

Article

A Multidisciplinary Framework for Assessing Public Transit Readiness for Smart City Integration: A Case Study of Austin, Texas

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Abstract

Public transit agencies are increasingly expected to support smart city goals, but the existing assessment tools often examine transit technology, urban design, environmental performance, or service quality separately. This paper develops a multidisciplinary framework for assessing how ready a public transit system is for integration into a smart city environment. The framework organizes readiness into eight dimensions: technological integration, accessibility, mobility, sustainability and environmental impact, data security and privacy, resilience and adaptability, community engagement and feedback, and safety, security, and rider comfort. These dimensions are further divided into operational subcategories that can be examined using quantitative indicators, public documents, and expert ratings. The framework is applied to Austin, Texas, using CapMetro service information, static GTFS data, census and ACS data, public agency documents, and a short expert rating exercise. The Austin case indicates relatively stronger performance in sustainability and technology adoption, supported by electric and hybrid fleet investments, mobile fare payment, and real-time vehicle information. Lower scores are observed in resilience, community feedback, mobility, and spatial accessibility, particularly in areas where peripheral neighborhoods have limited stop coverage or long scheduled headways. The paper contributes a practical screening tool that can help planners identify where public transit systems are aligned with smart city objectives and where additional investment, governance, or data transparency is needed.

Keywords: public transit; smart mobility; smart city integration; transit readiness; GTFS; accessibility; mobility performance; transit resilience; urban transportation planning



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1. Introduction

Cities are investing in smart infrastructure, real-time information systems, open data platforms, and cleaner mobility technologies. Public transit is central to these efforts because it affects congestion, emissions, access to employment, and the daily mobility of people who do not drive. For this reason, the performance of a transit system cannot be judged only by the presence of digital tools. A system may have mobile ticketing and real-time vehicle information, but still fall short if service is infrequent, stops are difficult to reach, data practices are unclear, or public feedback does not influence planning decisions [1–4].

Research on smart mobility has expanded quickly, but much of the literature remains divided by topic. Some studies emphasize intelligent transportation systems, digital platforms, or automated data collection. Others focus on transit-oriented development, service reliability, emissions reduction, accessibility, or public participation [5–8]. These perspectives are useful, but they do not always give transit agencies and city planners a single assessment structure that connects technology, equity, environmental performance, governance, and operational resilience.

This paper addresses that gap by developing a multidisciplinary framework for assessing public transit readiness for smart city integration. The framework is designed as a practical screening tool rather than a replacement for detailed engineering, planning, or equity analysis. It groups readiness indicators into eight dimensions and applies them to Austin, Texas, to examine whether the framework can identify strengths, gaps, and priorities for improvement.

The Austin case is useful because the city has invested in transit modernization, open data, digital information tools, and long-term mobility planning, while also facing challenges associated with rapid growth, spatial inequality, heat exposure, and car dependence. By applying the framework to Austin, the study shows how a transit system can be evaluated across both technical and social dimensions of smart city readiness.

The paper is organized as follows. Section 2 reviews the literature and positions the proposed framework relative to the existing assessment tools. Section 3 describes the framework, data sources, expert rating procedure, score calculation, and spatial analysis. Section 4 presents the Austin case study results. Section 5 discusses implications for planning and governance. Sections 6 and 7 present limitations and conclusions.

2. Literature Review

2.1. Smart Cities and Public Transit

Smart city research increasingly treats digital technology as one component of urban governance rather than as an end in itself. In transportation, this distinction is important. Sensors, mobile applications, smart cards, vehicle location data, and connected infrastructure can improve service monitoring and passenger information, but they do not automatically improve access, reliability, affordability, or trust [1–3]. A transit-oriented smart city therefore requires both technical capacity and institutional capacity: agencies need data systems, but they also need service planning, privacy safeguards, equity analysis, and mechanisms for public accountability.

2.2. Smart Transportation and Operational Readiness

Smart transportation systems include technologies that collect, exchange, and analyze information across vehicles, infrastructure, passengers, and control centers. In public transit, these systems commonly include automatic vehicle location, real-time arrival prediction, mobile fare payment, GTFS and GTFS-realtime feeds, transit signal priority, and integrated trip planning [4–7]. The value of these tools depends on whether they improve service outcomes that riders experience directly, such as shorter waiting times, more reliable transfers, safer access to stops, and clearer information during disruptions.

2.3. Equity, Accessibility, and Mobility Performance

Transit readiness for smart city integration also depends on spatial and social accessibility. A digitally advanced transit system can still be weak if low-income neighborhoods, older adults, disabled riders, or households without cars face long walks to stops, infrequent service, or poor first- and last-mile conditions. Accessibility indicators should therefore be considered alongside mobility indicators such as headway, reliability, travel

time, transfer burden, service span, demand-responsive service performance, and multi-modal connection [8–16].

2.4. Sustainability, Resilience, and Governance

Sustainability indicators are commonly linked to fleet electrification, renewable energy, mode shift, and support for walking and cycling [17–19]. However, climate adaptation and resilience are equally important for transit systems operating in cities exposed to extreme heat, flooding, winter storms, or infrastructure disruptions [18,19]. Data security and privacy are also part of governance readiness because smart transit services often depend on passenger, payment, and location data. A readiness framework should therefore examine whether agencies have transparent data practices, cybersecurity safeguards, and feedback loops that allow riders and communities to influence decisions [20–26].

2.5. Positioning the Proposed Framework

The existing frameworks contribute important but partial perspectives. The ITDP TOD Standard focuses strongly on walkability, density, land-use mix, and station-area design. The NACTO Transit Street Design Guide provides detailed guidance for streets, stops, and transit-priority treatments, while ISO 37120 provides standardized city-level indicators, including selected transportation measures [27–29]. The proposed framework differs from these tools in purpose and scope. It is a transit-specific screening structure that brings technological, operational, accessibility, environmental, governance, resilience, community, and rider-facing evidence into one assessment. Its contribution is the integration of these dimensions and the use of both expert judgment and publicly available evidence, rather than the replacement of specialized design or performance standards. The framework is therefore intended as a complementary diagnostic tool that can indicate where a more detailed assessment is needed.

Table 1 summarizes the dimensions and subcategories used in the proposed framework.

Table 1. Framework dimensions, readiness criteria, objectives, and supporting references.

Dimension	Readiness Criterion	Objective	References
Technological integration	Smart sensing and data analytics	Use IoT sensors, GPS tracking, and real-time data analytics to support system monitoring and decision making.	[3,6,7,20,30]
	Mobile applications	Support route planning, fare payment, and real-time information on schedules and service disruptions.	
	Smart infrastructure	Improve traffic flow, reduce congestion, and strengthen connections among transportation modes.	
	Transit priority treatments	Improve public transit speed and reliability through transit signal priority, bus-only lanes, queue jumps, dedicated transit lanes, and curbside priority management.	
	Advanced signal operations	Use adaptive signal control, corridor coordination, and real-time transit and traffic data to reduce intersection delay and support scheduled service.	
	Driver support systems	Improve safety and operational performance through collision warning, blind-spot detection, pedestrian detection, lane-departure warning, and driver-fatigue monitoring.	

Table 1. Cont.

Dimension	Readiness Criterion	Objective	References
Accessibility	Fare affordability	Improve fare affordability for riders across income groups.	[8,9,12,14–16,31–33]
	Service availability for access	Maintain a basic level of service availability needed to reach daily opportunities.	
	Geographic service coverage	Provide service across different parts of the city, including lower-density and peripheral areas.	
	Accessible services for people with disabilities	Provide transit services and facilities that can be used by people with disabilities.	
	Demand-responsive access flexibility	Adjust service or access options when demand or local conditions change.	
	Physical access to transit stops and stations	Improve pedestrian and spatial access to transit stops and stations.	
	Physical multimodal access	Connect transit stops and stations with walking, cycling, bike-share, e-scooter, and other first- and last-mile options.	
Mobility	Reliability and on-time performance	Improve schedule adherence, reduce service variability, and increase consistency in transit operations.	[3,6,7,12,14,15,31,34]
	Travel time and transfer efficiency	Reduce in-vehicle travel time, transfer time, the number of transfers, and additional journey time compared with direct trips.	
	Real-time passenger information	Improve the accuracy of predicted wait times, journey times, service alerts, and trip-planning information.	
	Service frequency and span	Improve scheduled headways, service availability, and operating hours across times of day and areas of the city.	
	Demand-responsive service reliability	Reduce missed trips, unfulfilled bookings, and service gaps in demand-responsive or paratransit services.	
	Fare payment reliability	Reduce incomplete mobile ticketing, smart-card, and digital-payment transactions.	
	Multimodal trip planning and integration	Improve coordination among transit, walking, cycling, bike-share, e-scooters, park-and-ride, and other shared mobility services.	
Sustainability and environmental impact	Cost-effectiveness	Reduce operating cost per revenue hour while maintaining service quality and coverage.	[3,4,8,16,17,35]
	Adoption of electric or hybrid vehicles	Reduce operational emissions and other environmental impacts.	
	Investment in renewable energy sources	Increase the use of renewable energy for transit facilities and operations.	
Data security and privacy	Promotion of sustainable transportation modes	Support walking, cycling, and shared travel through infrastructure and incentives.	[20–22,36]
	Cybersecurity measures	Protect passenger and operational data and maintain the integrity of transportation systems.	
	Data privacy compliance	Protect personal information and support compliance with applicable privacy requirements.	

Table 1. Cont.

Dimension	Readiness Criterion	Objective	References
Resilience and adaptability	Redundancy and backup systems	Maintain continuity of service during emergencies and system failures.	[19,37–42]
	Adaptive operational capacity	Adapt operations and technology to changing urban conditions.	
	Emergency preparedness and resilience	Prepare for and respond to natural disasters, extreme weather, and other service disruptions.	
Community engagement and feedback	Feedback mechanisms	Identify rider concerns, service issues, and improvement opportunities.	[19,23–25,38]
	Stakeholder engagement	Involve residents, businesses, advocacy groups, and transit-dependent communities in planning and decision making.	
	Incorporation of public input	Integrate community feedback into route planning, service changes, station design, and investment priorities.	
	Feedback-loop reporting	Report how public comments, rider feedback, and stakeholder input influence final decisions.	
	Inclusive and multilingual outreach	Improve participation among low-income riders, people with disabilities, non-English speakers, older adults, and underserved communities.	
Safety, security, and rider comfort	Crash and incident reduction	Reduce reported crashes, injuries, fatalities, passenger falls, and other transit-related safety incidents.	[7–9,26,43]
	Stop and station security	Improve actual and perceived passenger security through lighting, visibility, surveillance, emergency communication, and station-area design.	
	Heat exposure and weather protection	Reduce rider exposure to heat, sun, and severe weather through shelters, shade structures, tree canopy, and climate-sensitive stop design.	
	Passenger waiting environment	Improve waiting conditions through seating, lighting, shelter, real-time information, drinking water where appropriate, and accessible boarding areas.	
	Safe first and last-mile access	Improve pedestrian, cyclist, and ADA access to stops and stations through safer crossings, sidewalks, traffic calming, and protected access routes.	

Table 2 compares the proposed framework with selected public transit and smart mobility frameworks across key dimensions.

Table 2. Comparative assessment of selected public transit and smart mobility frameworks across key dimensions.

Framework	Technology Integration	Community Engagement	Mobility Analysis	Data Privacy/Security	Visualization	Primary Scope
ITDP TOD Standard	High	Low	Medium	None	Basic maps	Urban design and station-area development
NACTO Transit Street Design Guide	Medium	Medium	High	None	Illustrations	Street design and transit priority
ISO 37120	Low	Low	Low	Low	None	City-level indicators
Proposed framework	High	High	High	Medium	Flowchart and readiness summary	Transit readiness for smart city integration

Note: The ratings describe the scope and emphasis of each framework, not empirical performance. High indicates that a dimension is an explicit and substantial part of the framework; Medium indicates clear but partial coverage; Low indicates limited or indirect coverage; and None indicates that no explicit coverage was identified in the reviewed documentation.

3. Methodology

3.1. Framework Development

The framework was developed through a structured review and grouping process. Academic studies, planning guidance, and smart mobility frameworks were reviewed when they addressed at least one of the following areas: public transit operations, smart mobility technology, accessibility and equity, environmental performance, data governance and privacy, resilience, community engagement, or rider safety and comfort. Candidate indicators were retained when they were relevant to transit readiness at the agency or city scale and could be supported by public data, agency documents, expert judgment, or a combination of these sources. Indicators that were highly specific to a single technology, duplicated another item without adding a distinct function, or could not be interpreted consistently were not retained as separate criteria.

The retained indicators were grouped into eight dimensions according to their primary analytical purpose. Some concepts were kept in more than one dimension because they represent different functions. For example, service availability under accessibility concerns whether riders can reasonably reach opportunities, whereas service frequency and span under mobility describe scheduled operational performance. Similarly, demand-responsive flexibility under accessibility concerns access options when demand changes, while adaptability under resilience concerns continuity and system response during disruptions. The Austin application was then used to examine whether the resulting structure could organize expert judgment and publicly available evidence in a practical screening assessment.

3.2. Indicator Structure

The eight dimensions are technological integration, accessibility, mobility, sustainability and environmental impact, data security and privacy, resilience and adaptability, community engagement and feedback, and safety, security, and rider comfort. Each dimension contains criteria that can be examined using quantitative indicators, document review, expert judgment, or a combination of these sources. The framework is intended to identify relative strengths, gaps, and areas requiring more detailed analysis; it is not intended to produce a validated city ranking or a single universal readiness index.

Table 1 is the complete indicator inventory used to define the framework. Figure 1 provides a schematic overview of the eight dimensions and their criteria.

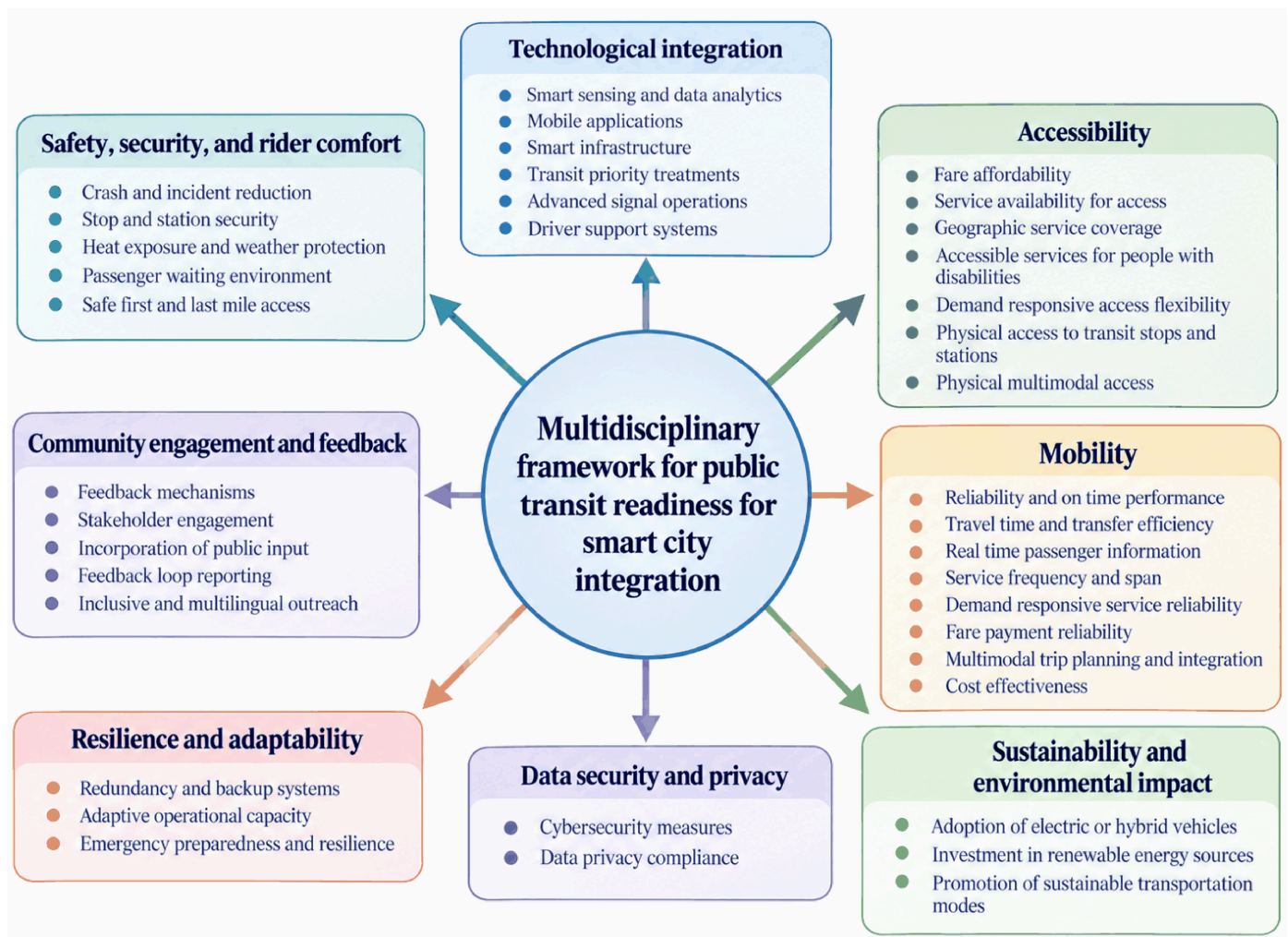


Figure 1. Multidisciplinary framework for public transit readiness for smart city integration. The eight dimensions and criteria correspond to Table 1.

3.3. Expert-Based Rating Procedure

A total of 24 individuals participated in the expert rating exercise. Five participants held master's degrees in transportation planning and were working in the transportation industry, 13 were doctoral students in transportation-related fields, and six held doctoral degrees in transportation-related fields and were working in the transportation industry. All 24 participants were living in Austin at the time of the study, providing direct familiarity with the local transportation context. Participants were selected using purposive and snowball sampling based on their relevant academic background, professional experience, and familiarity with transportation systems. The questionnaire recorded professional or academic area, current role, and level of familiarity with Austin's transportation system.

Ratings were collected individually and in person. The questionnaire included ratings of the eight main dimensions of the framework on a five-point scale from 1 to 5. The eight dimensions were technological integration, accessibility, mobility, sustainability and environmental impact, data security and privacy, resilience and adaptability, community engagement and feedback, and safety, security, and rider comfort. No names or direct personal identifiers were recorded with the rating results.

For each dimension, the individual 1 to 5 ratings were averaged to obtain the mean expert rating. The mean ratings were 4.1 for technological integration, 2.3 for accessibility, 2.2 for mobility, 3.7 for sustainability and environmental impact, 2.8 for data security and privacy, 2.6 for resilience and adaptability, 2.0 for community engagement and feedback, and 4.5 for safety, security, and rider comfort. These means summarize the expert questionnaire and were not direct numerical inputs to the criterion scores or the dimension-level readiness scores. Supplementary Table S2 reports the sample standard deviation, median, interquartile range, and rating frequencies from 1 to 5 for each dimension; sample standard deviations ranged from 0.36 to 0.66. For mainly qualitative criteria, expert judgment provided supporting context alongside agency documents and other publicly available evidence. The readiness scores were calculated separately, as described in Section 3.6. Table 3 presents the five-point scoring rubric used for the readiness assessment.

Table 3. Scoring rubric used for readiness assessment.

Score	Interpretation	Evidence Expected
1	Not implemented	No documented or operational evidence; the criterion is absent or not functioning.
2	Limited implementation	Pilot, partial, or uneven implementation; evidence or coverage is limited.
3	Moderate implementation	The core function exists, but coverage, reliability, transparency, or integration is inconsistent.
4	Mostly implemented	Broad implementation, with limited or localized remaining gaps.
5	Well implemented	Broadly operational and documented, with consistent supporting evidence.

3.4. Data Sources

The case study used publicly available transit and urban data, including CapMetro GTFS data, CapMetro planning and performance documents, Austin open data sources, census tract boundaries, ACS demographic variables, and transit safety information [44–48]. For the accessibility analysis, January 2025 CapMetro Stops and Service Area shapefiles [49] were combined with 2023 U.S. Census TIGER/Line census tracts [50]. These sources were used to examine stop locations, route coverage, scheduled service frequency, spatial accessibility, reported safety events, selected sustainability indicators, and community engagement evidence.

The evidence base was not a single-year panel. The principal reference periods were 2023 ACS demographic data [45], the 2022 National Transit Database safety records [48], 2023 Project Connect outreach material [51], 2022 rider survey results [52], the January 2025 CapMetro stop and service-area shapefiles [49], 2023 TIGER/Line census tracts [50], the CapMetro static GTFS feed covering 22 May through 16 August 2025 [53], FY2023 operational and safety performance reported in CapMetro’s FY2024 budget [54], the 2023 CapMetro Service Standards and Transit Stop and Station Design Guidelines [55], the January 2025 fare-payment system update [56], the CapMetro privacy policy effective in 2019 [57], zero-emission fleet milestones documented for 2020–2024 [58], and Transit Speed and Reliability Program outcomes reported for 2018–2024 [59]. For each indicator, the most relevant public source available to the study was used. The results are therefore interpreted as a readiness screening assembled from different evidence vintages rather than as a synchronized same-year performance evaluation.

3.5. Spatial and GTFS Analysis

GTFS files were used to identify stops, routes, trips, and scheduled stop times. Stop locations were mapped and linked to route information to estimate the number of routes serving each stop. The archived CapMetro GTFS version whose service window included 28 July 2025 covered 22 May through 16 August 2025 and contained 72 routes, 2356 stops, 29,594 trips, and 1,119,765 stop-time records [53]. Scheduled intervals were derived from stop_times.txt and trips.txt for weekday service records and are reported as a full-day weekday screening. Because static GTFS represents planned schedules, the analysis describes scheduled service frequency only and does not measure actual schedule adherence, observed delay, or on-time performance.

Accessibility was treated as a screening-level spatial measure. The analysis retained 2023 census tracts whose geometric centroids fell within the Austin polygon in the January 2025 CapMetro Service Area shapefile ($n = 210$). Straight-line distances were calculated in UTM Zone 14N (EPSG:32614) from each tract centroid to the nearest January 2025 CapMetro stop, and 800 m was used as an approximate walk-access benchmark [13,49,50]. Each tract therefore contributed one centroid-to-stop distance. The measure was not population-weighted and did not use the pedestrian street network or the within-tract distribution of residents. It may therefore overstate practical walking access in large or heterogeneous tracts and in areas with disconnected streets, barriers, or unsafe pedestrian conditions.

3.6. Score Calculation and Evidence Use

Dimension-level scores in Table 4 were calculated as the arithmetic mean of the final criterion scores within each dimension. Supplementary Table S1 reports each final criterion score, the principal supporting evidence, the specific documentary or data source and reference period, the Table 3 scoring basis, and the role of expert input. The principal investigator assigned the initial criterion scores by synthesizing the available quantitative and documentary evidence against the five-point rubric in Table 3. Two co-authors then reviewed the supporting evidence and the evidence-to-score mapping and approved the final criterion values. The coauthors did not conduct independent blind scoring; therefore, an inter-rater agreement statistic was not calculated for this criterion-scoring stage. The 24 participants rated the eight main dimensions rather than the individual criteria, so the criterion-scoring process was separate from the expert dimension-rating exercise. Subcategories were assigned equal weight, and the eight dimension scores were not combined into a single overall index. Direct quantitative indicators were used as the primary evidence where available. For mainly qualitative criteria, the corresponding expert dimension rating was used only as supporting context alongside documentary evidence and was not entered as a numerical input to the criterion score. The evidence-to-score audit also distinguished the existence of a program or feature from its documented breadth, systemwide coverage, reliability, and performance; consequently, a low score does not necessarily indicate that a function is absent, and a high score does not imply complete systemwide implementation.

Equal weighting was retained as a transparent screening rule because the study did not have a validated basis for assigning different weights to the subcategories. Decimal dimension scores were interpreted using midpoint ranges derived from the five-point rubric: 1.00–1.49, not implemented; 1.50–2.49, limited implementation; 2.50–3.49, moderate implementation; 3.50–4.49, mostly implemented; and 4.50–5.00, well implemented. The decimal values result from arithmetic averaging of integer criterion scores. Differences of a few tenths should not be interpreted as precise performance differences. The resulting values are screening-level summaries and are not formally validated performance measurements.

Table 4. Summary of Austin public transit readiness scores.

Dimension	Score	Interpretation	Main Strength	Main Weakness
Technological integration	3.0	Moderate	Mobile fare payment and real-time vehicle information	Limited multimodal integration and public documentation on user-generated data
Accessibility	2.9	Moderate	Strong stop access in central corridors	Longer access distances and lower route density in eastern, southeastern, and peripheral areas
Mobility	2.5	Moderate	Shorter scheduled headways on major routes and useful service in key corridors	Long scheduled intervals on lower-frequency routes and uneven network usefulness
Sustainability and environmental impact	4.3	Mostly implemented	Electric and hybrid fleet investments and active transportation support	Limited public emissions reporting at a detailed operational level
Data security and privacy	3.0	Moderate	Basic digital services and fare/vehicle information systems	Limited public documentation on data governance, retention, anonymization, and cybersecurity
Resilience and adaptability	2.0	Limited	Basic service adjustment and emergency response capacity	Limited public evidence of predictive disruption planning and adaptive system reconfiguration
Community engagement and feedback	2.4	Limited	Public meetings, surveys, open houses, and project outreach	Limited evidence that rider input is representative and visibly incorporated into final decisions
Safety, security, and rider comfort	3.2	Moderate	Public reporting of significant safety events and rider-comfort considerations	Raw incident counts are not exposure normalized, and proactive stop-level safety and comfort monitoring is limited

4. Case Study and Results

4.1. Austin Case Study Context

Austin, Texas, was selected as the case study because it combines rapid population growth, an expanding regional transit agency, active smart mobility initiatives, and persistent spatial equity challenges. CapMetro has introduced several digital and sustainability-oriented services, including mobile fare payment, real-time service information, and fleet modernization. At the same time, Austin's development pattern creates uneven transit access across central, eastern, southeastern, and peripheral areas. This mix of progress and remaining gaps makes Austin a suitable setting for testing a readiness framework.

4.2. Technological Integration

CapMetro has adopted several core technologies associated with smart transit systems, including mobile fare payment, real-time vehicle information, and integration with third-

party trip-planning platforms. These tools improve passenger information and reduce some barriers to using the system. However, technology integration remains incomplete. Multimodal coordination with bike-share, micromobility, park-and-ride, and rail services is still uneven, and public evidence on how user-generated data are collected, analyzed, and protected is limited. Based on the available evidence, technological integration is assessed as moderate, with stronger performance in passenger-facing digital tools and weaker performance in systemwide multimodal integration and data governance. Figure 2 summarizes the main strengths, weaknesses, opportunities, and threats associated with Austin’s transit technology integration.

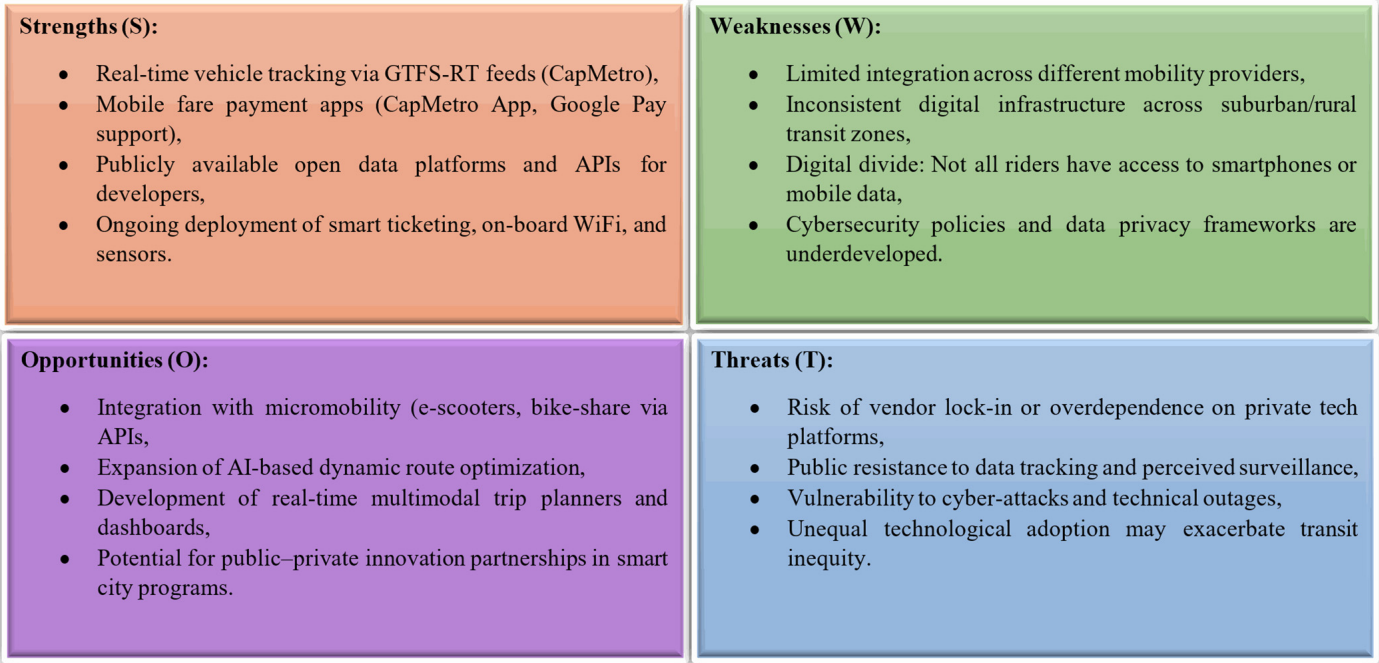


Figure 2. SWOT summary of Austin’s transit technology integration based on public agency information and expert assessment.

4.3. Accessibility

The accessibility analysis included 210 census tracts. Of these, 159 tracts (75.7%) had centroid-to-nearest-stop distances of 800 m or less, while 51 tracts (24.3%) exceeded 800 m. The mean straight-line distance was 737 m and the median was 402 m; the interquartile range was 159 to 771 m, and the 90th percentile was 1415 m. The difference between the mean and median reflects a right-skewed distribution produced by a relatively small number of peripheral tracts with large centroid-to-stop distances. These values are screening measures and should not be interpreted as actual pedestrian walking distances.

Figure 3 maps bus stops by the number of routes serving each stop. The highest concentrations are in and near central Austin, where transfer opportunities and route density are greatest. Figure 4 shows the 20 census tracts with the largest straight-line centroid-to-nearest-stop distances in the revised accessibility calculation. The figure and summary statistics are not population weighted and do not account for the pedestrian street network, crossings, barriers, or the within-tract distribution of residents; they are intended to identify areas that warrant more detailed pedestrian-network and equity analysis.

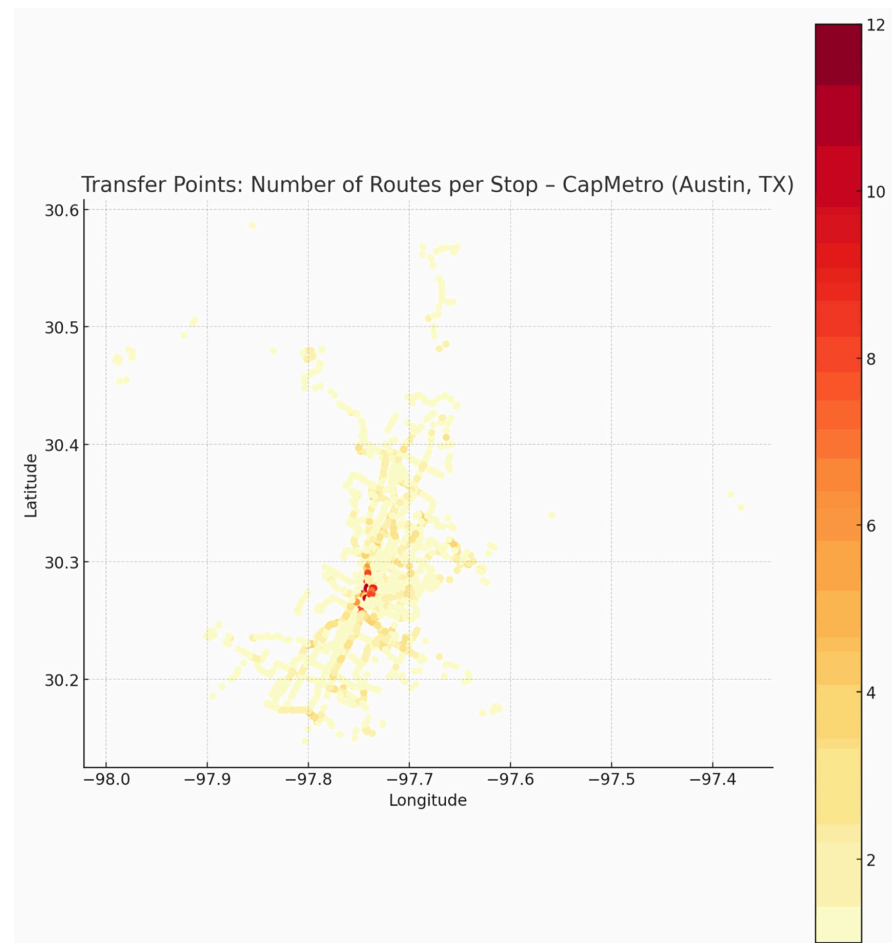


Figure 3. CapMetro bus stops by number of routes served. Source: CapMetro GTFS feed.

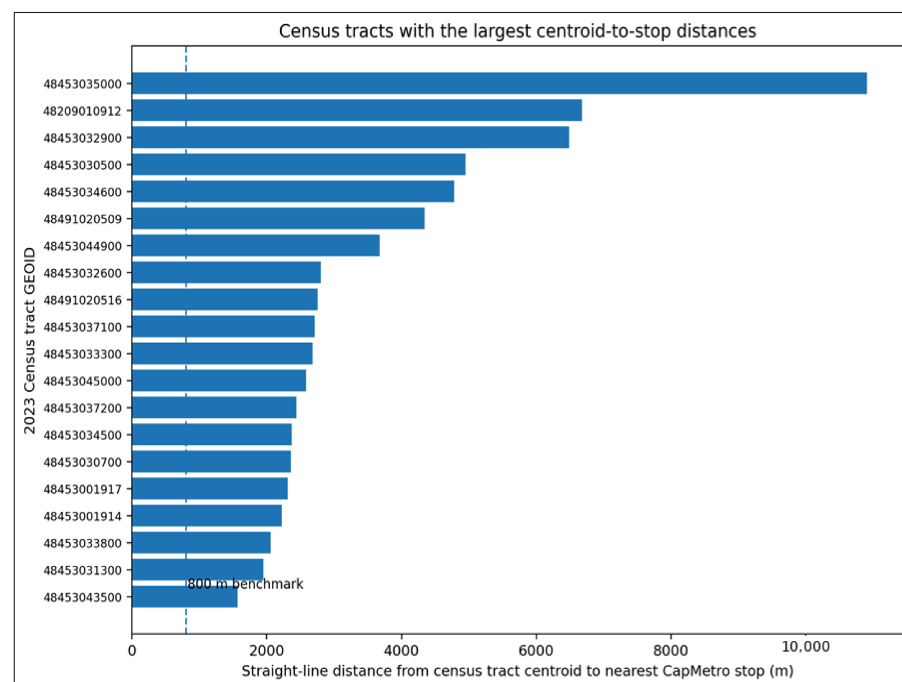


Figure 4. Twenty 2023 census tracts with the largest straight-line distance from the census tract centroid to the nearest CapMetro stop among tracts whose centroids fall within the Austin service-area polygon. The dashed line marks the 800 m screening benchmark. Distances are not population weighted and do not represent pedestrian-network distance. Source: January 2025 CapMetro Stops and Service Area shapefiles and 2023 U.S. Census TIGER/Line census tracts [49,50].

4.4. Safety, Security, and Rider Comfort

CapMetro reports significant transit safety events through the National Transit Database and other public reporting channels. Figure 5 presents reported event, injury, and fatality counts by service mode for 2022 [48]. These values are raw counts and are not normalized by vehicle mileage, service hours, or passenger volume; they therefore should not be interpreted as exposure-adjusted safety rates or as a complete measure of safety performance. The safety, security, and rider comfort dimension also considers reporting practices, stop and station conditions, first- and last-mile access, and rider-comfort factors. The available evidence supports a screening-level interpretation, while a stronger safety assessment would require exposure-normalized indicators and more detailed stop-level data.

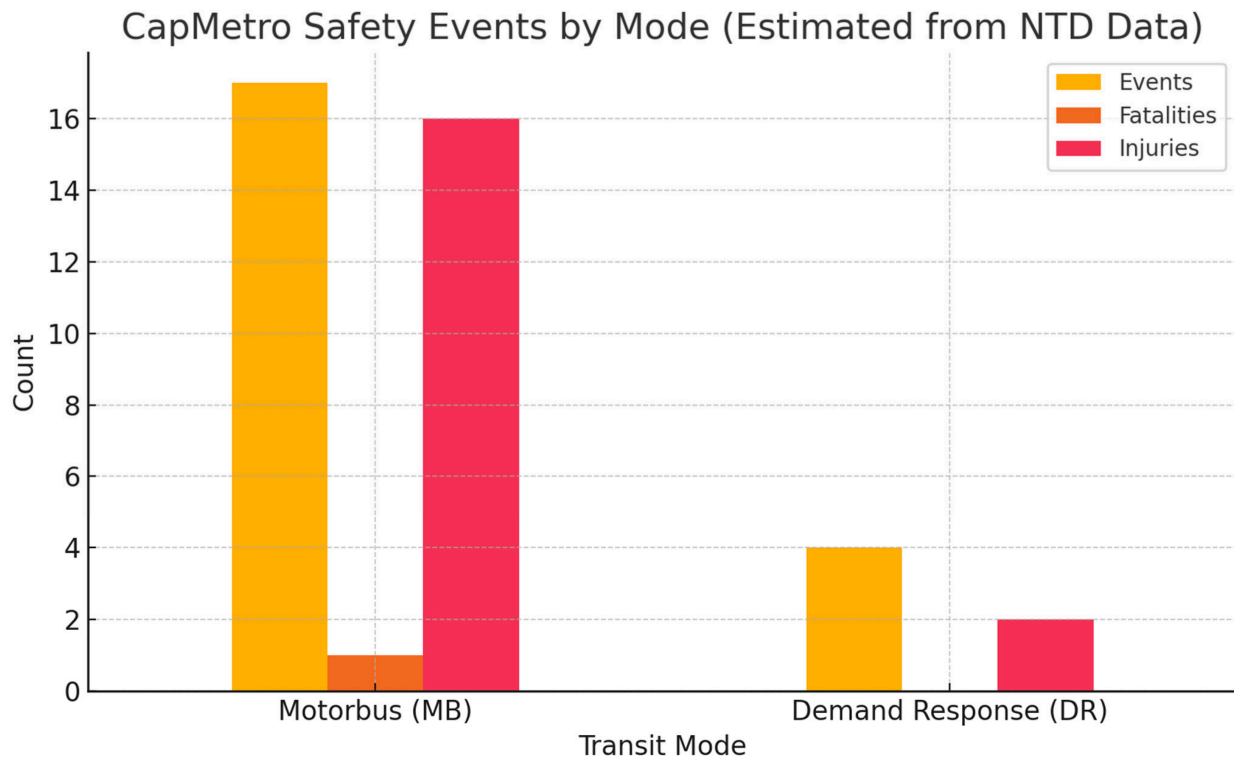


Figure 5. Reported CapMetro significant safety events by service mode in 2022. Values are unnormalized counts and should not be interpreted as exposure-adjusted safety rates. Source: National Transit Database.

4.5. Mobility

The mobility analysis indicates that scheduled service is more frequent on major routes, while the 2025 GTFS distribution also contains a long tail of less frequent scheduled service. The archived feed version covering the study date contained 72 routes, 2356 stops, 29,594 trips, and 1,119,765 stop-time records [53]. The weekday screening showed a concentration of scheduled intervals in the 2–15 min range and a long tail extending beyond 60 min on lower-frequency service. Official route schedules from the same June–August 2025 service period provide complementary route-level benchmarks. Across the eight listed UT Shuttle routes, approximate weekday morning frequencies ranged from 8 to 15 min, daytime frequencies from 10 to 20 min, evening frequencies from 12 to 23 min, and night frequencies from 15 to 45 min; Sunday frequencies ranged from 30 to 50 min [60]. Route 333's outer Oak Hill branch was explicitly scheduled at 30 min frequencies on weekdays and 60 min frequencies on Saturdays and Sundays [61]. These route-level values are consistent with the GTFS pattern of short intervals on higher-frequency services and a longer tail on lower-frequency or branch service. All of these measures describe planned

service and should not be interpreted as observed on-time performance or day-to-day reliability. Figure 6 shows the descriptive distribution of scheduled headways from the 2025 CapMetro static GTFS screening.

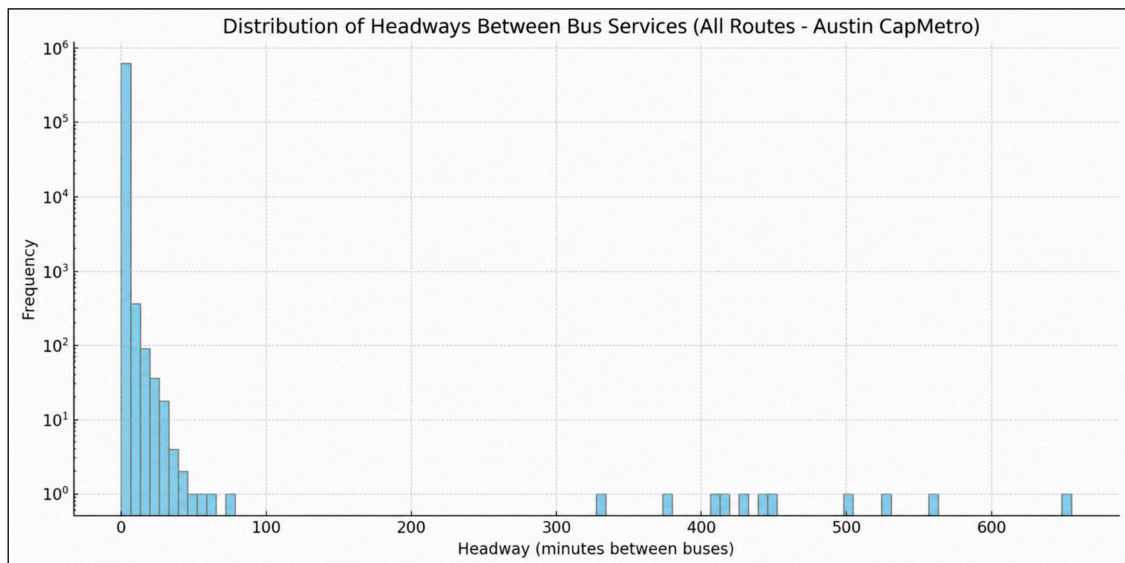


Figure 6. Descriptive distribution of scheduled intervals from the 2025 CapMetro static GTFS screening. The distribution is concentrated in the 2–15 min range with a long tail extending beyond 60 min. Official schedules from the same service period provide route-level examples ranging from 8–15 min in the morning on the listed UT Shuttle routes to 30–50 min on Sundays, while the outer branch of Route 333 is listed at 30 min on weekdays and 60 min on weekends [60,61]. Long intervals may reflect low-frequency routes, branch service, or breaks between service periods and do not represent measured on-time performance. Source: CapMetro GTFS feed and official route schedules [44,53,60,61]. Figure 7 shows the spatial distribution of CapMetro transit stops across Austin, Texas.



Figure 7. Spatial distribution of CapMetro transit stops in Austin, Texas. Source: CapMetro GTFS feed.

4.6. Sustainability and Environmental Impact

Austin and CapMetro have made visible progress toward lower-emission transit. CapMetro reports that its first electric buses entered service in 2020, the Board approved the purchase of nearly 200 electric buses in 2021, and construction began in 2024 on a North Austin facility designed to support the electric fleet; the agency also states that these buses source electricity from solar and wind energy [58]. Transit Speed and Reliability Program investments have also supported transit-priority and active-transportation improvements [59]. These actions support the sustainability dimension of the framework. The main gap is transparency: publicly available emissions reporting is not sufficiently detailed to show how fleet changes, service changes, and mode shift affect emissions over time. The sustainability score is therefore relatively strong, but future assessment would be improved by agency-level emissions indicators, passenger-kilometer estimates, and clearer reporting of fleet energy use.

4.7. Data Security and Privacy

Smart transit systems rely on passenger information, fare-payment data, real-time vehicle data, and sometimes location-based services. CapMetro's published privacy policy describes administrative, technical, and physical safeguards, regular auditing, and intrusion-detection practices [57], while the FY2024 budget describes secure and resilient information-technology functions [54]. These documents provide evidence of formal privacy and security practices, but they do not constitute an independent cybersecurity maturity or compliance audit. The data security and privacy score is therefore moderate, with the main recommendation being greater public transparency on data governance, retention, anonymization, privacy impact assessment, and cybersecurity performance.

4.8. Resilience and Adaptability

In this framework, resilience refers to the continuity of transit service and the capacity to adapt when disruptions occur. It includes redundancy, backup capability, emergency preparedness, and the ability to adjust operations as conditions change [19,37–42]. CapMetro's FY2024 budget documents business-continuity and information-technology resilience functions as well as Public Safety and Emergency Management activities, including emergency exercises, training, an Emergency Response Plan, and Continuity of Operations planning [54]. The Transit Speed and Reliability Program also documents operational and infrastructure adaptations intended to improve reliability [59]. The criterion scores remain conservative because the public evidence does not provide systemwide, criterion-specific outcome measures for redundancy, adaptive reconfiguration, or emergency-response performance. Thus, the scores reflect the breadth of publicly demonstrated performance rather than the absence of emergency plans or response capability.

4.9. Community Engagement and Feedback

CapMetro and regional partners have used public meetings, online surveys, open houses, and project-specific engagement activities to gather input [51,52]. Participation numbers show that outreach is occurring. The main concern is whether participation is representative and whether riders can see how their input changes decisions. Available survey evidence suggests that many riders are satisfied with service, but a smaller share feel that they have meaningful influence over transit planning. Under the revised score ranges, the dimension is interpreted as limited implementation. Stronger multilingual outreach, community advisory panels, real-time feedback tools, and public reporting on how comments affect decisions would improve this dimension.

4.10. Integrated Readiness Summary

Figure 8 presents the Austin case-study assessment at the criterion level across all eight readiness dimensions and includes all 39 criteria listed in Table 1. Each criterion is shown with its assigned score and a color category based on the scoring ranges used in this study: red for scores from 1.0 to 2.5, yellow for scores above 2.5 to 3.5, and green for scores above 3.5 to 5.0. The criterion-level display makes differences within each dimension visible. Higher-scoring items are concentrated in sustainability, selected digital technologies, physical access to transit stops and stations, and the crash-reduction and station-security criteria. Lower-scoring items occur in several mobility and accessibility criteria, all three resilience criteria, several community-engagement criteria, and heat exposure and weather protection. Yellow items represent criteria with moderate implementation or mixed evidence.

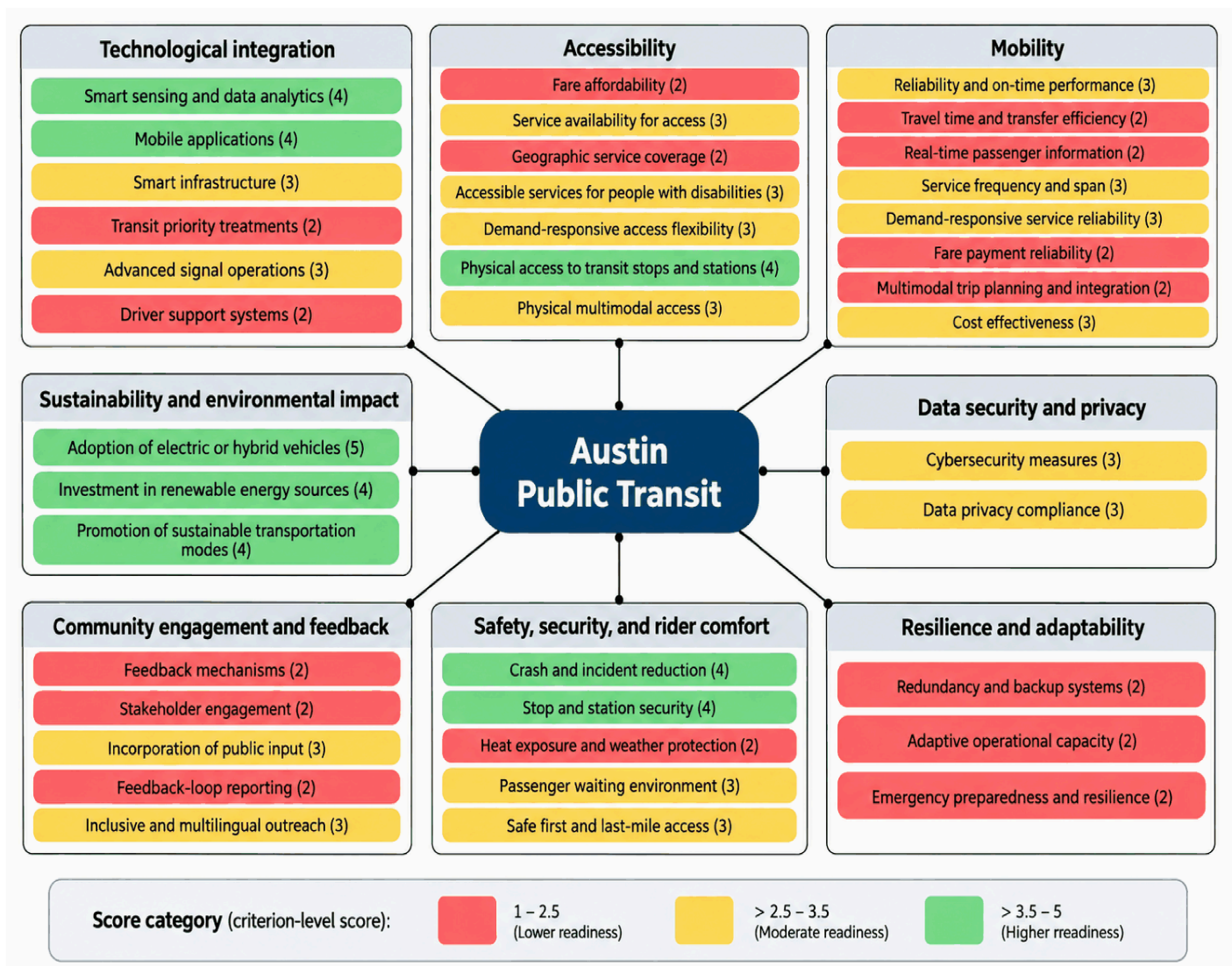


Figure 8. Criterion-level assessment of Austin public transit readiness for smart city integration. All 39 criteria from Table 1 are displayed. Red indicates scores from 1.0 to 2.5, yellow indicates scores above 2.5 to 3.5, and green indicates scores above 3.5 to 5.0.

5. Discussion

The Austin case shows that smart transit readiness is not determined by technology alone. CapMetro has adopted several digital tools and has made progress toward cleaner transit, but the lower scores in resilience, community feedback, accessibility, and mobility

indicate that a smart city transition also depends on service design, governance, equity, and operational preparedness.

One implication is that technology investments should be evaluated against rider-facing outcomes. Real-time information and mobile payment are useful, but they do not compensate for long headways, poor first- and last-mile access, or weak feedback loops. Similarly, fleet electrification can reduce environmental impacts, but its benefits are stronger when paired with mode shift, reliable service, and transparent emissions reporting.

The framework also highlights trade-offs that agencies may face. More data can improve planning and service reliability, but it also increases the need for privacy safeguards and clear data governance. Expanding digital tools can improve convenience for many riders, but agencies must still provide access for riders with limited smartphone access, limited English proficiency, disabilities, or low digital literacy.

The Austin application demonstrates how the framework can organize different types of evidence, but it does not by itself establish formal validity or cross-city transferability. The eight dimensions may also be useful in other cities, but that possibility should be tested through replication with comparable data sources and assessment procedures. Compared with the ITDP TOD Standard and the NACTO Transit Street Design Guide, the proposed framework is broader but less detailed in any one design domain. Compared with ISO 37120, it is more transit specific and includes governance and resilience evidence that is not captured by a small set of city-level indicators. These differences support its use as an early diagnostic structure rather than as a replacement for specialized standards or a validated cross-city index.

The proposed framework is therefore most useful as an exploratory diagnostic tool. It can help agencies organize evidence, identify missing information, and communicate priorities to decision makers. It should not replace project-level alternatives analysis, operational modeling, exposure-adjusted safety analysis, environmental assessment, or community-led planning.

6. Limitations

This study has several limitations. First, the framework was tested in one city, so the findings should not be interpreted as a general ranking of smart transit readiness across cities. Applying the framework to additional cities would make it possible to evaluate consistency and transferability.

Second, some criteria, especially in data governance, resilience, and community engagement, are not fully represented in public datasets and therefore include a qualitative component. The expert questionnaire provides a descriptive professional perspective on the eight framework dimensions, while the criterion scores are based on the quantitative and documentary evidence summarized in Supplementary Table S1. Expert-rating dispersion and response distributions are reported in Supplementary Table S2. The dimension scores should therefore be read as screening summaries rather than precise or validated performance measures.

Third, the accessibility analysis uses straight-line distance from census tract centroids to the nearest transit stop. It is not population weighted and does not represent pedestrian-network distance or the within-tract distribution of residents. Actual walking access may therefore be overestimated in large tracts and in areas with disconnected streets, barriers, or unsafe pedestrian conditions. Future applications should use network-based walking distance and, where appropriate, population-weighted and socioeconomic accessibility measures.

Fourth, several dimensions, including data privacy, cybersecurity, resilience, and community feedback, are difficult to evaluate from public documents alone. The absence of public documentation should not be interpreted as proof that a practice does not exist. It does, however, indicate a transparency gap that matters for public trust and smart city governance.

The evidence also comes from different reference periods, including 2022 safety data, 2023 census and ACS data, January 2025 CapMetro spatial data, and an archived GTFS feed whose service window included July 2025. This reflects the most suitable public source available for each indicator but limits direct same-year comparison across dimensions. The GTFS headway results are therefore interpreted descriptively as a scheduled-service screening rather than as a precise operational reliability measure. Future applications should use closely aligned data vintages where feasible.

Finally, the framework is intended as a screening tool. It can identify areas that deserve attention, but detailed investment decisions should be supported by additional cost–benefit analysis, equity analysis, operational modeling, and community consultation.

7. Conclusions

This paper developed and applied a multidisciplinary framework for assessing public transit readiness for smart city integration. The framework brings together eight dimensions that are often evaluated separately: technology, accessibility, mobility, sustainability, data security and privacy, resilience, community engagement, and safety, security, and rider comfort.

The Austin case demonstrates the practical use of this integrated screening approach. The assessment identifies relatively stronger performance in sustainability and selected digital transit services, including fleet modernization, mobile fare payment, and real-time passenger information, while indicating weaker documented performance in resilience, community feedback, mobility, and spatial accessibility. These findings are specific to the evidence and scoring procedures used in the Austin application and should not be interpreted as validation of the framework for other cities.

The framework is designed to support planners and transit agencies in organizing readiness evidence rather than producing a single definitive score. Its main contribution is to connect technical, environmental, social, and institutional dimensions in one practical assessment structure. Future research should test the framework in multiple cities, use more closely aligned data vintages, and examine whether the indicator structure and score interpretations remain stable across different transit and governance contexts.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/futuretransp6050229/s1>, Table S1: Evidence-to-Score Matrix for the Austin Case Study; Table S2: Descriptive Distribution of the 24 Expert Dimension Ratings.

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