New and Emerging Mobility and Technology in the Public Right of Way” (NCHRP 20-102(26)), and incorporating recent sources to reflect current developments related to the curb. The NCHRP report serves as a foundational guidebook for state, regional, and local transportation agencies, providing comprehensive strategies for implementing dynamic curbside management programs. In this context, "dynamic" refers to the adaptable and flexible allocation of curb space that changes in response to varying demands and uses throughout the day, ensuring efficient and effective management of urban curb spaces.

Framework Adaptation

The literature review adopted the structured framework from the NCHRP Dynamic Curbside Management Literature Review & Policy Scan. This guided the categorization and evaluation of pilot programs, policies, and practices related to curbside management.

Literature Search and Source Selection

A search was conducted using government publications, industry reports, and online resources. Key search terms included "curbside management," "dynamic curbside management," "electric vehicles," "autonomous vehicles," "multimodal transportation," "sustainability," “equity and accessibility” and "data collection." Publications from 2021 to 2024 were prioritized to include the most recent developments in curbside management.

Data Extraction and Synthesis

Information from selected sources was extracted and organized according to the established framework. Key themes, trends, and findings were synthesized to provide a comprehensive overview of current curbside management practices.

Integration of Recent Developments

Recent curbside management plans, technological innovations, policy implementations, and research findings were integrated to reflect the latest advancements in curbside management.

LITERATURE REVIEW

Evolution of Curbside Demand

FACTORS DRIVING GROWTH AND CHANGES IN CURBSIDE DEMAND

Four Primary Drivers

The urban curbside has undergone significant transformation in recent years, driven by various factors that have reshaped demand patterns and underscored the need for adaptive management strategies. The NCHRP Dynamic Curbside Management Literature Review identified four primary drivers of this change: the proliferation of transportation network companies (TNCs), the expansion of shared micromobility options, the surge in e-commerce activity, and the recent impacts of the COVID-19 pandemic.

The advent of TNCs such as Uber and Lyft have altered pick-up and drop-off dynamics, particularly in high-activity zones like airports and entertainment districts. Data from the Institute of Transportation Engineers (2018) indicate that TNC operations have accelerated curbside turnover rates, requiring flexible allocation of curb space to accommodate brief stops while minimizing congestion impacts.

Concurrently, the introduction of docked and dockless shared mobility services—including e-scooters and bike-share systems—has further diversified curbside utilization, intensifying competition for this limited resource (Marsden et al., 2020). These micromobility options may require dedicated space for parking and docking, adding another layer of complexity to curbside management.

E-commerce growth represents another critical factor influencing curbside demand. The rise of online retail has precipitated an increase in delivery vehicle activity, with more frequent curb interactions occurring throughout the day. This trend is particularly pronounced in commercial and residential areas, where package and meal delivery services are prevalent.

Most recently, the COVID-19 pandemic reshaped curbside usage patterns, as cities quickly adapted curb spaces to support new needs such as curbside pickup, outdoor dining, and social distancing measures. These changes have highlighted the need for flexible and adaptive management strategies that can respond to shifting demands (Transportation for America, 2021). In the pandemic's wake, some of these curb changes have become permanent fixtures in urban design, while others have been phased out as conditions evolved.

Supporting Equity, Accessibility, Sustainability, and Safety

Prioritizing curb space for specific uses has profound implications for mode share equity, accessibility, and safety. Historically, curb space has been predominantly allocated for private vehicle storage through short- and long-term parking provisions. This allocation impacts travel behavior, inducing vehicle travel and benefiting those who can afford to drive, while disadvantaging lower-income individuals who are less likely to own a vehicle and are more reliant on public transit (McCahill et al., 2016; Weinberger, 2012; Blumenberg & Pierce, 2012; Giuliano, 2005).

Furthermore, free or underpriced curbside parking leads drivers to "cruise" for parking, resulting in numerous negative externalities. These include increased congestion and elevated tailpipe emissions due to frequent acceleration, deceleration, and idling (Shoup, 2006; Eisele et al., 2014).

The increasing demand for curb space has also led to behaviors such as vehicles picking up and dropping off passengers in active travel lanes, obstructing bus bays, and pedestrians crossing streets at unsafe locations to access parked vehicles. These behaviors create additional conflict points, raising significant safety and accessibility concerns.

Furthermore, curbside management strategies, such as dynamic parking and flexible curb allocations, aim to improve overall efficiency but can inadvertently overlook the specific needs of disabled individuals. While many jurisdictions attempt to incorporate American with Disabilities Act (ADA) and Public Right of Way Accessibility Guidelines (PROWAG) guidelines, the literature review shows that these principles are not always operationalized effectively. When making decisions related to traffic flow, congestion reduction, and sustainability, accessibility should be considered or an agency runs the risk of unintentionally diluting the importance of curb accessibility.

For example, in San Francisco's curbside management strategy, efforts were made to incorporate equity and accessibility by designing accessible passenger loading zones and improving curbside access for paratransit services. However, challenges remained in balancing these needs with other priorities like managing commercial loading zones and reducing congestion (San Francisco Municipal Transportation Agency, 2020). These findings highlight that while accessibility is considered, it is not always the highest priority and could unintentionally be sidelined in the pursuit of other planning goals. Balancing these competing demands while maintaining accessibility for all users is key to the success of modern curbside management.

CURRENT CURBSIDE USAGE PATTERNS AND CHALLENGES

Capacity Strains and Suboptimal Behaviors

Current curbside usage patterns reflect a complex and dynamic interplay of the aforementioned demands, often resulting in capacity strains and suboptimal behaviors that can compromise safety and mobility. Studies have documented that the demand for passenger loading zones often exceeds the available supply, leading to congestion and inefficiencies. For instance, research conducted by Fehr & Peers (2018) in San Francisco found that at four out of five locations, the demand for passenger pick-up and drop-off zones surpassed the available curb space, highlighting the critical need for dynamic management solutions.

The strain on curbside capacity due to increased e-commerce deliveries often manifests in unauthorized loading activities. Research by Girón-Valderrama et al. (2019) found that insufficient loading zone availability correlates with higher incidences of double-parking and bike lane obstructions by delivery vehicles. These behaviors not only disrupt traffic flow but also elevate collision risk for vulnerable road users, undermining safety initiatives.

The proliferation of shared mobility options has exacerbated these challenges, as docked and dock-less e-scooters and bike-sharing programs compete for limited curb space. Without proper management, this can lead to cluttered sidewalks and reduced accessibility for pedestrians, particularly those with mobility impairments.

IMPLICATIONS FOR CURBSIDE MANAGEMENT

These observations highlight the imperative for data-driven, responsive curbside management frameworks. Recognizing that not all cities and towns have the resources or data systems for sophisticated approaches, a good starting point would be to implement flexible curb management. This involves determining which curbs are suitable for multiple purposes, but does not require continuous real-time data and adjustments. For cities with more resources, leveraging real-time occupancy data and employing dynamic pricing and space allocation models to optimize curb utilization, can help meet meet evolving demands. This approach is known as dynamic curbside management. Both strategies enhance operational efficiency and support broader goals of equitable access and sustainable mobility.

The COVID-19 pandemic further underscored the value of flexible management approaches. As cities pivoted to accommodate new curbside needs, the adaptability of urban spaces became paramount. While some pandemic driven curb changes were temporary, moving forward, curbside management must continue to evolve, balancing the diverse needs of TNCs, transit, micromobility and active transportation users, delivery services, streateries, and traditional parking, while remaining agile enough to respond to unforeseen challenges.

Comprehensive dynamic or flexible management practices can be a tool to manage conflicts at the curb and supports the safe, efficient, and equitable movement of people and goods. This approach lays the groundwork for a resilient curbside ecosystem capable of adapting to future mobility innovations and societal shifts.

Response to Changing Demand at the Curb

SHIFTING TO DYNAMIC CURBSIDE MANAGEMENT

Cities are increasingly adopting dynamic curbside management to address the evolving demands on curb space. This approach leverages real-time data and flexible policies to optimize the use of curbside areas based on varying needs throughout the day. Unlike traditional static management, which often relies on fixed regulations and enforcement, dynamic curbside management uses tools such as pricing, digital reservations, and adaptive allocation of space to better align with current usage patterns. For example, San Francisco's SFpark program, one of the first to implement demand-responsive parking, adjusts parking rates quarterly based

PARK DC

The District Department of Transportation's (DDOT) parkDC pilot (2014-2017) in Penn Quarter/Chinatown explored demand-based parking management using an "asset-lite" strategy. This approach focused on maximizing efficiency of existing curbside assets through dynamic pricing, rather than investing heavily in new infrastructure (District Department of Transportation et al., 2019).

The pilot used real-time occupancy data to adjust parking rates, aiming for an 85% occupancy target. This demand-responsive model aimed to reduce traffic from circling vehicles and promote sustainable transportation alternatives (Pérez et al., 2020).

This proactive approach to managing increasing curbside demands from various users (ride-hail, commercial loading, micro-mobility) is seen as crucial for optimizing urban mobility and achieving policy goals.

on real-time occupancy data to maintain optimal availability (San Francisco Municipal Transportation Agency, 2014). The District's parkDC program (see sidebar) is another noted example. Arlington County is in the early stages of piloting a Performance Parking program that will use in-curb sensors to measure on-street parking capacity and demand and periodically adjust parking prices in response (Arlington County Government, 2024).

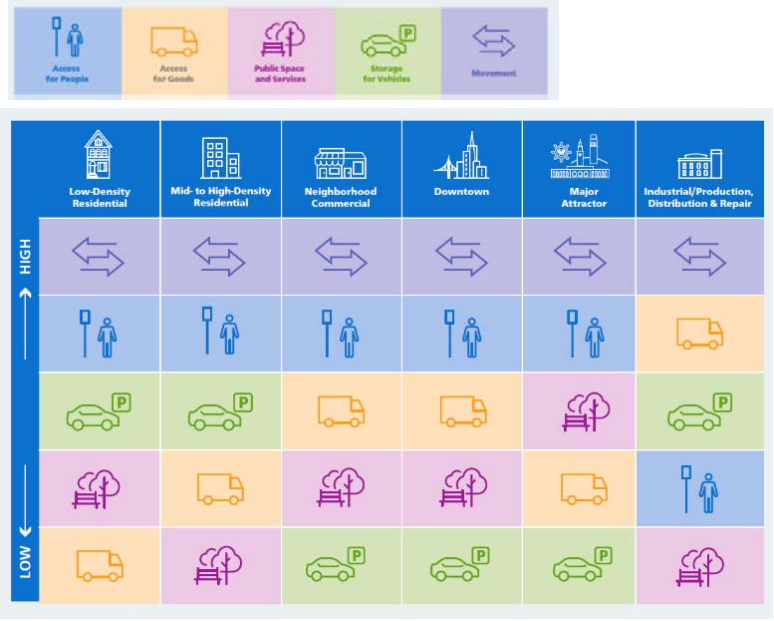
Dimensions of Dynamic Curbside Management

Dynamic curbside management varies depending on the location where it is implemented. To optimize curb space allocation, cities focus on four key dimensions: context, space, use, and time. These elements are complementary and factor into the decision-making process, with their input weighted differently depending on the jurisdiction's available resources and goals (e.g., curbside inventory, available data, etc.).

- **Context:** Prioritizing curb space based on surrounding land use and neighborhood needs. For example, commercial areas may favor loading zones, while residential areas may prioritize parking.
- **Space:** Maintaining accurate, digitized inventories of available curb space using technologies like GPS sensors and digital mapping.
- **Use:** Tracking current curb space usage and demands from different user groups (e.g., private vehicles, delivery trucks, pedestrians) to inform allocation decisions.
- **Time:** Adapting to varying demand patterns throughout the day and week. This involves implementing time-based regulations and using digital platforms for real-time adjustments.

Figure 2 illustrates the SFMTA's allocation of curb functions across various land use types. In high-activity areas, such as Downtown and Major Attractors, curb space allocation favors pedestrian access and traffic movement. Residential areas, particularly those with lower density, prioritize vehicle storage and public spaces. Commercial and industrial zones consistently emphasize access to goods. The SFMTA's curb use allocations vary according to the characteristics of each land use type, reflecting an effort to address different needs across the city.

Figure 2: SFMTA curb functions prioritized by land use



Source: San Francisco Municipal Transportation Agency, 2020

INTEGRATING TECHNOLOGY INTO CURBSIDE POLICY AND REGULATIONS

Traditional curb management practices are increasingly inadequate in the face of rising urban mobility complexities. Cities are now adopting more flexible and responsive frameworks, integrating advanced technologies to better align curbside policies with real-time usage patterns and broader transportation goals.

- **Dynamic Pricing Models:** Programs like San Francisco's SFpark and Washington DC's parkDC adjust parking rates based on occupancy data to maintain optimal space utilization and reduce congestion (San Francisco Municipal Transportation Agency, 2014; District Department of Transportation et al., 2019).
- **Flexible Allocation:** Cities are redefining curb space allocation to prioritize different users at different times. For example, Seattle's Flex Zone program categorizes curb space into distinct uses such as mobility, access for people, access for commerce, activation, greening, and storage (Seattle Department of Transportation, n.d.).
- **Digital Inventories and Mapping:** Cities like Los Angeles and Seattle have undertaken comprehensive digital curb inventories using technologies such as GPS sensors, LiDAR, and augmented reality apps. These digital tools enable the collection and analysis of data on curb space usage, facilitating informed decision-making and policy adjustments (Howell et al., 2019).
- **Automated Enforcement:** Integration of technologies like automated license plate readers and video analytics enables more precise and efficient enforcement of curbside policies (National Conference of State Legislatures, 2021; Automotus, 2020).

- **Digital Platforms:** Solutions like Coord and curbFlow offer digital interfaces for curb space reservations and real-time monitoring, providing valuable data on curbside demand and utilization (Coord, 2021).

PILOT PROGRAMS

Dynamic curbside management pilot programs across various cities have implemented a range of innovative strategies to address the challenges of curb space allocation and utilization. These pilots share common goals of improving efficiency, safety, and adaptability of curb usage through the integration of advanced technologies and data-driven approaches. Some of the performance measures commonly evaluated are dwell time, types of stopovers, type of vehicle or device, and occurrences of facility blockage (e.g., double parking, blocking bus of bike lanes). Aligning projects goals with performance metrics can help identify success, such as reduced dwell time to decrease emissions, or reduced facility blockage to improve safety.

One common strategy is the use of digital platforms for curb space reservations and real-time monitoring. For example, Washington, DC's partnership with CurbFlow introduced app-based reservations for loading zones, allowing commercial vehicles and ride-hail services to book curb space in advance (Pérez et al., 2020). This approach streamlined curb space utilization and reduced illegal parking and double-parking incidents. Similarly, the Smart Zones pilot in Omaha, NE employed Coord's platform to manage curb reservations, leading to significant decreases in double-parking and improved compliance with loading zone regulations (Coord, 2021).

Another shared strategy is the implementation of dynamic pricing models to manage demand. The parkDC pilot in Washington, DC, adjusted parking rates based on real-time occupancy data to maintain optimal availability and reduce congestion (District Department of Transportation et al., 2019). This model demonstrated how economic incentives could influence driver behavior and enhance curb space efficiency. Arlington County, Virginia is one year into a three-year Performance Parking pilot that will measure on-street parking capacity on two corridors, and periodically adjust parking costs in response. Pilot programs also emphasized the importance of robust data collection and analysis for decision making, as seen previously with the cities of Los Angeles and Seattle’s digital inventories and mapping efforts.

Despite these commonalities, pilot programs also have unique aspects that set them apart. For instance, Santa Monica's Zero-Emissions Delivery Zone pilot specifically focused on promoting the use of electric delivery vehicles by providing priority loading zones and monitoring usage through video analytics (Bergman & Billington, 2021). This pilot aimed to reduce greenhouse gas emissions and improve air quality, highlighting a targeted environmental goal not seen in other programs.

Furthermore, the Dupont Circle Safety Demonstration Pilot in Washington, DC, incorporated temporal aspects by designating specific curb spaces for passenger loading during late-night hours to improve safety and reduce congestion during peak times (DDOT, 2021). This time-based allocation strategy is tailored to the unique needs of a high-traffic nightlife area.

Lessons Learned

KEY SUCCESS FACTORS

One of the primary success factors in dynamic curbside management is the integration of advanced technologies for real-time monitoring and data collection. The use of automated license plate readers (ALPRs) and video analytics has proven effective in enhancing enforcement and compliance. These technologies provide accurate, real-time data that cities can use to adjust policies dynamically, ensuring that curb space is used efficiently and effectively (Automotus, 2020). Additionally, the implementation of digital platforms for curb space reservations, as seen in Washington, DC's CurbFlow pilot and Omaha's Smart Zones, has facilitated better management of curb demand and reduced instances of illegal parking (Coord, 2021). Another critical success factor is the adoption of flexible pricing models that reflect real-time usage patterns. This approach not only reduces congestion but also encourages the use of alternative modes of transportation, such as transit and biking, contributing to broader sustainability goals (District Department of Transportation et al., 2019).

COMMON PITFALLS AND CHALLENGES

Despite these successes, several challenges remain in the implementation of dynamic curbside management. One significant challenge is the coordination among multiple government agencies and stakeholders. Effective curbside management requires collaboration across various departments and with external partners, such as transportation network companies, delivery services, and technology infrastructure vendors. This coordination can be complex and time-consuming, often leading to delays and inconsistencies in policy implementation (City of Boston, 2019).

Another challenge is the high initial capital cost associated with installing and maintaining advanced technological systems. Although these technologies can provide long-term benefits, upfront investments can be prohibitive for many municipalities, especially those with limited budgets. Additionally, ensuring data privacy and security is crucial when using technologies that collect and process large amounts of personal and vehicle data (National Conference of State Legislatures, 2021).

BEST PRACTICES

Several best practices have emerged from the pilot programs that can guide future implementations. First, conducting comprehensive digital inventories of curb assets is essential. Cities like Los Angeles and Seattle have successfully created detailed, real-time maps of curb usage, which serve as a foundation for dynamic management strategies (Howell et al., 2019). These inventories allow for more informed decision-making and efficient allocation of curb space. Jurisdictions do not need to inventory all their curbs at once, they can start with a few high-demand block faces and expand as necessary.

Second, engaging with community stakeholders early and often is critical to the success of curbside management initiatives. Effective communication and collaboration with local businesses, residents, and other stakeholders help ensure that the policies implemented meet the community's needs and gain broader support (DDOT, 2021).

Lastly, adopting a phased approach to implementation allows cities to test and refine their strategies before scaling up. Pilot programs provide valuable insights and feedback that can be used to adjust policies and technologies, ensuring that they are effective and sustainable in the long term. For example, the Dupont Circle Safety Demonstration Pilot used specific time-based allocations to address peak demand periods, allowing for adjustments based on observed outcomes (DDOT, 2021).

In summary, the lessons learned from dynamic curbside management pilots highlight the importance of technological integration, flexible pricing, and stakeholder engagement. While challenges remain, the best practices identified can help cities navigate these complexities and implement effective curbside management strategies.

New and Emerging Curbside Management Trends

Prior to 2020, curbside management strategies increasingly incorporated technological advancements and multimodal transportation trends to enhance urban mobility efficiency. Cities allocated curb space to accommodate emerging mobility options, including TNC pickup/drop-off zones, dockless and docked micromobility stations, and dedicated transit space. These allocations reflected a broader shift towards sustainable transportation solutions and improved first/last mile connectivity. The COVID-19 pandemic precipitated an abrupt shift in curbside priorities, imposing a rapid and adaptive response to urgent public health requirements. Curb spaces were promptly repurposed to support curbside pickup for retail and dining establishments, expanded outdoor dining areas, and social distancing measures for pedestrians and transit users. These adaptations were typically implemented through temporary infrastructure modifications and expedited regulatory adjustments.

While pre-pandemic trends focused on long-term technological integration and multimodal efficiency, pandemic-era responses underscored the critical importance of flexibility and rapid adaptability in the urban streetscape. This shift highlighted the need for resilient and agile urban planning strategies capable of responding to unforeseen disruptions. As cities look to the future, effective curbside management will require integration of lessons learned from pandemic-era adaptations, incorporation of emerging technologies, development of data-driven, holistic approaches that balance diverse stakeholder needs, and implementation of flexible design standards that can accommodate changing priorities.

AUTOMATED DATA COLLECTION

The sophistication and diversity of automated data collection methods for curbside management have grown substantially. These methods provide crucial insights that enable cities to optimize

curbside usage efficiently. The Federal Highway Administration (Gopalakrishna, 2021) identifies three primary automated data collection techniques:

- **Video Data Collection:** Cameras equipped with image processing algorithms capture detailed curb activities, revealing usage patterns and peak times.
- **Radar Sensing:** This method monitors vehicle speed and volume, providing accurate data on movements and occupancy rates across various weather conditions.
- **Communications-Based Sensing:** Utilizing Bluetooth or Wi-Fi to detect connected devices, this approach offers insights into vehicle dwell times and turnover rates, particularly useful for tracking shared mobility services.

Complementing these automated methods, third-party data providers play a vital role in enhancing curbside management. These providers offer data from various sources, including mobility service companies, freight carriers, and specific-use data tools. The integration of third-party data with automated collection methods allows for a comprehensive and dynamic view of curbside usage. For instance, the Open Mobility Foundation's Mobility Data Specification (MDS) standardizes data exchange protocols, enabling efficient management and optimization of curbside spaces based on real-time conditions and long-term trends.

EMERGING TECHNOLOGIES AND INNOVATIONS

The integration of electric vehicles (EVs) and autonomous vehicles (AVs) is reshaping curbside management practices. Cities are rethinking how curbside spaces are allocated and managed to accommodate the unique needs of these technologies.

Autonomous Vehicles (AVs):

AVs present both opportunities and challenges for curbside management. They require precise infrastructure for efficient operation, as their navigation and parking systems depend on detailed curb data for physical and digital guidance (WGI, 2024). The deployment of AVs is expected to increase demand for dedicated loading and unloading zones, needing the design of unobtrusive and accessible pick-up/drop-off points that can be efficiently used by both autonomous and manually driven vehicles (WGI, 2024).

Electric Vehicles (EVs):

The growing adoption of electric vehicles (EVs) is significantly impacting curbside management due to the need for charging infrastructure. Cities must strategically integrate charging stations into curbside areas, balancing this new demand with traditional parking and loading functions (Gopalakrishna, 2021). Careful planning is required to ensure charging stations are placed in high-demand areas without causing congestion or reducing the availability of other essential curbside uses.

In addition to planning, cities must consider equitable access to EV charging. Installing charging equipment at the curb converts the space into an on-street parking spot, accessible only to a subset of vehicles. This presents challenges in residential areas, where residents without access to off-street parking seek EV charging facilities in spaces traditionally used for on-street residential parking.

To address these issues, NYCDOT is increasing access to curbside Level 2 electric vehicle charging, prioritizing high-density areas with limited off-street parking, neighborhoods with many taxi and for-hire drivers, and historically disadvantaged communities (New York City Department of Transportation, 2024). However, different jurisdictions are tackling this challenge in various ways. Montgomery County, for instance, is opting to place their charging stations in off-curb public locations, such as parking garages, park-and-ride lots, libraries, and community centers (Montgomery County, 2024).

Data and Technology Integration:

Programmable curbs, which use dynamic signage and data analytics to allocate curb space based on real-time demand, are becoming increasingly important (National Academies of Sciences, Engineering, and Medicine, 2022). These technologies enable cities to adapt to the varying needs of EVs, AVs, and traditional vehicles throughout the day, ensuring efficient and effective use of curb space.

SUSTAINABLE AND GREEN INITIATIVES

Cities are increasingly adopting sustainable curbside management strategies to address urban challenges such as congestion, emissions, and space utilization. Denver's Citywide Curbside Action Plan exemplifies this trend, emphasizing a flexible, dynamic system that prioritizes sustainable transportation modes over single-occupancy vehicles. By implementing Bike+ Parking (short term storage for personal or shared bicycles and scooters) and pedestrian-friendly infrastructure, Denver aims to encourage active transportation, reduce vehicle emissions and promote public health (Denver Department of Transportation & Infrastructure, 2024).

Building on these efforts, research from the National Center for Sustainable Transportation (NCST) highlights innovative strategies that further minimize emissions and congestion. Cities like San Francisco have piloted demand-based parking, time-of-day restrictions, and dynamic pricing, significantly reducing cruising time for parking and decreasing vehicle emissions by up to 40% in commercial areas (Jaller et al., 2021). These initiatives, coupled with Complete Streets policies, optimize curbside space and improve overall urban mobility.

New York City's approach complements these strategies, focusing on modernizing curb lanes with bike-sharing stations, electric vehicle chargers, and expanded pedestrian spaces. The city's Curb Management Action Plan also includes the implementation of low-emission zones and the promotion of cargo bikes for deliveries, aligning with broader climate goals (New York City Department of Transportation, 2024). This approach demonstrates how cities can prioritize environmental sustainability while addressing diverse urban needs.

INTEGRATION OF MULTIMODAL TRANSPORTATION

The evolution of curbside management reflects a growing recognition that urban curb space must serve diverse mobility needs beyond private vehicles and parking. Cities are implementing strategies to integrate multiple transportation modes, increasing inclusivity and efficiency.

New York City exemplifies this approach through its comprehensive redesign of curb spaces. The city has strategically allocated areas for bike parking and micromobility options, while also positioning bike lanes adjacent to curbside parking, as shown in **Figure 3**. This layout enhances cyclist safety without compromising street efficiency (New York City Department of Transportation, 2021).

Figure 3: NYC bike lanes protected by parked vehicles

Bicycle lane (NYC DOT Curb Management Action Plan)

Denver has taken a different yet equally innovative approach, by implementing multimodal lanes that accommodate bicycles and e-scooters, separated from vehicular traffic by physical barriers, as illustrated in **Figure 4**. This design enhances the safety and appeal of micromobility options. The city has also focused on pedestrian-friendly curbside designs, incorporating wider sidewalks, pedestrian plazas, and curb extensions to improve walkability and access to public transit (Denver Department of Transportation & Infrastructure, 2024)

The Denver's Citywide Curbside Action Plan also outlines strategies for integrating transit with curbside uses to manage the available space effectively. In Bus Rapid Transit (BRT) corridors on commercial streets, curbside uses such as Passenger Pick-Up/Drop-Off (PUDO) and Bike+ Parking are prioritized to facilitate transit operations without impacting other activities. Flex Zones accommodate various short-term uses, including commercial loading, TNCs like Uber and Lyft, and PUDO, which helps to manage congestion near transit stops. By placing these zones near bus lanes and transit shelters, the plan addresses multiple curbside demands while maintaining transit accessibility.

Figure 4: Denver's protected bike lanes and exclusive bus lanes

Cyclists in separated bicycle lane (Denver's Citywide Curbside Action Plan)

These city-level innovations highlight key elements of successful multimodal curbside integration: flexible design, clear space delineation, smart technology integration, and consideration of first/last mile connections to public transit. By reimagining curbside spaces to accommodate multiple modes, cities are supporting broader goals of reducing congestion and emissions.

EQUITY AND ACCESSIBILITY

Equity and accessibility have become central considerations in modern curbside management strategies. Cities are recognizing the importance of serving all community members, particularly those from historically underserved or marginalized groups.

Denver and New York City exemplify this approach in their curbside action plans. Denver's plan makes equity a core principle, ensuring that curb space allocation benefits diverse users including pedestrians, cyclists, transit riders, and people with disabilities (Denver Department of Transportation & Infrastructure, 2024). Similarly, New York City prioritizes curb uses based on neighborhood-specific needs, implementing accessible loading zones and expanded bike parking in areas that need them most (New York City Department of Transportation, 2024).

Data-driven approaches are crucial in achieving these equity goals. The National Academies of Sciences, Engineering, and Medicine emphasize the importance of robust data collection and analysis to understand utilization patterns and identify access disparities. This approach, combined with diverse stakeholder involvement, ensures policies reflect community needs (National Academies of Sciences, Engineering, and Medicine, 2022). Technology is also enhancing accessibility, with digital platforms providing real-time information about available spaces and facilitating easier navigation for people with disabilities.

The Public Right of Way Accessibility Guidelines (PROWAG) outline necessary accessible curb elements, such as curb ramps, on-street parking spaces, and other curb right-of-way components. PROWAG is anticipated to be adopted by the U.S. Department of Justice and Department of Transportation in the coming years which will mandate the curb access elements as required and enforceable. In preparation for this adoption, many jurisdictions are incorporating these accessible curb elements to improve curb access for all.

NEXT STEPS

After the Curbside Forum, participants received a post-event survey to provide feedback on various aspects, including the discussion topics and event format. Please refer to the TPB Regional Curbside Management Forum Post Event Report, which summarizes the event outcomes, participant feedback, and survey results.

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