Planning amidst Planetary Crisis: Rethinking Theory and Practice through Adaptive Transformations in Public Transport

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Abstract
Planetary climate and resource crises reshape urban spatial logic and transport networks. With diverse mobility modes emerging, sustainable and adaptive planning is key to managing uncertainty. Traditional approaches fail to capture dynamic demand and complex variables, causing supply adjustments to lag. This study explicates adaptive planning theory, revisits the pivotal support role of buses and structural causes of imbalances, and proposes an adaptive evaluation framework integrating spatial and social indicators. It embeds mobility-mode interactions and uncertainty-response methods to extend conventional bus-planning paradigms. Analysing representative cities' bus supply-demand matching in China and Europe, we propose possible pathways for adaptive response, including multi-level governance, data-driven systems, resource allocation, and emergency mechanisms, which provide resilient, science-based decision support for transport planning in crises.

Keywords: Adaptive Transformations; Mobility Crisis; Public Transport; Evaluation System; Sustainable Development

1. Introduction

1.1 Background and Problem Statement

Composite shocks from climate change, energy scarcity and public health crises are systematically reshaping the sustainable development agenda of urban transport (Meyer and Weigel, 2011; Gaskin, Zare and Delarmente, 2021; Payakkamas, de Kraker and Dijk, 2023; Macdonald et al., 2024). Against a backdrop of frequent extreme weather events, heightened dependency risks on fossil fuels and routine epidemic control, public transit—as a critical urban system embodying social equity (Palm et al., 2021; Gadson and Park, 2024) and environmental benefits (Jiang, Zhou and Liu, 2019; Zhao et al., 2024)—have transcended mere mobility services to become core carrier for urban resilience construction (Goncalves and Ribeiro, 2020; Mirzaee and Wang, 2020).

However, the traditional transport planning paradigm, long constrained by efficiency-driven static optimisation logic (Horiuchi et al., 2024; Li et al., 2024), exhibits clear limits when addressing dynamic supply-demand imbalances, service Resilience deficits and shock events (Cats and Jenelius, 2015). Classical tools such as the four-stage model, due to excessive reliance on historical extrapolation and steady-state equilibrium assumptions (Li et al., 2021), fail to adapt to non-linear evolutions like sudden demographic change (Kasu and Chi, 2018), heterogeneous travel behaviour (Wang et al., 2024) or urban-rural transport dynamics (Xiao and Xu, 2022).

For instance, the pandemic-induced collapse in bus ridership revealed a stark mismatch between rigid service supply and elastic travel demand (Petrov and Petrova, 2020), exposing structural flaws in vulnerability assessment and adaptive regulation within modern bus systems (Man, Andor and Birsanuc, 2022). This underscores the urgent need to shift from a predict-control paradigm to a monitor-respond approach, reconstructing an adaptive methodology for planning and transport under uncertainty by integrating Adaptive Planning theory with socio-technical transition frameworks (Xiang et al., 2023; Deng et al., 2025).

1.2 Research Questions and Objectives

This study addresses three questions: **First**, how can we deconstruct the theoretical core of adaptive planning under planetary crisis, and delineate its transformational features—in value orientation, methodology and implementation—relative to traditional paradigms? **Second**, how can we develop a dynamic, feedbackcapable evaluation framework for bus systems that accurately identifies supply-demand imbalance transmission mechanisms? **Third**, how can innovative governance models translate planning concepts into operational practice?

To answer these, we integrate complex adaptive systems theory with Transformation Planning thought to build an Adaptive Planning framework for buses, propose sociotechnical transition analysis tools, and construct a dynamic evaluation model. Descriptive analyses of representative Chinese and Central European cities then distil governance pathways for transport Adaptive Planning under varied institutional contexts.

1.3 Significance and Innovation

By uniting the theoretical lineages of Adaptive Planning and Transformation Planning, this study transcends the cognitive limits of traditional static analysis paradigms. Employing a multicriteria dynamic evaluation system, it introduces a quantitative method to assess vulnerability transmission pathways in bus systems. This method exemplifies the interdisciplinary nexus of urban planning, public policy, equity, environmental sustainability and system Resilience, offering effective policy interfaces for innovating bus service provision in the postpandemic era. The paper unfolds along the logic of theory review–dilemma analysis–method development–case validation–policy translation.

2. Theoretical Foundations: Adaptive Planning and Its Transformative Logic

2.1 Overview of Adaptive Planning Theory

Adaptive Planning, emerging as a novel paradigm for navigating uncertainty and complexity under the planetary crisis (Pelling, O'Brien and Matyas, 2015), centres on continuous adjustment and feedback to ensure co-evolution between planning systems and external environments (Smith, 2016; Thomas Machiels et al., 2023). Rooted in late-20th-century concepts of Dynamic Planning and Adaptive Management (Margoluis and Salafsky, 1998; Schreiber et al., 2004), it later integrated with theories of urban resilience and complex adaptive systems (Dovey, 2012; Meerow, Newell and Stults, 2016), culminating in a process-oriented, systems-thinking framework (Ahern, 2011; Davoudi, 2021).

The theoretical evolution of Adaptive Planning spans ecological resource management and urban resilience enhancement, eventually advancing into multidimensional, collaborative governance tailored to climate crises and digital transformation (Varzeshi, Fien and Irajifar, 2024). Three core principles underpin this approach:

Dynamic Responsiveness: Enhancing systemic responsiveness to external disruptions—such as extreme climate or public health emergencies—through real-time monitoring and flexible adjustment mechanisms.

Multidimensional Collaboration: Building cross-sectoral (transport, energy, environment), cross-scalar (urban–regional–national), and multi-actor (government, residents, enterprises, planners) governance networks that transcend administrative boundaries and conventional models.

Social Inclusiveness: Embedding equity in planning decisions, prioritising the needs of vulnerable groups, particularly in relation to mobility and welfare.

Essentially, Adaptive Planning operationalises the Sustainable Development Goals (SDGs) and the principle of equity. Through phased policy adaptation and flexible interventions (Haasnoot et al., 2024), it aims to mitigate spatial exclusion (Ghasemi et al., 2025).

2.2 Transformative Logic of Adaptive Planning

Transformative Planning entails a paradigmatic shift from linear growth thinking to circular, low-carbon, and resilience-oriented transformation (Huq, 2020; Novalia and Malekpour, 2020). Its intellectual foundations lie in Socio-Technical Transitions (Kern, 2012) and Just Transition frameworks (Forde, 2024). Within the planetary crisis context, urban planning transformation engages three interlinked dimensions:

Cognitive Reconstruction: A shift from static, blueprint-oriented visions to dynamic goals of safety, resilience, and liveability;

from fixed long-term planning cycles to a hybrid of short-term action and long-term targets; and from linear planning–implementation–completion trajectories to iterative cycles of identification–action–evaluation–adjustment–re-identification.

Institutional Innovation: A transition from top-down decision-making to bottom-up, citizen-driven governance. This involves multi-level institutional architectures integrating central policy guidance, urban pilot innovations, and community co-governance.

Technological Transformation: Leveraging tools such as digital twins and AI-based forecasting to enhance systemic resilience, enable adaptive planning implementation, and ensure rapid response.

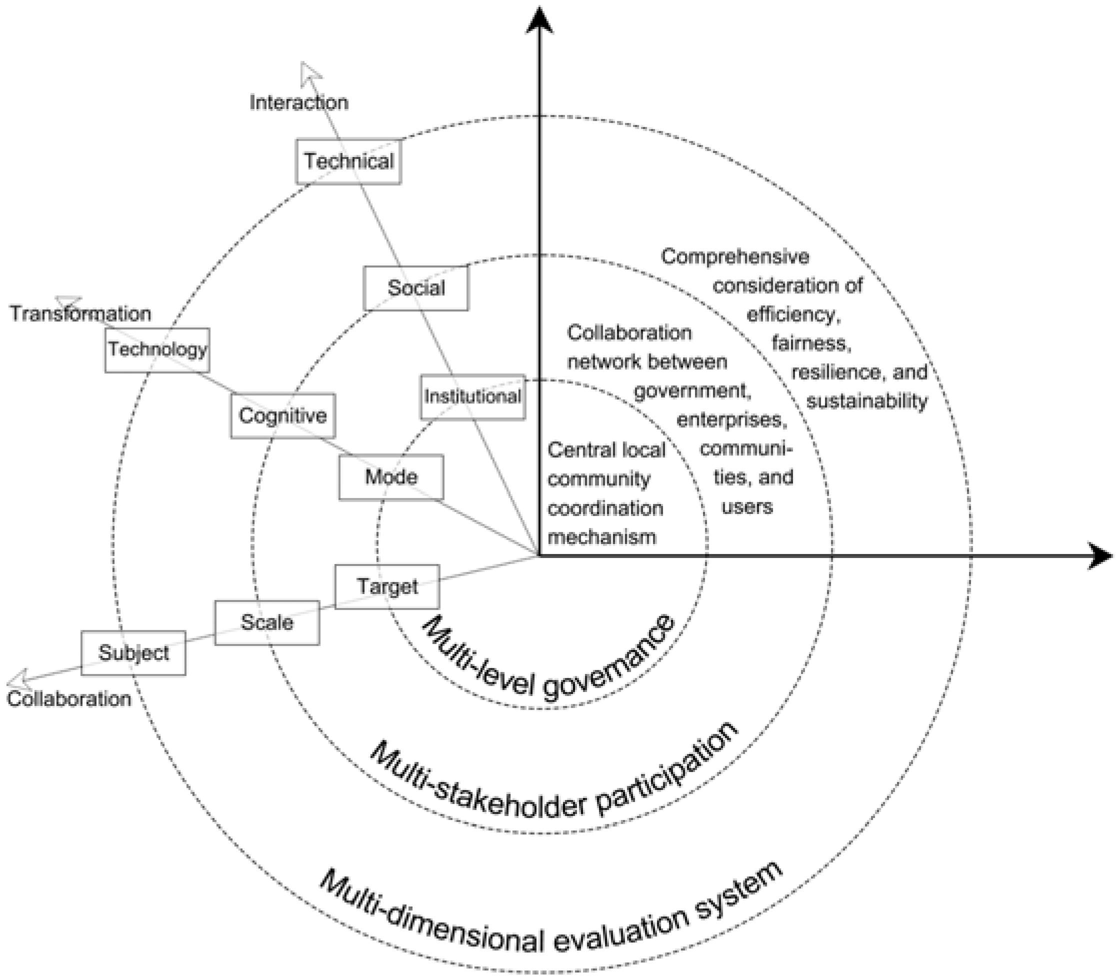

Fig.1 Theoretical Framework for Adaptive Planning Transformation

Overall, the transformation of planning should follow a co-evolutionary pathway across technological, social, and institutional domains (Figure 1). On the governance front, it entails forging risk-sharing and benefit-sharing coalitions among governments, businesses, and the public. On the evaluation front, it necessitates establishing composite indicator systems that integrate efficiency, equity, resilience, and sustainability (Fu and Li, 2022).

3. Role Reconfiguration: Supply–Demand Imbalance and Coopetition in the Context of the Mobility Crisis

3.1 Global Mobility Crisis and Transport Challenges

The dominant paradigm of public transport planning—rooted in car-centric and efficiency-focused logics—is increasingly being challenged. In the face of unpredictable disruptions triggered by climate, economic, or healthrelated events, the limitations of conventional planning models become evident. Their reliance on static equilibrium assumptions and technocratic optimisation tools renders them ill-equipped to address dynamic and uncertain conditions. This often results in structural rigidity within transit networks and inadequate responsiveness in resource allocation (Schmidt and Meyer, 2009; Efthymiou et al., 2018).

Globally, the transport sector faces dual pressures from planetary crisis-induced events and shifting mobility demand. Climate imperatives compel a low-carbon transition in bus systems, necessitating breakthroughs in energy structure and emission intensity (Yang, Ma and Sun, 2018). Simultaneously, recurring public health and extreme weather events expose vulnerabilities in operational resilience. Moreover, the proliferation of remote work and diversified travel behaviours have profoundly altered demand structures, rendering fixed-service models increasingly mismatched with spatially and temporally dispersed patterns (Van Nieuwerburgh, 2023).

In China's rapidly urbanising context, these mobility crises are even more acute. While urban expansion fuels travel demand, a car-centric mobility structure exacerbates congestion and pollution. Persistent underfunding, spatial mismatches between networks and jobs-housing patterns, and uneven service quality underscore deeper structural tensions. Temporal and spatial imbalances in supply and demand of public transport remain evident (Wan, Wang and Sperling, 2013).

Resolving these contradictions requires a multidimensional analytical framework encompassing spatial fragmentation (e.g., jobs–housing separation), social stratification (e.g., limited accessibility for vulnerable groups), and technological lag (e.g., inadequate real-time demand sensing). Adaptive planning offers a mechanism for institutional transformation, bridging the disjuncture between static planning paradigms and dynamic urban change. It provides a pathway for bus systems to integrate environmental resilience and social equity as core values (Wall et al., 2015).

3.2 Coopetition between Diverse Transport Modes and Bus Systems

Amid mobility transformation, bus systems are undergoing a critical redefinition of roles (Knowles, Ferbrache and Nikitas, 2020). The interplay among diverse transport modes exhibits dynamic and complex characteristics. Real-time data-sharing platforms dismantle information silos, enabling responsive demand sensing—setting the stage for adaptive transformation in the transport domain.

On the side of coordination, the innovation of "bus+" models has facilitated deep multimodal integration. A composite network combining trunk-line buses and microcirculation feeders can achieve seamless modal linkages. For example, shared bicycle systems extend the effective service radius of buses, while multimodal hubs promote regional integration. This requires planners to reassess the foundational role of buses as both structural backbones and connective supports.

On the side of competition, emerging mobility modes are reshaping urban transport hierarchies. Rising private car ownership and the immediacy of ride-hailing services place buses at a disadvantage in terms of time efficiency and comfort. Micromobility options—such as shared bikes and e-scooters—have significantly diverted demand for short-distance trips (3–5 km). Surveys in cities like Beijing indicate that up to 15% of bus demand has already been displaced by such modes.

In the future, disruptive technologies such as autonomous driving and vehicle–infrastructure integration may trigger fundamental shifts in mobility structures. Market mechanisms also deepen inequality: high-income groups shift towards customised services, while marginalised populations bear the brunt of declining service quality. This necessitates public service safeguards within competitive transport ecosystems.

In sum, the evolution of future transport systems will increasingly hinge on the diversified roles of multiple modes.

The digital revolution is accelerating adaptive transformation: real-time demand sensing and optimisation algorithms enable dynamic system adjustments (Legaspi et al., 2020). Consequently, buses can be deeply integrated within service-oriented platforms such as Mobility-as-a-Service (MaaS), shifting from physical connectivity to service fusion.

With digital technologies as enablers, governance mechanisms should also undergo adaptive transformation to balance market dynamism with public value. Crucially, beyond redesigning institutional arrangements such as bus priority or carbon quota trading, policy frameworks should also recognise the public nature of buses—reinforcing their role in mobility systems through precise targeting, quality enhancement, and service innovation. Ultimately, this would enable a strategic leap for bus systems—from mere transport vehicles to resilient urban infrastructure. A rational understanding and evaluation of the bus system constitutes a critical step in this policy pathway, serving as a fundamental reference for quality service innovation.

4. Rethinking Approach: Evaluation Framework and Indicator System for Adaptive Bus Planning

4.1 Design Principles and Structural Logic of the Evaluation Framework

In response to the transformative demands of bus systems under the planetary crisis, this study develops a dual-layered evaluation framework (Figure 2). Grounded in the paradigm shift towards the reconfiguration of planning values—efficiency (accessibility), equity resilience, and sustainability—it aims to enhance crisis responsiveness, service sustainability, and social inclusiveness through multidimensional coordination mechanisms.

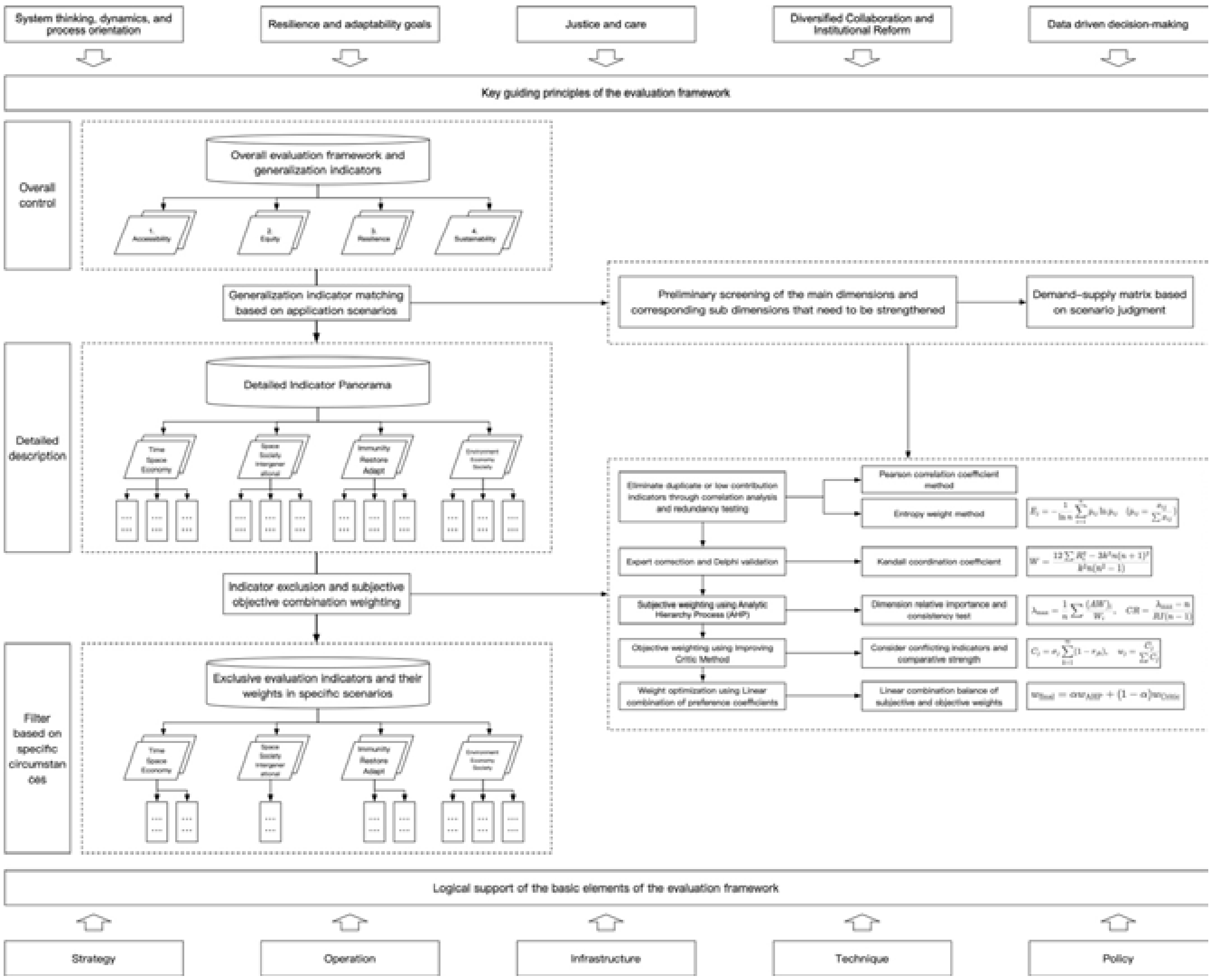

Fig.2 Evaluation Framework for Adaptive Bus Planning

The framework follows a three-tiered progressive structure.

First, at the value level, it moves beyond the efficiency-dominant paradigm, drawing on degrowth theory and care mobility to propose a holistic evaluation matrix centred on accessibility, equity, resilience, and sustainability.

Generalised indicators are accordingly introduced to capture the coupling of system resilience, environmental sustainability, and spatial justice.

Second, a scenario-oriented indicator mapping process constructs a panoramic indicator library, offering dimensional depth as the foundation of the framework.

Third, through systematic indicator screening and a combined subjective-objective weighting mechanism, context-specific indicators and weighting schemes are developed to support tailored evaluations. This process involves correlation analysis, redundancy detection, expert-based elimination, hybrid weighting, and linear combination optimisation.

The framework is supported by a multi-level logic structure. Strategically, it incorporates long-term visions and multi-scenario planning to guide adaptive mechanisms. Operationally, it introduces flexible network and frequency scheduling. Infrastructurally, it addresses the integration of stations, energy, and other physical resources. Technically, it considers real-time data monitoring. Also, at the policy level, it emphasises crisis preparedness and low-carbon mobility incentives.

These are reinforced by key guiding principles such as dynamic systems thinking, resilience-oriented mechanism design, and pluralistic participatory models grounded in social equity. Collectively, these elements enable iterative feedback loops and continuous system evolution under conditions of uncertainty.

4.2 Multi-Criteria Indicator System for Adaptive Evaluation: Accessibility, Equity, Resilience and Sustainability

Under the integrated framework, a comprehensive multi-criteria indicator system is established (Table 1), spanning both supply and demand dimensions. Centred on four core principles—accessibility, equity, resilience, and sustainability—the system bridges internal operational efficiency and external societal effects, providing a dynamic tool for adaptive planning.

Supply-side indicators address resource allocation, service provision, and operational control, while demand-side indicators reflect user satisfaction, perceived equity, and environmental interaction. Their interaction captures the multidimensional essence of bus system transformation.

Tab.1 Multi-Criteria Evaluation Indicators

		Supply Side	Demand Side
1. Accessibility	Space Time Economic	Service coverage, Service frequency, Site coverage……	Walking distance, Ticket affordability, Travel time cost ……
2. Equity	Spatial Social Intergenerational	Regional allocation of public transportation resources, Coverage of barrier free facilities……	Satisfaction rate of vulnerable groups' needs, Subjective evaluation of fairness……
3. Resilience	Immunity Recover Adaptability	Emergency response time, Redundancy of backup facilities……	Evaluation of passenger diversion efficiency, Reliability of emergency services……
4. Suitability	Environmental Economic Social	Carbon emission intensity, Operational efficiency, On-time performance……	User satisfaction, Public participation……

The framework further disaggregates each dimension, yielding a panoramic set of 68 supply-side and 60 demand-side indicators, serving as a reference for context-specific indicator selection in diverse scenarios.

4.2.1 Accessibility Evaluation: Coupling Spatial-Temporal Opportunity and Cost Constraints

As the core functional expression of bus services, accessibility should be analysed through spatial, temporal, and economic lenses (Table 2).

Spatial accessibility is assessed via supply indicators such as S1 and S3, reflecting network layout efficiency, while demand indicators like D1 and D4 measure users' practical ease of network access. Temporal accessibility relies on supply-side operational parameters (e.g., S8, S11) and demand-side metrics (e.g., D6, D9) that quantify user experience in space-time cost. Economic accessibility combines supply indicators (e.g., S15, S16) capturing affordability policies with demand indicators (e.g., D10, D14) that reveal service penetration across socio-economic gradients. This dimension also introduces GIS-based spatial analytics, incorporating non-transport variables to evaluate the system's latent support for urban functions.

Tab.2 Accessibility Evaluation

1. Accessibility	Space	S1	Stop density	D1	Average distance of walking to the nearest stop
		S2	Line network density	D2	Walking accessibility time distribution
		S3	Service coverage rate within xx meters	D3	The straight-line distance from residential areas to stations
		S4	Coverage rate within a 500- meter service radius	D4	Differences in accessibility among different land use types
		S5	Number and distribution of transfer nodes		/
		S6	Network connectivity index		/
		S7	Average distance between stops		/
	Time	S8	Departure frequency	D5	Average travel time
		S9	Length of operating hours	D6	Total door-to-door travel time
		S10	Average operating speed	D7	Delayed time during peak hours
		S11	On-time performance rate	D8	Time costs between different Origin-Destination (OD) pairs
		S12	Stability of headway	D9	User perception of time reliability
		S13	Transfer waiting time		/
	Economic	S14	Fare level setting	D10	The ratio of fares to household income
		S15	Fare structure (sectional/zonal)	D11	Travel cost per unit distance
		S16	Transfer discount policy	D12	Comparison of costs with other modes of transportation
		S17	Fare discounts for special groups	D13	Price sensitivity among different income groups
		S18	Allocation of operating costs	D14	Travel cost burden index

4.2.2 Equity Evaluation: Aligning Spatial Balance and Group Justice

Equity evaluation transcends traditional homogenised approaches by integrating spatial, social, and intergenerational dimensions (Table 3).

Spatial equity is reflected in indicators such as S19 and S21, which reveal spatial disparities in resource allocation, while D18 captures travel exclusion experienced by residents in marginalised areas. Social equity includes institutional inclusiveness (e.g., S24, S28) and demand-side perceptions of justice (e.g., D20, D23). Intergenerational equity introduces long-term low-carbon transitions into present planning via indicators like S29 and D25. This dimension highlights path dependence rooted in historical injustices and interrogates structural contradictions embedded in bus service distribution.

Tab.3 Equity Evaluation

		Supply Side		Demand Side	
2. Equity	Spatial	S19	Standard deviation of service levels in different regions	D15	Evaluation of travel convenience for residents in different regions
		S20	Service ratio between the central urban area and the peripheral regions	D16	Inter - regional accessibility difference coefficient
		S21	Gini coefficient of bus network coverage	D17	Travel time cost for residents in peripheral areas
		S22	Spatial distribution equilibrium of transport capacity input	D18	Spatial Deprivation Index
		S23	Regional differences in facility configuration standards	D19	Differences in service satisfaction across different regions
	Social	S24	Coverage rate of barrier-free facilities	D20	Travel satisfaction levels among different age groups
		S25	Proportion of low-floor vehicles	D21	Evaluation of Travel Convenience for People with Disabilities
		S26	Multilingual information service coverage	D22	Bus dependence of low-income groups
		S27	Configuration of special facilities for the elderly and children	D23	Gender differences in perceived travel safety
		S28	Service policies for special groups	D24	The degree of travel exclusion for vulnerable groups
	Intergenerational	S29	The proportion of renewable energy use	D25	Intergenerational sharing of environmental costs
		S30	Level of investment in green technology	D26	Satisfaction of future travel demand prediction
		S31	Environmental protection facilities configuration standards	D27	Preferences for sustainable travel mode selection
		S32	Proportion of sustainable development investment	D28	Assessment of intergenerational environmental burden
		S33	Technology upgrade cycle	D29	Long-term development benefit distribution

4.2.3 Resilience Evaluation: Reconstructing Systemic Resilience and Adaptive Capacity

The resilience of bus systems is assessed through a tripartite framework encompassing resistance, recovery, and adaptation (Table 4).

Structural robustness, as an expression of resistance, is captured by supply-side indicators such as S34 and S39, while D30 and D31 reflect the social cost of disruption propagation on the demand side. Recovery is evaluated through technical metrics including S40 and S44, alongside behavioural adjustment processes tracked by D36. Adaptation focuses on the system's capacity for dynamic realignment under climate variability and demand fluctuations. The coupled analyses using S47 and D40 reveal the system's evolutionary potential. This dimension emphasises stress testing and scenario simulation, validating resilience indicators through compound scenarios involving extreme climate and energy crises.

Tab.4 Resilience Evaluation

		Supply Side		Demand Side	
3. Resilience	Immunity	S34	Network redundancy coefficient	D30	Impact scope of single-point failures
		S35	Identification and protection of critical nodes	D31	Passenger detention time during service interruptions
		S36	Number of backup facilities/paths	D32	Availability of alternative routes
		S37	System fault-tolerant design level	D33	Performance of system stress testing
		S38	Completeness of emergency response plans	D34	Service stability perceived by users
		S39	Dispersion of critical facilities		/
	Recover	S40	Emergency response time	D35	User acceptance time after service restoration
		S41	Average duration of fault repair	D36	Travel mode conversion during the recovery period
		S42	Emergency vehicle and personnel deployment	D37	Users' satisfaction with the recovery effect
		S43	Response speed of information release	D38	Increased travel costs during the recovery process
		S44	Initiation time of alternative services	D39	Time to reach normal service level
		S45	Standardized process for resuming operations		/
	Adaptability	S46	System upgrading and transformation capabilities	D40	Adaptability of response to demand changes
		S47	The application level of technological innovation	D41	New technology acceptance and utilization rate
		S48	Flexibility in adjusting the operation mode	D42	Adaptation time for service mode changes
		S49	Adaptability of long-term planning	D43	Long-term evolution trends of travel modes
		S50	Diversified service supply capacity	D44	The dynamism of meeting user needs

4.2.4 Sustainability Evaluation: Dynamic Equilibrium of the Triple Bottom Line

Sustainability is assessed through a lifecycle-based framework aligned with the environmental-economic-social triple bottom line (Table 5).

Environmental sustainability is quantified via S51 and S52, indicating progress towards low-carbon Transformation, while D45 captures ecological behavioural responses. Economic sustainability is reflected in balanced cost inputs (S57) and the long-term market viability of service provision (D50, D52). Social sustainability transcends conventional satisfaction metrics, with indicators such as S64 and S67 illuminating the social capital underpinning system operation, while longitudinal data like D60 trace the cumulative effect of institutional credibility.

Tab.5 Sustainability Evaluation

		Supply Side		Demand Side	
4. Suitability	Environmental	S51	Carbon emissions per unit of transport volume	D45	The proportion of bus trips replacing private car trips
		S52	Proportion of new energy vehicles	D46	Residents' preference for environmentally friendly travel choices
		S53	Energy consumption efficiency	D47	Users' awareness of environmental benefits
		S54	Noise control level	D48	Degree of change in green travel behavior
		S55	Air pollutant emission standards	D49	Acceptance of internalizing environmental externalities
		S56	Green infrastructure configuration		/
	Economic	S57	Operation cost control level	D50	Stability of fare affordability
		S58	Degree of diversification of income structure	D51	Matching degree between demand growth and input
		S59	Degree of dependence on government subsidies	D52	Changes in users' willingness to pay
		S60	Asset utilization efficiency	D53	Service quality-price satisfaction
		S61	Payback period	D54	Long-term awareness of financial sustainability
		S62	Operation efficiency indicators		/
	Social	S63	Maintenance of service quality standards	D55	User satisfaction and its trends
		S64	Stability of practitioners	D56	Perceived stability of service quality
		S65	Level of investment in technical training	D57	Social recognition and support
		S66	User complaint handling mechanism	D58	Perceived continuous improvement of travel experience
		S67	Degree of community participation in decision - making	D59	Perception of equity in public services
		S68	Level of information transparency	D60	Long-term service trustworthiness

Taken together, the integrated panorama of supply–demand indicators across the four dimensions offers a robust foundation for selecting context-specific metrics in diverse application scenarios. The framework's value lies not only in its comprehensiveness but in its dynamic calibration mechanism. Through regionalised adjustment of weighting parameters (as detailed in Figure 2), tailored submodules may be derived for mountainous cities,

high-density metropolises, and suburban development zones, thereby providing methodological support for differentiated Transformation of bus systems under planetary crisis.
Preliminary findings suggest that while enhanced accessibility may exacerbate spatial inequity, improved resilience often entails economic trade-offs. In practical planning scenarios, the equity threshold and resilience baseline may be constrained in accordance with specific planning goals, enabling differentiated strategies. The following case studies and planning propositions will offer more targeted insights.

5. Case Outlook: Descriptive Comparison and Evaluation Application of Chinese and European Cities
5.1 Research Design and Methods
This study selects Shanghai, Shenzhen, and Paris as core cases to preliminarily explore adaptive strategies of urban bus systems under differing institutional and cultural contexts in response to the planetary crisis, using descriptive comparative analysis. The study also aims to demonstrate the potential application of a multidimensional evaluation framework.

Shanghai and Shenzhen, as megacities in China, respectively represent characteristics of high-density built-up areas and rapidly expanding urban forms. Paris exemplifies a mature European metropolitan region, with its "15-minute city" vision and low-carbon policies offering global reference value. While Chinese cities are primarily driven by top-down planning, European cities emphasise participatory processes and multimodal integration. These divergences between the two make their comparison more representative.

Drawing on publicly accessible policy documents and interview materials, this section identifies both commonalities and divergences among the three cities. It distils their planning logics and governance attributes while reflecting on existing shortcomings. This provides insight into the mutual responsiveness between evaluation frameworks and planning practices. Additionally, the study assesses the framework's feasibility in each case, incorporating both the effectiveness of routine planning and dynamic scenarios involving extreme events.

5.2 Case Comparison and Evaluation Application
5.2.1 Shanghai: Exploring Bus System Resilience in a High-Density City
Shanghai's high-density built-up areas feature a complex bus network, yet significant passenger loss persists due to modal competition. In recent years, improvements in service efficiency have been achieved through bus electrification and intelligent dispatching platforms such as Shencheng Mobility. However, deficiencies remain in suburban coverage and peak-time capacity. During the pandemic, partial suspension of bus services exposed severe supply–demand mismatches under extreme conditions.

This suggests that even under normal conditions, Shanghai's bus services face persistent imbalances and operational inefficiencies. During crises, buses have yet to serve as effective mechanisms for dynamic response and baseline mobility provision. It is therefore essential to establish an evaluation system that accounts for both regular and emergency scenarios, and to develop corresponding mechanisms for dynamic coordination in infrastructure and operations.

5.2.2 Shenzhen: Supply–Demand Mismatch in Rapid Urbanisation
Shenzhen's bus system supports the city's polycentric expansion through an extensive road network. The Transit Metropolis policy has successfully integrated buses with metro systems and shared bikes. In response to extreme coastal weather, real-time route adjustments and reserve dispatching have proven effective. Nonetheless, accelerated urbanisation has resulted in lagging bus services in peripheral areas, with equity indicators significantly lower than in the city centre.

Although the technologically driven planning model has enhanced operational efficiency in new districts, the key issue lies in its limited community engagement, resulting in insufficient responsiveness to vulnerable groups. An evaluation framework guided by mobility equity goals should therefore be introduced to identify deficiencies and enhance public participation and interdepartmental coordination.

5.2.3 Paris: Dual Pathways of Decarbonisation and Resilient Governance
Beyond its bus network, Paris operates a multi-tiered public transport system including metro and RER services.

Recent efforts have centred on decarbonisation through the "15-minute city" initiative and policies focused on low-emission zones (Zone à faibles émissions, ZFE), aimed at reducing car dependency. Measures include bus fleet decarbonisation, cycling infrastructure expansion, and carpooling promotion to reduce transport-related emissions.

However, Paris's green transition has prompted concerns over policy efficiency and fiscal sustainability. Thus, evaluation frameworks for Paris and similar cities should adopt an environment- and sustainability-oriented scenario, with indicators explicitly addressing effective mobility and economic viability. This would help avoid compromises in service quality due to fiscal constraints and efficiency challenges.

5.3 Preliminary Insights from Comparative Analysis

Descriptive comparison reveals divergent patterns in urban bus planning between Chinese and European cities. Chinese cases exhibit technology-driven, centralised responses prioritising hardware upgrading and large-scale interventions. In contrast, Paris emphasises societal engagement and green transformation, focusing on policy flexibility and equitable distribution.

Preliminary findings suggest: Shanghai's central areas enjoy good bus accessibility but suffer from peak-hour pressure. Shenzhen shows strong resilience in crisis scenarios but should enhance equity in service provision. Paris ensures equitable bus coverage but still faces questions regarding operational efficiency and fiscal viability.

The proposed Evaluation Framework for Adaptive Bus Planning demonstrates cross-cultural applicability by enabling tailored indicator systems for varying scenarios. Given data limitations, the study uses 2013 data from Shenzhen to illustrate urban bus supply–demand conditions (Figure 3, 4). Future research should employ updated datasets to better characterise dynamic patterns, integrate supply–demand modelling, and contribute to globally relevant strategies for planning transformation under planetary crisis.

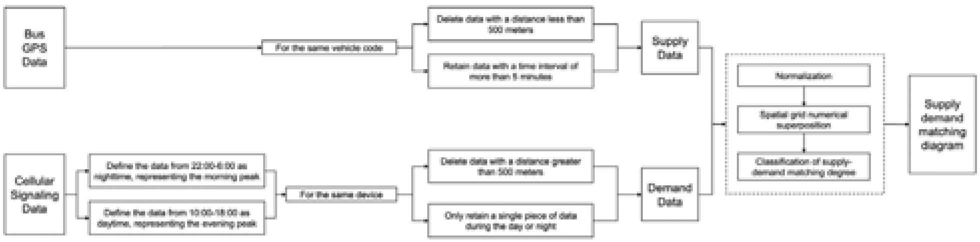

Fig.3 Flowchart of the Supply–Demand Matching Analysis

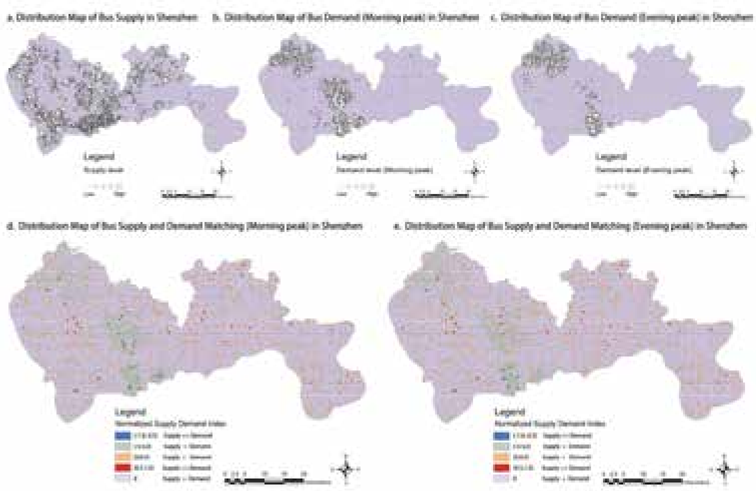

Fig.4 Bus Supply–Demand Conditions and Matching in Shenzhen in 2013

6. Discussion: Planning and Policy Implications

6.1 Theoretical Linkages and Transformative Innovation of the Framework

The adaptive transformation and evaluation framework for bus systems developed in this study integrates resilience-oriented design and community engagement mechanisms, achieving theoretical convergence with urban resilience theory, the Sustainable Development Goals, and system transformation theory.

By incorporating both the shock resistance of physical infrastructure and the self-organising recovery capacity of socio-ecological systems, the framework underscores the structural advantage of public transport in achieving dynamic balance during the adaptation–transformation process. This advantage lies in turning short-term crisis responses into long-term drivers of low-carbon technology adoption, inclusive service provision, and intelligent governance upgrades, thereby shifting planning paradigms from passive adjustment to proactive guidance.

Conceptually, adaptive planning for buses reflects three major shifts. **First**, it reorients from efficiency-driven to equity-led values, restructuring spatial justice through optimised accessibility. **Second**, it moves from static blueprints to dynamic adaptation, establishing real-time data-driven planning responses. **Third**, it transforms governance from siloed departments to cross-sectoral, multi-system coordination.

To ensure the framework's policy feasibility, institutional safeguards are needed—such as planning standards, emergency protocols, and public participation procedures—alongside fiscal instruments including green bonds and reinvestment of carbon trading revenues. These institutional designs, together with the multidimensional evaluation model proposed in this study, form a dynamic monitoring synergy that underpins governance for adaptive transformation in transport systems.

6.2 Planning Strategies for Coping with Crisis and Uncertainty

6.2.1 Establishing a Data-Driven and Scenario-Based Dynamic Response System

Addressing complex and evolving internal and external shocks requires a dynamic mechanism that integrates real-time sensing, intelligent analytics, and agile responses.

First, a real-time monitoring network should be deployed to continuously and accurately track passenger flows, traffic conditions, and service quality, thereby providing timely data support for decision-making.

Second, intelligent dispatching capabilities should be enhanced through big data analytics and demand forecasting, enabling flexible capacity allocation and dynamic optimisation of bus operations to improve resource efficiency.

Third, a feedback and iteration mechanism should be established to ensure closed-loop management based on performance evaluation, driving continual improvement in service processes and standards.

Lastly, scenario simulation and risk assessment should be deepened by constructing multiple future scenarios—such as climate events, technological shifts, and demographic changes—to identify latent vulnerabilities in the bus network and to pre-develop targeted strategies for risk mitigation and adaptive planning.

6.2.2 Advancing Innovation in Emerging Technologies

Technological empowerment is a critical driver of bus system transformation. In the era of planetary crisis, the development of intelligent technologies offers new possibilities for adaptive bus planning.

Advanced tools—such as big data, artificial intelligence, and synthetic population modelling—should be leveraged to enhance the scientific rigour and operational efficiency of bus systems. This includes real-time route optimisation, intelligent dispatching, and improved transparency of information services.

Forward-looking exploration is also needed, including the integration of autonomous driving and vehicle–infrastructure cooperation technologies, which may offer complementary functions to conventional bus services, such as automated feeder systems.

6.2.3 Enhancing Operational Resilience and Flexibility through Institutional Empowerment

On the one hand, innovative models of operation and governance should be promoted, including the adoption of flexible routes and service modes. Responsive service models—such as network optimisation based on real-time demand and on-demand buses—should be developed to enable finely tuned operational adjustments.

On the other hand, redundancy mechanisms should be established through the strategic reserve of routes, vehicles, and critical infrastructure to ensure rapid recovery and the maintenance of minimum service levels during major disruptions. This calls for the deep integration of all transport subsystems in emergency planning, resource sharing, and coordinated dispatching, supported by a more flexible and responsive dynamic planning decision-making framework.

6.2.4 Strengthening Equity-Oriented Resource Allocation and Multi-Actor Collaboration

Ensuring the inclusiveness and accessibility of bus services is vital for maintaining basic societal functioning during crises. This demands planning based on fine-grained travel demand analyses, especially focusing on the mobility patterns of vulnerable groups, to optimise route networks and ensure balanced and effective service coverage. It also requires targeted support policies, such as fare subsidies for low-income populations and the widespread implementation of accessible infrastructure, to guarantee mobility rights for disadvantaged users.

Moreover, spatial equity under multi-modal coordination should be prioritised by enhancing the physical integration and operational synergy between buses, walking, micro-mobility, and rail systems to reduce service disparities through shared resources.

Deepening participatory governance and collaboration is also key to advancing social equity in transport. This includes building multi-actor platforms led by government, operated by service providers, engaged by communities, and supported by academic institutions, to foster public participation in planning, evaluation, and oversight, and to explore effective models of public–private partnerships and community co-governance.

7. Conclusion

In response to the urgent need for planning transformation under the planetary crisis, this study first systematically reviews adaptive planning theory and interrogates the mobility crisis alongside the developmental dilemmas of buses. Building on this foundation, it proposes a resilience-oriented adaptive planning framework for public buses, accompanied by a multi-criteria evaluation system. By integrating transport efficiency, social equity, system resilience, and environmental sustainability into a unified decision-making perspective, the study extends the theoretical boundaries of adaptive planning within the transport domain.

Case-based analysis reveals interurban disparities in bus adaptability. Cities with high resilience typically exhibit institutional flexibility, technological inclusiveness, and deep civic engagement, confirming the framework's practical efficacy in enhancing system robustness. The resulting policy implications underscore a shift from passive defence to proactive adaptation, requiring legislative safeguards, fiscal incentives, and smart technological empowerment.

Nonetheless, this study has limitations. Case selection is constrained by data availability, particularly the lack of long-term operational data from cities in the Global South. Specific dynamic crisis scenarios—such as cascading disaster chains or multi-modal low-carbon transitions—remain underexplored, and their associated weighting mechanisms call for further empirical validation.

Future research should leverage big data and updated datasets for quantitative refinement of the evaluation framework, conduct comparative analysis across more cities, investigate the impacts of other crisis types on bus planning, and explore theoretical and practical extensions across disciplines and transport network models.

In the era of planetary crisis, the planning paradigm should shift from growth-oriented to resilience-centred. As the backbone of urban life, the adaptive transformation of public transport is not merely a technical endeavour but a governance revolution—redefining human-environment relations and advancing spatial justice.

Critical research frontiers remain open, including context-specific localisation and transnational cooperation aimed at dismantling epistemic silos and co-developing crisis-responsive knowledge systems. What is certain, however, is that embedding adaptive logic into the core of planning institutions offers a guiding compass for navigating urban uncertainty.

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