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Guangzhou's Third-Generation Transportation Model System: Framework Development and Technological Innovation

MA Xiaoyi[1,2], ZHANG Ke[1,2], JIN An[1,2], SONG Cheng[1,2], CHEN Xianlong[1,2]

1. Guangzhou Transport Planning Research Institute Co., Ltd., Guangzhou 510030, Guangdong, China;
2. Guangdong Sustainable Transportation Engineering Technology Research Center, Guangzhou 510030, Guangdong, China

Abstract: Against the backdrop of regional integration and refined urban governance, Guangzhou's third-generation transportation model system addresses the spatial and temporal constraints of conventional models, offering a quantitative decision-making tool for transportation governance in the new era. The system is based on a three-tier architecture of "data–model–application" and achieves a dynamic interaction of the two major foundational model subsystems of regional integration and transportation governance. Technical characteristics are highlighted for the two core subsystems: the regional integration model and the transportation governance model. The regional integration model expands its modeling scope from the metropolitan area to the provincial scale, with the transportation network construction evolving from single-mode road systems to integrated road-rail networks. Technologically, it focuses on identifying regional travel patterns and forecasting mobility demand, with application scenarios extending to facilitate intercity connectivity and optimize rail hub clusters. The transportation governance model addresses the limitations of traditional planning models. Its network construction incorporates population data at the building level, and its modeling techniques emphasize uncovering the behavioral stability patterns of travelers. Application scenarios include dynamic monitoring of job-housing relationships, congestion hotspot mitigation, and traffic diversion planning for complex interchange construction. Empirical results demonstrate that the model system enables full-process coverage from macro-level strategic planning to micro-level scenario governance, and from plan formulation to dynamic governance. **DOI:** 10.13813/j.cn11-5141/u.2025.0306-en

Keywords: transport model; regional integration; transportation governance; big data; transportation network construction; behavioral stability of travelers; Guangzhou

0 Introduction

Transportation modelling has long served as a fundamental decision-support tool for urban transport planning and infrastructure development in Guangzhou. The city's modelling system was initiated alongside the first household travel survey and the inaugural transport development strategic plan; it has since evolved in lockstep with two additional surveys and strategic plans, progressing through three distinct generations.

The first-generation Guangzhou transport model is notable for successfully localizing state-of-the-art international modeling techniques and for institutionalizing an evidence-based planning paradigm, thereby providing quantitative support for mitigating early-stage motorization-induced road congestion. Building on this foundation, the second-generation model introduced a hierarchical macro–meso–micro analytical framework capable of evaluating complex scenarios such as the traffic impacts of mega-events and the performance of urban rail-transit networks, facilitating the city's transition from a road-centric system to an integrated multimodal transport system.

Under the dual impetus of new-type urbanization and digital transformation, Guangzhou is actively advancing metropolitan-area expansion and the digital economy. Concurrently, the continuous evolution of internet technologies is driving methodological upgrades in transport modelling, while marked improvements in data granularity and acquisition efficiency have furnished robust technical support for refined urban governance decision-making. Against this backdrop, Guangzhou has established its third-generation transport modelling system. This paper focuses on the suite of key technologies and application scenarios arising from the dual evolutionary trajectories of regional integration and urban governance embedded in the third-generation system. By transcending the spatiotemporal constraints inherent in conventional models, the system delivers quantitative decision-support

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First author: MA Xiaoyi (1975–), male, born in Nantong, Jiangsu Province, holds a master's degree and is a professor-level senior engineer. He currently serves as Deputy General Manager of Guangzhou Transport Planning Research Institute Co., Ltd. His research interests include urban planning and transport planning. E-mail: pow2006@163.com

Corresponding author: ZHANG Ke (1989–), male, born in Nanchang, Jiangxi Province, holds a master's degree and is a senior engineer. His research focuses on urban planning, transport planning, and transport modeling. E-mail: 865831890@qq.com.

tools for transportation governance in the new era, signifying that Guangzhou's transport models have formally entered a phase of regional synergistic governance and fine-grained management.

1 Overview of Guangzhou's third-generation transport model system

According to three household travel surveys [1] and three rounds of the city's transport development strategic plans [2], Guangzhou has completed the iterative evolution of three generations of transport models, yielding a technology system tailored to successive development stages (Fig. 1). From the first to the third generation, the city's transport models have undergone marked advances in data sources, modelling scope, model functionality, and application domains, thereby providing robust support for innovations in urban transport planning and governance.

The third-generation system is conceived as a multi-layered, full-cycle decision-support framework under the dual lenses of regional coordination and urban governance. Driven by multi-source data, it transcends the spatio-temporal limitations of traditional models and establishes a dual-track synergy between "regional coordination analysis" and "fine-grained urban governance", enabling end-to-end coverage from macro-level strategy to micro-level scenarios and from plan formulation to dynamic governance.

1.1 Technical framework

Underpinned by a three-tier "data–model–application" architecture, two foundational modelling subsystems—regional integration and urban governance—were built, linked through a dynamic data backbone (Fig. 2).

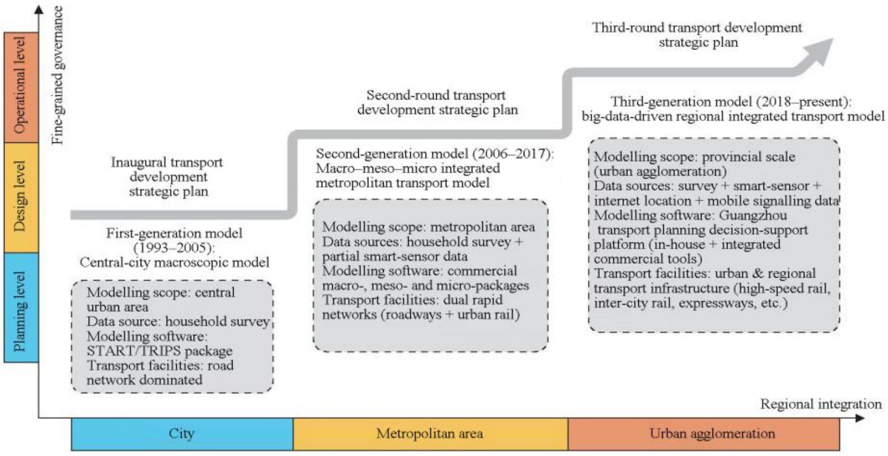

Fig. 1 Evolution and characteristics of Guangzhou's three generations of transportation models

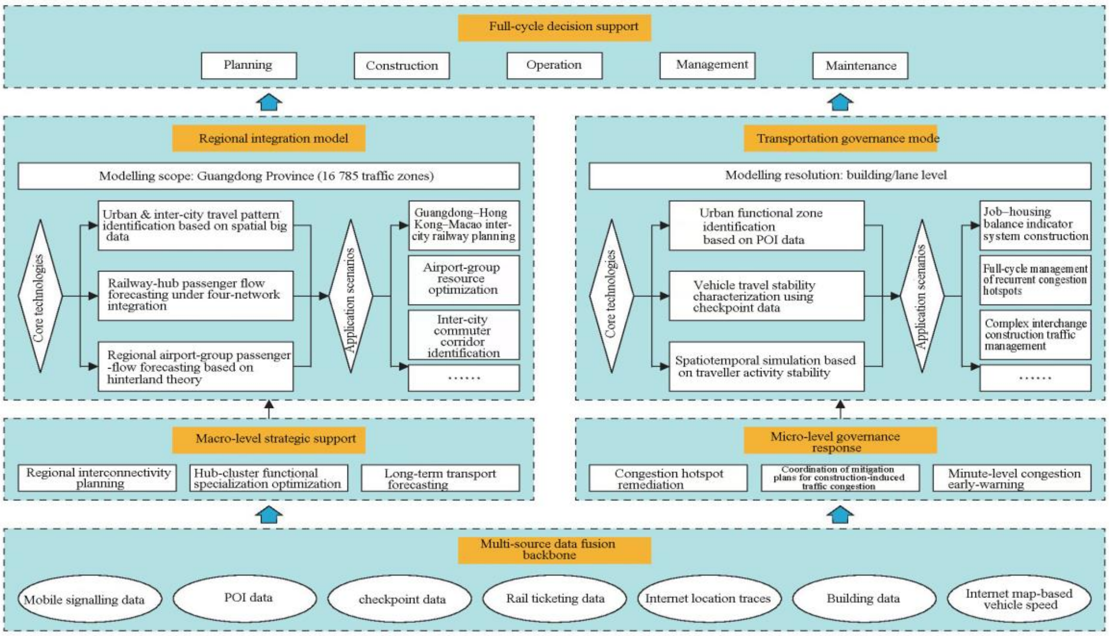

Fig. 2 Technical framework of Guangzhou's third-generation transportation model system

1) Dual-track architecture: It encompasses the regional integration model subsystem and the transportation governance model subsystem. The regional integration model addresses the coordinated development needs of the Guangdong–Hong Kong–Macao Greater Bay Area, encompassing 16 785 traffic analysis zones (TAZs) across Guangdong Province and integrating both highway and rail networks to focus on inter-city travel pattern mining and hub-cluster allocation optimization. The transportation governance model centers on the efficient utilization of existing assets, refining demographic inputs to building-level granularity and the road network to lane-level fidelity, thereby supporting high-frequency applications such as job-housing balance monitoring and congestion mitigation.

2) Multi-source data fusion: The backbone assimilates heterogeneous data streams—including mobile signaling data (covering > 2 million base stations province-wide), building-level data (2.33 million structures), checkpoint data, and internet-based location traces—to create a continuously updated data foundation that enables seamless interaction and synergy between the two subsystems.

3) End-to-end governance support: The regional integration model delivers macro-level constraints (e.g., external travel volumes) to the transportation governance model, while the latter feeds micro-level behavioral insights (e.g., traveller activity stability) back to the former, thereby establishing a closed loop that integrates top-down planning with bottom-up responsiveness.

1.2 Dual-track synergy

The regional integration model, anchored in supporting infrastructure interconnectivity, constructs an integrated technical architecture of "spatial expansion–network integration–pattern mining". The modelling domain is extended from the Guangzhou–Foshan–Dongguan metropolitan area (1 788 TAZs) to the entire Guangdong Province (16 785 TAZs), with the mean zone size refined to 2.66 km^2 per zone to align the resolution of peripheral zones with that of the urban core. A gravity-based urban model was developed to quantify the interactions among regional economy, population, and transport infrastructure, thereby underpinning the identification of inter-city travel patterns and the optimization of facility provision. Leveraging mobile signaling and rail ticketing data, a 10-million-level inter-city OD matrix was constructed to precisely delineate spatial features such as the Guangzhou–Foshan commuter corridor and inter-city travel hotspots within the Bay Area. Trunk railways, inter-city railways, suburban (regional) railways, and urban rail transit were integrated into a "four-network-converged" transport model that enables resource sharing across multi-tier rail systems. A hinterland-theory-based hub competition-cooperation analysis framework was further developed to demarcate passenger catchments for major hubs such as Baiyun International Airport and Guangzhou South Railway Station, thus optimizing the allocation of aviation and rail resources across the Greater Bay Area.

The transportation governance model adopts a chain of "fine-grained data–dynamic technology–scenario-based application" to build life-cycle governance tools, refining demographic and job-housing data to building-level granularity. Key technologies integrate point-of-interest (POI) data to identify urban functional zones such as central business districts and residential clusters; a dual-line operational road network replaces the traditional single-line representation, achieving lane-level fidelity that faithfully reproduces microscopic traffic behaviors in weaving areas and on ramps; coupling checkpoint license-plate data with real-time vehicle speeds from AutoNavi enables clustering identification of chronic congestion hotspots and OD backtracking; and an activity-stability simulation model replaces the conventional four-step method with probabilistic sampling to replicate individual space–time activity patterns.

2 Regional integration model

2.1 Modelling scope and traffic analysis zones

The regional integration model extends its modelling domain from the metropolitan area to the provincial scale. To meet the spatial zoning requirements imposed by the integrated development of the Guangdong-Hong Kong-Macao Greater Bay Area, the model's coverage is significantly expanded from the Guangzhou–Foshan–Dongguan metropolitan area to the entire Guangdong Province. TAZs are correspondingly refined; the resolution of peripheral zones is aligned with that of the urban core, pushing the total number of TAZs beyond 16 000 and reducing the average zone size from 7.66 km^2 per zone to 2.66 km^2 per zone (Fig. 3).

2.2 Transport network construction

With the construction of a multi-tier rail network in the Greater Bay Area, conventional regional transport models—traditionally focused on the road system—can no longer accommodate the expanding rail network. Moreover, the coexistence of trunk railways, inter-city railways, suburban (regional) railways, and urban rail transit further complicates network representation. The Guangzhou regional integration model broadens its network scope to encompass all four rail modes, establishing a multi-tier rail-transport network model (Fig. 4).

2.3 Core modelling technologies

Against the backdrop of regional integration, Guangzhou's transport model research has shifted its emphasis toward "mega-transport" modelling at the regional scale. A suite of key technologies has been developed, including inter-city travel pattern identification, passenger flow allocation

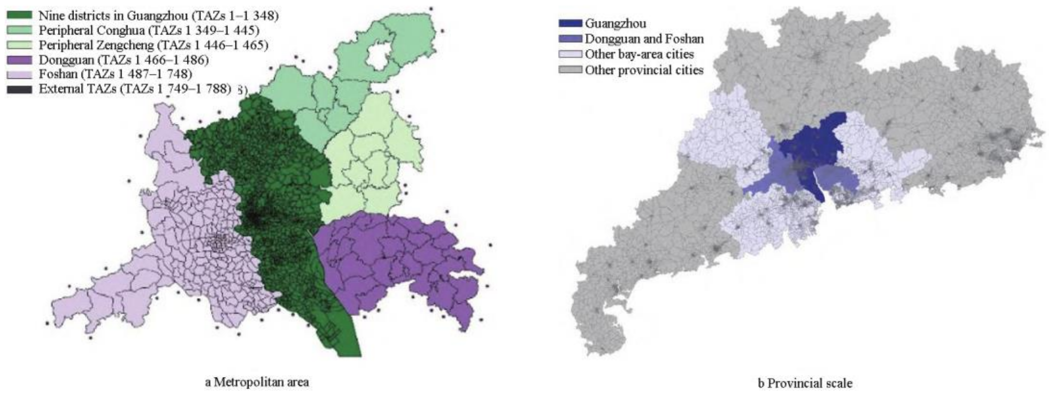

Fig. 3 Modeling scope and zoning expansion in the regional integration model of Guangzhou

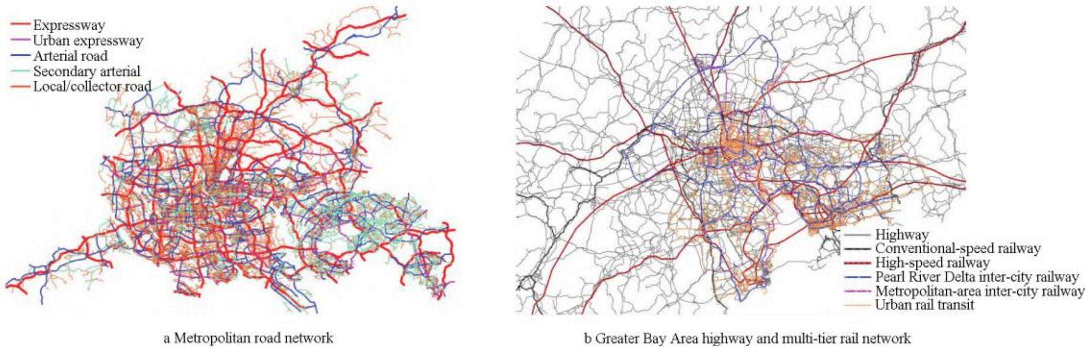

Fig. 4 Road and rail network modeling in the regional integration model of Guangzhou

forecasting for railway-hub clusters, and competitive-cooperative analysis of regional airport groups. By enhancing cross-boundary regional data fusion and advancing the application of core techniques such as inter-city mobility analysis and hub competition-cooperation modelling, the system now possesses the capacity to identify and simulate the evolution of cross-city travel patterns for tens of millions of residents using big data, thereby supporting coordinated and competitive forecasting of railway stations and airports across the Guangdong–Hong Kong–Macao Greater Bay Area.

2.3.1 Urban and inter-city travel pattern identification based on spatial big data

Traditional travel pattern analysis relies on citywide household travel surveys, which cannot readily support modelling at the provincial scale. In response to this, multi-source spatial big data—including provincial mobile signaling data, internet-based migration traces, expressway toll records, and railway ticketing data—were integrated to develop a province-wide travel pattern identification technique that systematically parses mobility patterns and characteristics. The technique comprises three core components: mobile data preprocessing and individual attribute classification, home–workplace and activity-stop identification [3], and urban and inter-city travel pattern recognition (Fig. 5).

2.3.2 Railway-hub passenger flow forecasting under the four-network integration

Conventional transport models exhibit limited coverage and insufficient accuracy in railway passenger-flow forecasting. Firstly, long-distance passengers account for a significant share of total flow and often lie beyond model boundaries. Secondly, under four-network integration, the composition of railway passengers has become more complex, encompassing not only traditional long-distance travellers but also hub-sharing passengers across the urban agglomeration, metropolitan-area passengers, and intra-city travellers. To respond to regional integration and the four-network integration trend, Guangzhou's transport model has upgraded its railway-hub cluster function-allocation and passenger-flow forecasting framework [4].

Aligned with four-network integration requirements, the Guangzhou regional integration model classifies railway passengers into four categories—long-distance, Bay-Area inter-city, intra-metropolitan, and hub-transfer flows—across multiple spatial scales and functional contexts (metropolitan, Greater Bay Area, provincial, and hub interchange). A two-stage choice approach was adopted to capture the full trip chain from traffic zones to railway hubs and onward to external provinces, with model calibration informed by railway ticketing data and mobile-signaling-based hub-tracing data. Ultimately, the proportional distribution of passenger dispatch volumes across various railway hubs was determined by forecasting categorized passenger flows, offering scientific support for the functional planning and division of labor within railway hub clusters (see Fig. 6).

2.3.3 Regional airport-group passenger-flow forecasting based on hinterland theory

Conventional airport-demand forecasting relies on historical data and employs time-series or regression models; it suffers from two principal limitations. Firstly, it inadequately accounts for the hinterland factors that drive regional air-travel demand. Secondly, it cannot systematically evaluate the competitive-cooperative relationships within an airport group from a regional integration perspective. To this end, the hinterland theory was introduced to delineate the airport hinterland areas based on the accessibility of the airport collection and distribution system, using travel time as an indicator, and to construct a competitive and cooperative relationship model for airport clusters (Fig. 7) [5]. The method first forecasts regional per-capita air trips to determine total air-travel demand, then allocates this demand among airports, and finally applies adjustment factors reflecting each airport's functional role to obtain the projected passenger throughput for every airport.

2.4 Application scenarios

2.4.1 Facilitating high-level interconnectivity with peripheral cities

Leveraging the provincial-scale transport model and the fine-grained identification of urban and inter-city travel patterns, a "core–periphery" analytical framework was applied to classify the spatial linkage characteristics between Guangzhou and its neighboring municipalities. Inter-city travel demand was further disaggregated by analyzing the volume and spatial distribution of bidirectional commuter flows between Guangzhou and surrounding cities (Fig. 8). Guided by the principle of supply–demand matching, the

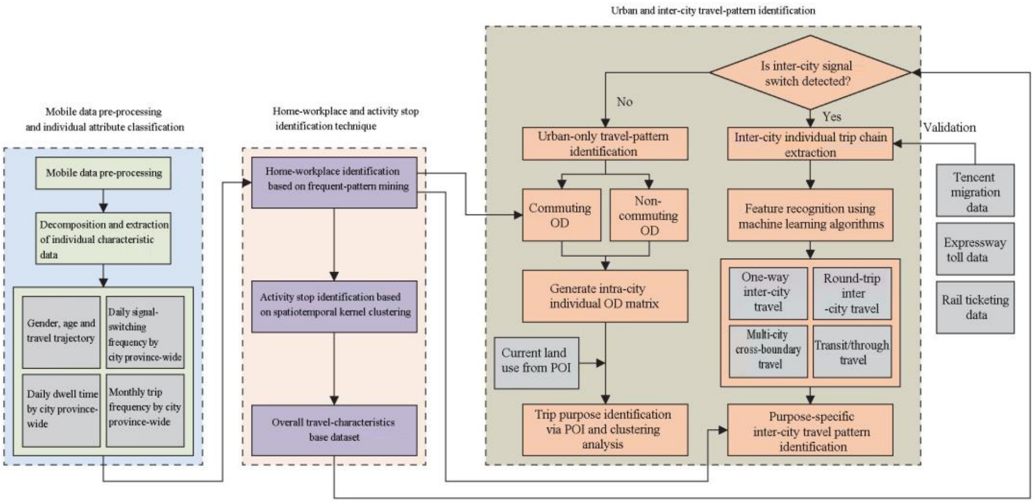

Fig. 5 Technical workflow for identifying urban and intercity travel patterns in the regional integration model of Guangzhou

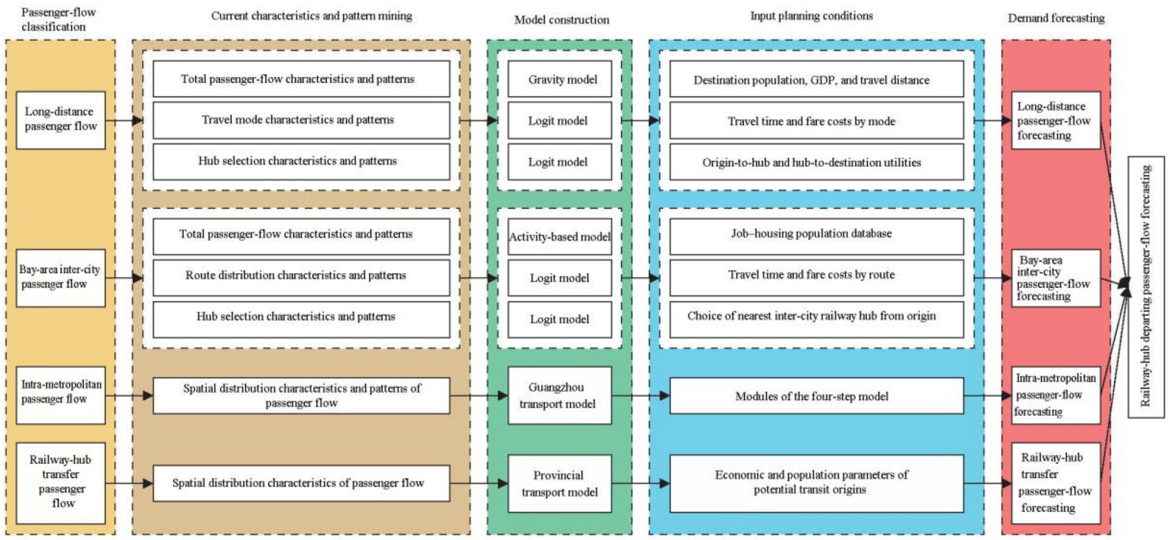

Fig. 6 Technical workflow for forecasting passenger flow at rail hubs in the regional integration model of Guangzhou

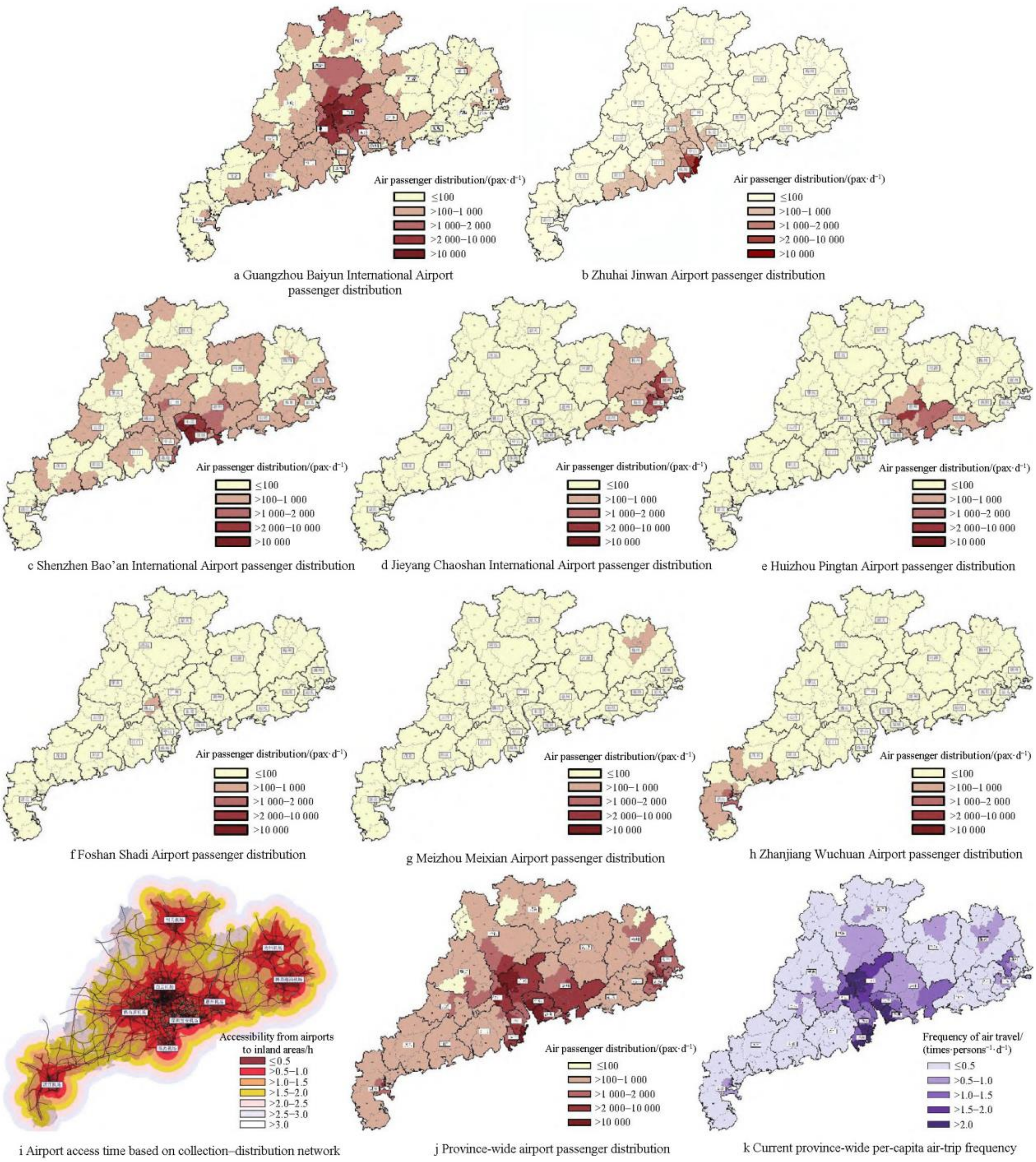

Fig. 7 Competitive and cooperative across regional airport clusters in the regional integration model of Guangzhou

Data source: Reference [5].

provision of multi-class roads and multi-modal rail transit between Guangzhou and its neighbors was optimized, and the layout of transport facilities was scientifically planned, thereby supporting the realization of high-level interconnectivity [6].

2.4.2 Supporting functional specialization and consolidated enhancement of the railway-hub cluster

Traditional urban transport planning for external hubs has focused primarily on aligning with trunk-railway network plans and improving collection–distribution systems; however, it lacks effective technical support for the functional specialization and resource sharing of the railway-hub clusters (more than 10 hubs) in megacities. Against the backdrop of four-network integration, Guangzhou employs the regional integration model to conduct passenger-flow forecasting for the hub cluster. Guided by the principles of balanced hub-cluster development and corridor-resource sharing, optimization studies on hub functional specialization were carried out. In

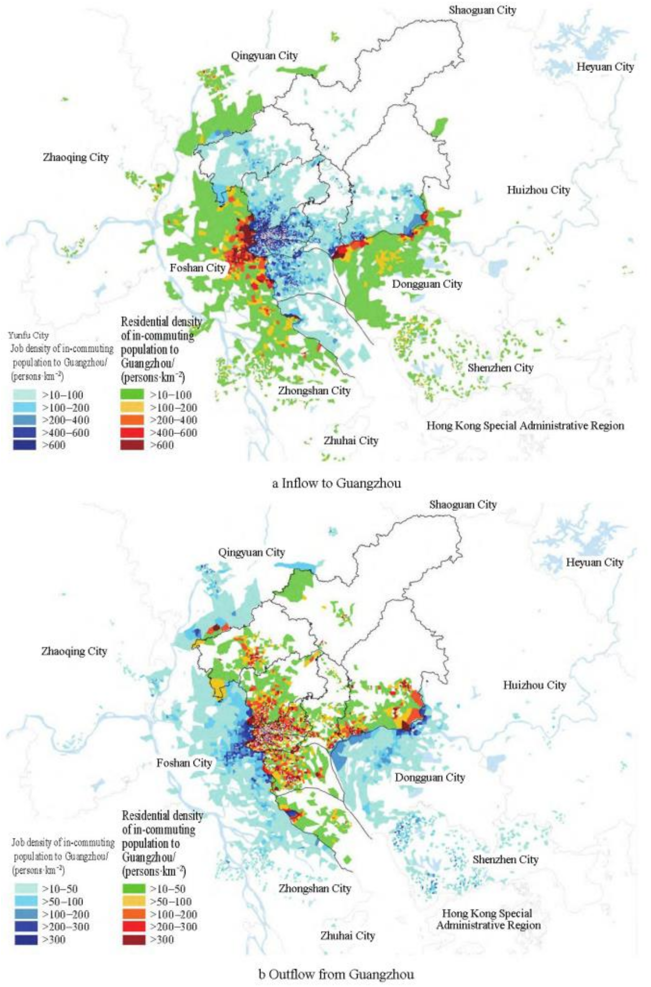

Fig. 8 Job-housing spatial distribution of bi-directional intercity commuter flows in the regional integration model of Guangzhou

conjunction with the construction/expansion of key hubs, inter-hub connector line schemes were proposed to strengthen interconnectivity and resource integration among hubs.

3 Transportation governance model

3.1 Population data granularity

The transportation governance model refines population data granularity from the TAZ level down to the individual building level. Employment and population data were conventionally obtained from annual statistical bulletins at the administrative-district resolution; disaggregating these data to the TAZ level necessitates multiple technical approaches. In the era of big data, the standard practice is to infer user residence locations via mobile-signaling base stations, yet this method carries inherent limitations: base-station coverage radii in Guangzhou are highly heterogeneous—about 500 m in the central area and 1–2 km in peripheral districts. Such discrepancies cause population distributions derived from base-station footprints to lose accuracy as spatial resolution increases. To compensate, the model fuses mobile signaling data with building-level data (about 2.33 million structures), integrating building footprints, land-use areas, and floor counts. A building-area allocation method was then applied to achieve a fine-grained population distribution (Fig. 9).

3.2 Transport network construction

The fidelity of conventional transport-planning models is insufficient for urban governance decision-making; critical

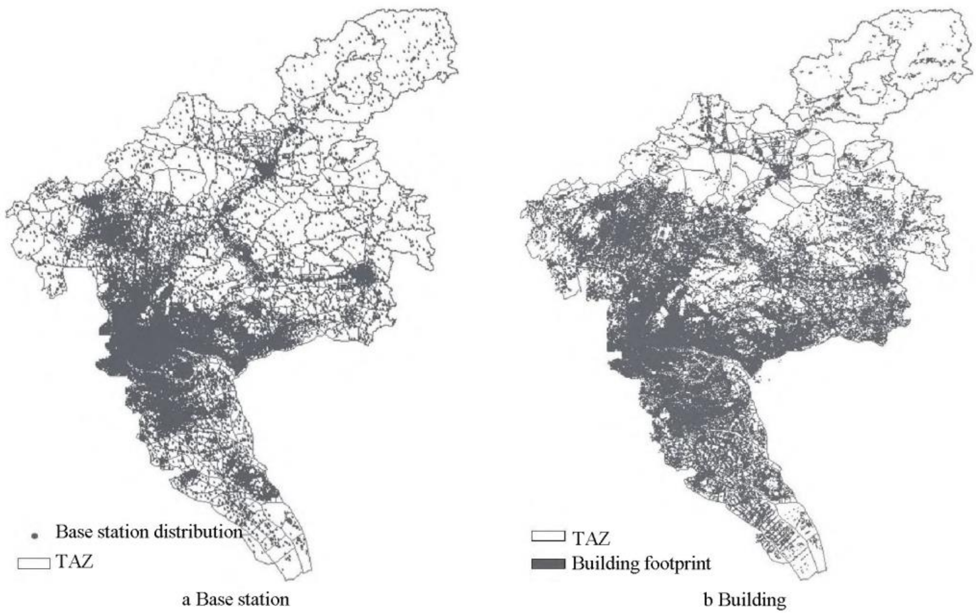

Fig. 9 Distribution of base stations and buildings based on mobile data in the transportation governance model of Guangzhou

details such as parcel access points and directional turning movements can only be captured through fine-scale network representation. During the development of an operational-level model, multi-source data from the "vehicle–city–network" ecosystem enables multi-scale perception of people, vehicles, and places, thereby establishing a robust data backbone for governance applications. Compared with planning-level models, the operational-level variant offers two advantages in TAZ ingress–egress modelling: (1) TAZs are refined from street-block level to parcel level, and (2) the road network is represented at markedly higher resolution. Planning-level models emphasize supply–demand balance and network connectivity, whereas governance-level models must replicate real-world traffic conditions, particularly with respect to weaving, merging, and diverging manoeuvres. At the road-network level, a dual-carriageway operational network replaces the traditional single-carriageway representation, yielding a road network that more accurately reflects actual traffic operations (Fig. 10).

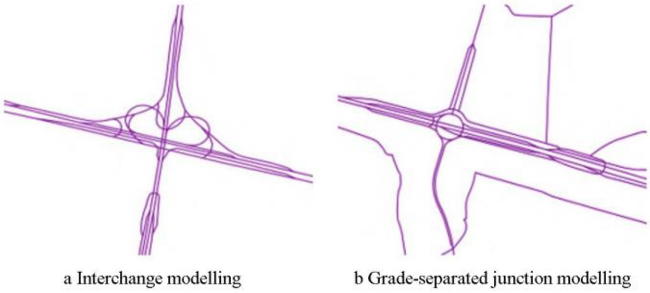

Fig. 10 Refined road network construction in the transportation governance model of Guangzhou

3.3 Core modelling technologies

3.3.1 Urban functional-zone identification based on POI data

Delineating the spatial distribution of urban functional zones is critical for uncovering the stability patterns of traveller activity. The Guangzhou transportation governance model fuses building-level, fine-grained population data with multi-attribute POI information. A kernel-density-estimation method was applied to identify functional-zone clusters at the city scale after rasterizing the discrete points [7]. POI categories encompass hospitals, schools, restaurants, hotels, supermarkets, office buildings, transport hubs, parks, petrol stations, financial institutions, leisure facilities and government offices, collectively reflecting the density of public service facilities and providing a proxy for regional development maturity (Fig. 11).

3.3.2 Vehicle-travel stability characterization using checkpoint data

Comprehensive vehicle-trip information and a deep understanding of travel patterns are essential for evidence-based urban transportation governance. The Guangzhou model's workflow for analyzing vehicle travel stability via checkpoint data is illustrated in Fig. 12.

Step 1: Pre-process checkpoint license-plate records for deduplication and error correction to yield validated data.

Step 2: Classify vehicles based on the number of days they are detected and their daily operational hours, generating vehicle data with distinct clustering characteristics. Extract individual travel information for each type of characteristic vehicle.

Step 3: Analyze the travel regularities and geographic affiliations of vehicles based on individual vehicle travel information.

3.3.3 Spatiotemporal simulation based on traveller-activity stability

Traditional four-step models disaggregate trip purposes into six classes (home-based work, home-based school, home-based life, home-based others, non-home-based work and non-home-based others). Their logic emphasizes the stability of trip purpose and origin–destination pairs while relying on constrained optimization for the remainder. This "reshuffling" at every iteration disregards traveller-activity stability, increases computational burden, and may degrade model fit.

Consequently, the model was enhanced through a spatiotemporal simulation that leverages the stability of residence, workplace, school, and daily activity stops, thereby faithfully reproducing the regularity of individual daily mobility rather than resorting to conventional optimization. This refinement aligns with observed travel behavior and substitutes statistical regularities of activity stability for mathematical optimization; the technical workflow is presented in Fig. 13.

3.4 Application scenarios

3.4.1 Establishment of a job–housing balance monitoring indicator system

Under the backdrop of urban renewal, relocating non-core functions of megacities offers a critical window for improving the job–housing balance. The key lies in accurately identifying the evolution of population and travel characteristics before and after urban renewal, and in systematically constructing a monitoring indicator system for job–housing balance. Leveraging spatiotemporal simulation of traveller-activity stability, the Guangzhou transportation governance model precisely tracks the travel patterns and changing trends of different population groups and articulates diverse demands from the perspectives of policy formulation, public participation, and sectoral development. Aiming for indicators that are measurable, manageable, and controllable, the model establishes a job–housing balance monitoring framework spanning macro, meso, and micro scales, integrating multi-dimensional, multi-core indicators (Fig. 14) to provide scientific guidance for transport and land-use planning in Guangzhou's urban renewal context.

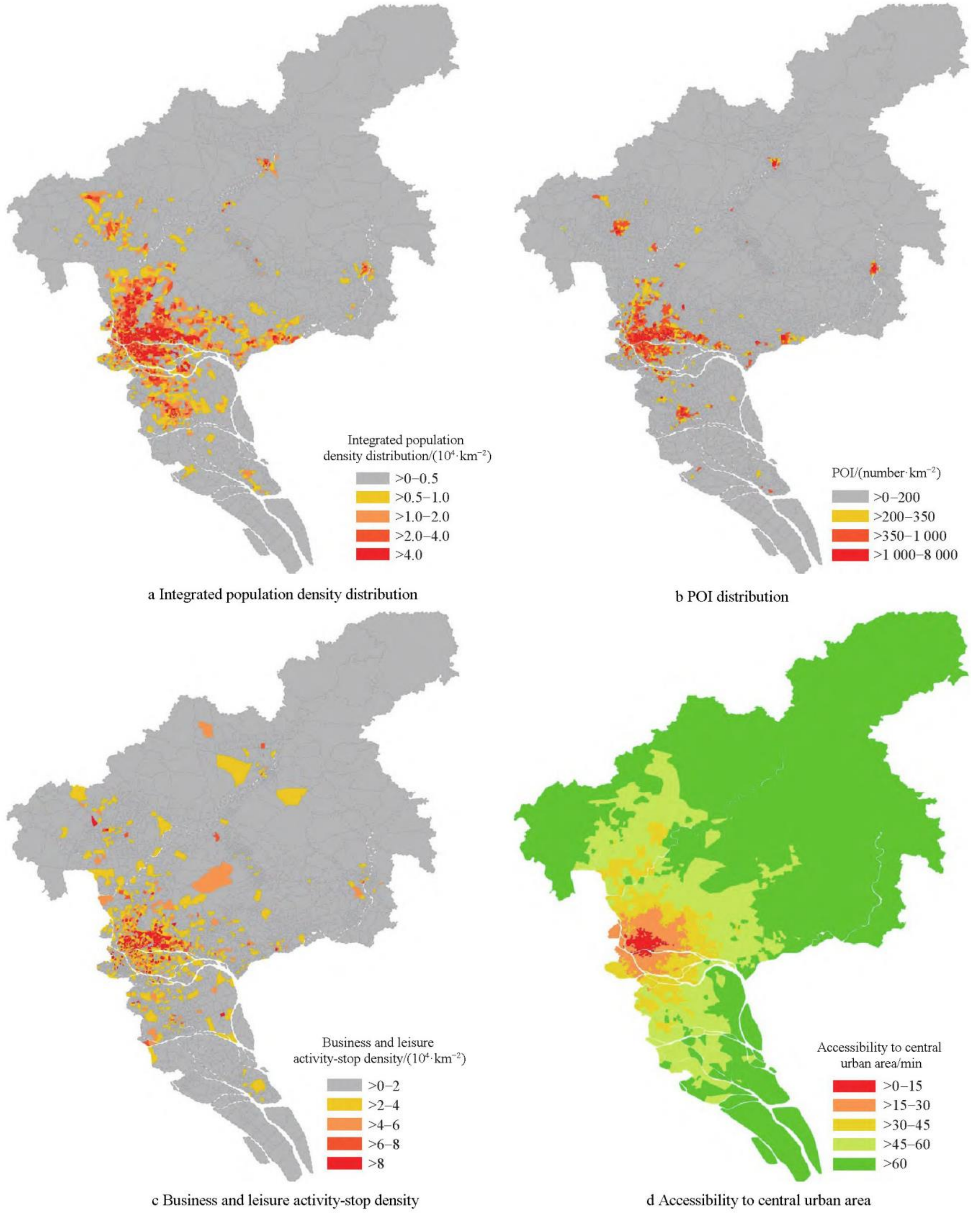

Fig. 11 Identification of urban functional zones based on mobile and POI data in the transportation governance model of Guangzhou

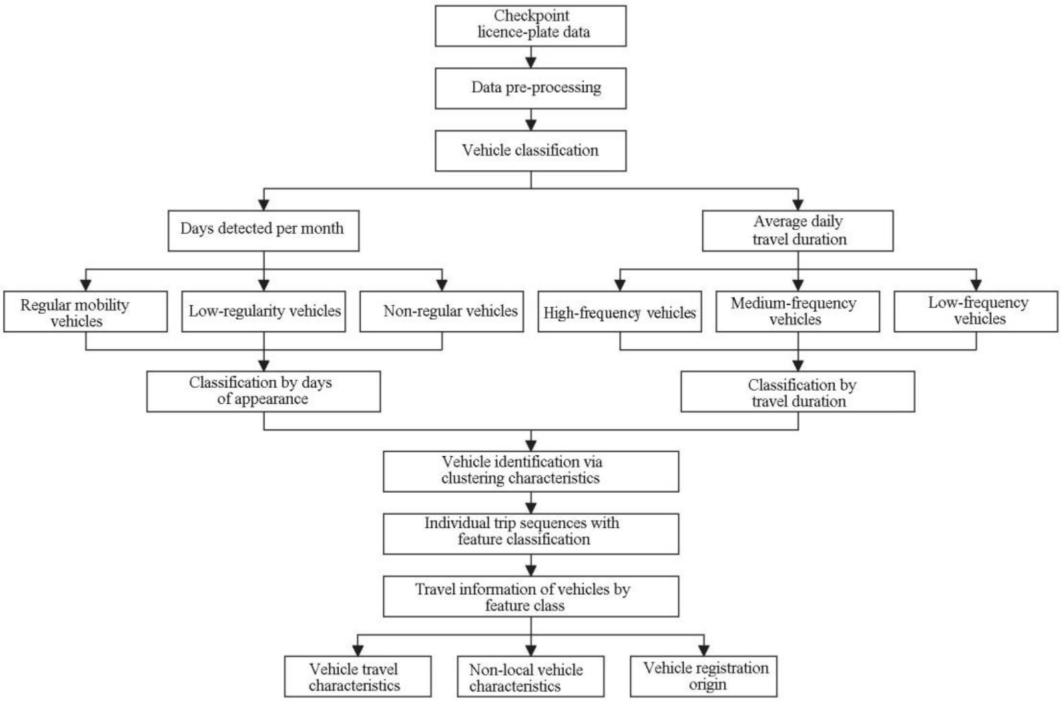

Fig. 12 Workflow for analyzing vehicle travel stability characteristics based on checkpoint data in the transportation governance model of Guangzhou

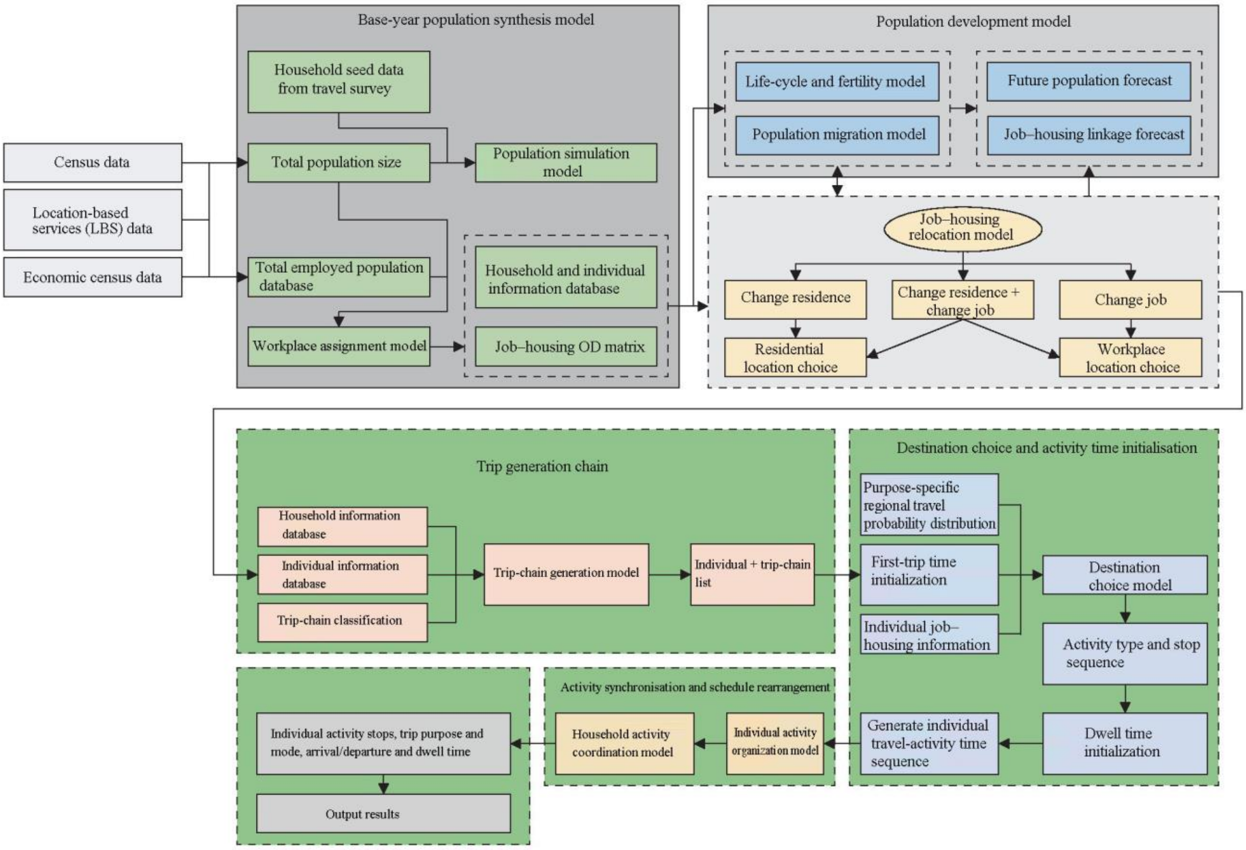

Fig. 13 Technical workflow for spatiotemporal simulation based on travelers' behavioral stability in the transportation governance model of Guangzhou

Data source: Reference [8].

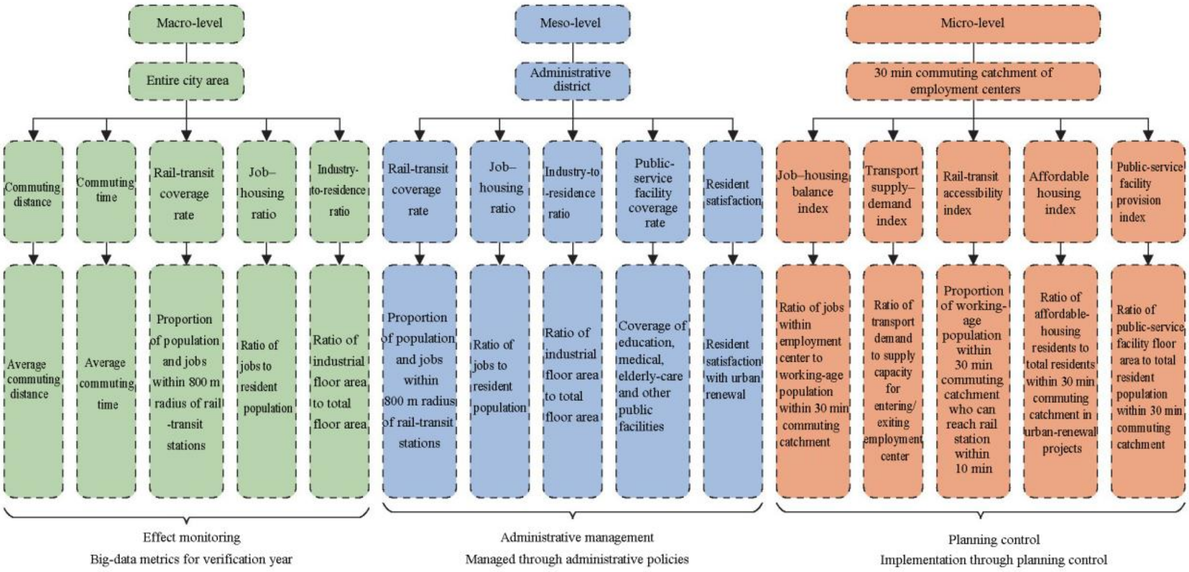

Fig. 14 Indicator system for monitoring job–housing balance in Guangzhou

3.4.2 Congestion hotspot identification–mitigation–post-evaluation governance

The Guangzhou transportation-governance model delivers a closed-loop, full-cycle framework that spans congestion-hotspot identification, remediation, and post-implementation evaluation, significantly extending the model's application envelope. During identification, static and dynamic vehicle-movement characteristics extracted via automatic number-plate recognition at checkpoints were fused with high-frequency, long-term internet-map speed data and congestion-index series to enable clustering analysis, typology identification, and precise geolocation of recurrent bottlenecks (Fig. 15). In the mitigation phase, vehicle-OD backtracking differentiates through traffic from local collection–distribution traffic, informing differentiated countermeasures such as upstream diversion and downstream dispersal. The post-evaluation phase systematically assesses the effectiveness of each implemented intervention.

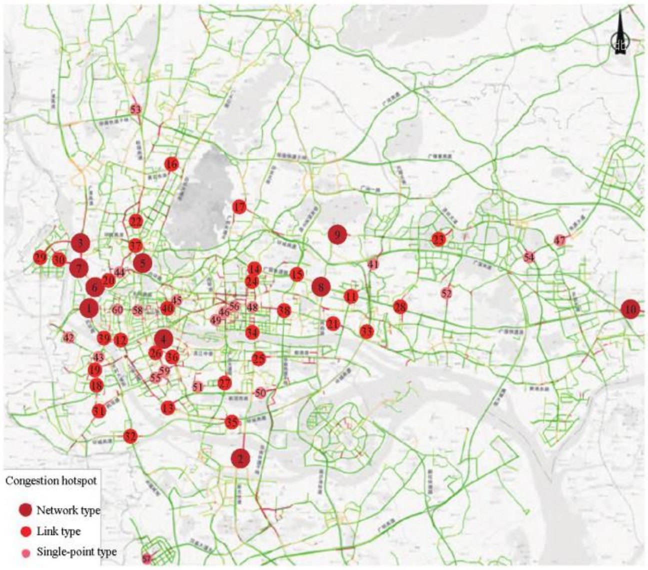

Fig. 15 Distribution of chronic congestion hotspots in Guangzhou

3.4.3 Full-cycle traffic management for complex interchange construction

As the city transitions to stock-based planning, scarce transport resources render construction-induced lane closures increasingly disruptive. By enhancing data granularity and refining the transport network—augmented by traveller-activity stability analysis—the Guangzhou model provides robust support for construction traffic management, realizing a closed loop spanning planning, design, and construction (Fig. 16). Take a complex interchange project as an example:

1) Planning phase: Macroscopic transport models forecast turning demand at the interchange; quantitative evaluation under resource constraints (funding, land availability, and engineering feasibility) informs alternative design selection.

2) Design phase: The governance model integrates upstream and downstream traffic-flow and operational characteristics, guiding lane-level detailed design through both system-wide and local-link performance metrics.

3) Construction phase: Coupled with micro-simulation, the model backtracks multilayer traffic flows affected by work-zone closures, quantifies impacts across construction stages, and proposes dynamic optimization measures.

4 Conclusion

This paper has systematically articulated the key technologies and application scenarios of Guangzhou's

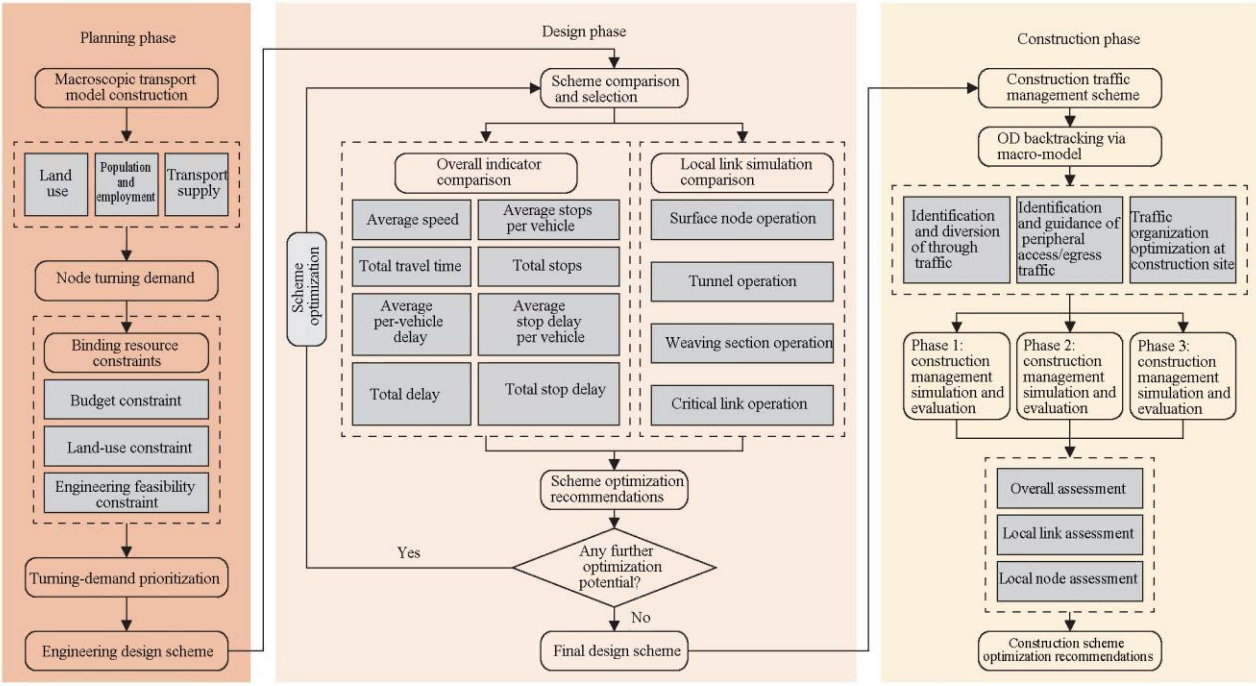

Fig. 16 Complete workflow for traffic diversion management of complex interchange construction in the transportation governance model of Guangzhou

third-generation transport modelling system from the dual perspectives of regional integration and urban governance. The system focuses on uncovering regional travel patterns in the regional integration dimension and on identifying traveller activity stability in the urban governance dimension. These contributions are not only theoretically innovative but have also demonstrated substantial practical effectiveness.

Looking ahead, the Guangzhou transport modelling system will evolve in tandem with emerging technologies and application contexts, prioritizing the following directions: 1) deep application of artificial intelligence: develop deep-learning-based travel-behavior prediction and dynamic-simulation techniques to enhance the model's capacity to evaluate policy interventions and governance measures; 2) innovative multi-source data fusion: integrate real-time data from the vehicle–city–network ecosystem and the urban traffic brain to refine modelling methodologies and bolster the model's dynamic responsiveness; 3) cross-disciplinary methodological expansion: incorporate social-network analysis and spatial econometrics to construct a coupled modelling framework for the transport–economy–environment complex system.

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