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Research on Traffic Volume Transfer Forecasting for Expressway Reconstruction and Expansion under the Condition of Regional Road Network Linkage

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Abstract: Against the backdrop of the concurrent advancement of China's expressway network development and large-scale reconstruction and expansion projects, the reconstruction and expansion of a single road section can trigger a redistribution of the overall traffic flow within the regional road network, with significant characteristics of traffic volume transfer across routes, corridors, and regions. Traditional traffic volume analysis methods, which focus on individual road sections, struggle to meet the practical demands of regional road network linkage, multi-path competition, and dynamic traffic organization. To scientifically grasp the traffic transfer patterns within the road network during reconstruction and expansion and ensure the safety and efficiency of road network operations during construction, this paper adopts a perspective of regional road network linkage to systematically analyze the internal mechanisms and spatiotemporal distribution characteristics of traffic volume transfer during expressway reconstruction and expansion. Furthermore, it proposes a traffic volume transfer forecasting and analysis system suitable for reconstruction and expansion scenarios. Through this analysis, the paper aims to provide theoretical support and practical references for formulating traffic assurance plans for expressway reconstruction and expansion projects, optimizing the allocation of regional road network resources, and preventing and controlling traffic operation risks. This research holds significant importance for enhancing the service level of the road network during expressway reconstruction and expansion.

Keywords: Regional road network linkage; Expressway reconstruction and expansion; Traffic volume transfer; Traffic forecasting; Road network coordination

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1. Introduction

As China's transportation infrastructure network continues to improve, early-built expressways are gradually entering the reconstruction and expansion cycle, with reconstruction and expansion becoming the primary means of enhancing quality and capacity for expressways [1]. Coastal core corridors such as the southern section of the Ningbo-Taizhou-Wenzhou Expressway in Wenzhou face challenges due to their long construction history and saturated traffic volumes, making the dual four-lane standard insufficient to meet passenger and freight transportation demands, thereby necessitating large-scale reconstruction and expansion projects. Unlike new construction projects, expressway reconstruction and expansion must be carried out without interrupting traffic flow. Measures such as construction lane occupation, lane reduction, and speed restrictions directly reduce the mainline capacity. In the context of a highly interconnected regional road network, construction disturbances in localized sections can rapidly propagate to parallel expressways, national and provincial highways, and urban arterial roads, triggering large-scale traffic diversion. Current traffic volume forecasts often focus on individual projects, neglecting the synergistic effects and dynamic transfer characteristics of the road network, leading to issues such as congestion on diversion routes, failure of mainline traffic preservation, and regional traffic paralysis. In a networked transportation landscape, only by adopting a regional road network interconnection perspective, clarifying the driving mechanisms, path patterns, and spatiotemporal patterns of traffic volume transfer, and constructing an accurate transfer prediction system can scientific bases be provided for construction traffic organization, road network diversion control, and traffic safety assurance. This represents a core issue that urgently needs to be addressed in current expressway reconstruction and expansion traffic management.

2. Analysis of traffic volume transfer mechanisms and characteristics in expressway reconstruction and expansion

2.1. Primary impacts of reconstruction and expansion projects on road network operations

Expressway reconstruction and expansion alter existing traffic conditions through methods such as lane occupation, half-closure, speed-restricted passage, and interchange modifications, producing multi-level impacts on regional road network operations [2]. Firstly, there is a reduction in mainline capacity. The decrease in the number of lanes, insufficient lateral clearance, and degraded alignment indicators in construction sections, combined with speed restrictions, result in a 10–35% decrease in capacity compared to normal sections. Core sections such as the southern Wenzhou to Ruian segment easily degrade from Level III to Level V service during peak hours, forming chronic bottlenecks. Secondly, there is a redistribution of road network traffic. With the decline in mainline capacity, long-distance transit, medium-distance interval, and short-distance intra-regional traffic flows are forced to transfer to parallel expressways and national and provincial highways. The Yongguan Expressway, Wenzhou Ring Expressway, and National Route G104 become primary carriers, with previously unsaturated road network nodes rapidly approaching saturation. Finally, there is an increase in traffic organization complexity. Reconstruction and expansion involve cross-construction of multiple processes such as subgrade, pavement, bridges, and interchanges, with dynamic adjustments to traffic preservation plans at different stages and frequent traffic conversions, further exacerbating road network traffic fluctuations and amplifying traffic operation risks.

2.2. Core driving factors for traffic volume transfer under regional road network interconnection

Under regional road network interconnection, traffic volume transfer results from the combined effects of supply-side constraints and demand-side choices, with core driving factors categorized into four types. The first is the decline in capacity caused by construction. Half-closure, speed restrictions, and ramp closures directly reduce mainline supply capacity, serving as the fundamental inducement for traffic volume transfer. During the Wenzhou Bridge closure construction, mainline traffic decreased by over 30%, with the transfer effect being most pronounced. The second factor is the supply conditions of alternative routes in the road network. The technical grade, capacity, and service level of parallel expressways and national and provincial highways determine transfer capacity [3]. The Yongguan Expressway, with its dual six-lane configuration and Level I service, becomes the preferred diversion route for long-distance freight vehicles; while certain sections of National Route G104, already saturated, can only accommodate short-distance traffic transfers. The third factor is traveler path selection preferences. Passenger vehicles prioritize paths with higher speeds and shorter distances, while freight vehicles focus on transportation costs and restriction policies. Concentrated travel by passenger vehicles during holidays amplifies transfer traffic, with holiday traffic volumes reaching 1.5 times the usual levels. The fourth factor is traffic control and guidance measures. Measures such as remote guidance, vehicle-type restrictions, and entrance controls actively guide traffic flow transfers. Restrictions on vehicles with five or more axles and mandatory diversions at hub interchanges directly alter traffic flow distribution. These four factors interact to form the traffic volume transfer mechanism under regional road network interconnection.

2.3. Primary paths and modes of traffic volume transfer

Based on the traffic flow composition in reconstruction and expansion projects, traffic volume transfer forms three types of paths and three modes, covering all regional traffic travel. Transfer paths are divided into long-distance transit paths, medium-distance interval paths, and short-distance intra-regional paths [4]. Long-distance transit primarily involves directions such as Ningbo-Fujian and Hangzhou-Fujian, achieving long-distance detours via the Yongguan Expressway and Zhuyong Expressway + Wenzhou Ring Expressway. Medium-distance intervals primarily involve travel from the main urban area of Wenzhou to Cangnan and Pingyang, relying on the Ouyue Avenue and National Route G322 for conversions. Short-distance intra-regional travel primarily involves travel by towns along the route, with transfers completed through local roads and interchange connections. Transfer modes include active diversion mode, passive transfer mode, and mandatory control mode. Active diversion involves travelers autonomously selecting alternative paths based on road condition information, often occurring during the initial stages of construction. Passive transfer involves forced detours due to mainline congestion, concentrated during peak hours. Mandatory control involves management departments guiding traffic flow through restrictions and closures, applicable to core bottleneck sections. The combination of these three modes constitutes a complete traffic volume transfer system for the regional road network.

2.4. Spatiotemporal distribution characteristics of traffic volume transfer

Traffic volume transfer exhibits significant spatiotemporal imbalance, serving as a key basis for predictive analysis. In terms of temporal distribution, annual variations are influenced by construction stages, with smaller transfer volumes during subgrade construction and peak transfer volumes during pavement construction and bridge splicing periods. Monthly variations exhibit a “double-peak, double-valley” pattern, with February (Chinese New Year) and September representing traffic valleys, and August and November representing peaks. Daily distributions peak during 7:00–9:00 and 16:00–17:00, with transfer volumes accounting for over 13% of the daily total. In terms of spatial distribution, there is a north-high, south-low, and core-concentrated characteristic. The southern Wenzhou to Feiyun section serves as the core transfer area, with transfer volumes accounting for over 60% of the entire route, gradually decreasing from north to south. In terms of road network dimensions, expressways account for 45% of transfers, national and provincial highways account for 35%, and urban roads account for 20%. Freight vehicles prioritize diversion to expressways, while passenger vehicles disperse to urban roads. In terms of vehicle type distribution, the transfer rate for vehicles with five or more axles exceeds 80%, while the transfer rate for small passenger vehicles is less than 30%, exhibiting differentiated transfer characteristics by vehicle type.

3. Prediction and analysis system for traffic volume transfer under regional road network linkage

3.1. Overall prediction approach and principles

Against the backdrop of regional road network linkage, the prediction of traffic volume transfer is guided by the core principles of “priority for unimpeded traffic flow, road network coordination, dynamic adaptation, and precise quantification”. This approach breaks away from the limitations of isolated predictions for single projects, treating the reconstructed or expanded road sections and the entire regional road network as an integrated whole. During the prediction process, emphasis is placed on simulating changes in road network capacity during construction, the effectiveness of various traffic control measures, and the dynamic adjustment patterns of traveler route choices. This enables precise calculation of the scale of traffic volume transfer among different routes, time periods, and vehicle types, providing support for maintaining unimpeded traffic flow during construction [5].

In line with practical engineering needs, the prediction work strictly adheres to four core principles: First, the principle of road network integrity ensures a comprehensive consideration of all road resources, including expressways, national and provincial trunk roads, and urban roads, covering all potential routes for traffic volume transfer to avoid prediction deviations caused by partial considerations. Second, the principle of stage-specific adaptability involves dynamically adjusting prediction parameters according to traffic maintenance plans at different construction stages, such as subgrade construction, pavement laying, and traffic engineering installation, ensuring that prediction results align with construction progress. Third, the principle of vehicle type differentiation fully considers the differences in travel purposes, driving characteristics, and route choices between passenger cars and freight vehicles, constructing separate prediction models for each to enhance prediction accuracy. Fourth, the principle of practical orientation ensures that prediction results directly serve the formulation of diversion plans and optimization of traffic control measures, balancing scientific rigor with on-site operability to ensure direct applicability of prediction outcomes.

3.2. Basic data requirements and collection analysis

The accuracy of traffic volume transfer predictions relies on multi-dimensional, comprehensive basic data support, necessitating the establishment of a robust data collection system that primarily covers four core categories of data: road network, traffic, construction, and control.

Road network data includes the topological structure of the regional road network, technical grades of various road sections, number of lanes, design speeds, and key parameters of interchange hubs. Focus is placed on core routes such as the Ningbo-Taizhou-Wenzhou Expressway, Ningbo-Dongguan Expressway, Wenzhou Ring Expressway, and National Highways G104, G228, and G322, with comprehensive collection of basic information on these routes to lay the foundation for linked road network analysis [6]. Traffic data encompasses historical cross-sectional traffic volumes, entrance and exit traffic volumes, vehicle type composition ratios, peak hour factors, and directional imbalance factors. Using 2021 as the base year, continuous observational data from the past five years is collected, strictly distinguishing between weekday and holiday traffic characteristics, as well as between passenger cars and freight vehicles, to fully grasp regional traffic operation patterns. Construction data requires clarification of construction stage divisions, road occupation methods, speed limit standards, closure periods, and interchange reconstruction plans to accurately grasp the impact of different construction stages on road network capacity. Control data includes traffic restriction policies, locations of diversion points, traffic guidance measures, and emergency control plans, providing a basis for simulating traffic volume transfer routes. During data collection, a combination of methods such as drone aerial photography, on-site observations, toll system statistics, and traffic model calibration is employed to verify data authenticity and completeness from multiple sources, ensuring that basic data can support accurate predictions.

3.3. Traffic volume transfer prediction and analysis process

Combining the characteristics of regional road network linkage, a prediction process of "four-stage method + construction disturbance correction" is adopted, completing the entire prediction and analysis process in four sequential steps to ensure that prediction results align with actual engineering conditions.

The first step involves current situation analysis and benchmark calibration. This includes a comprehensive review of the overall structure of the regional road network, systematic analysis of current traffic volume distribution, road network service levels, and traffic volume transfer potential, precise calibration of key parameters such as road network capacity and flow coefficients, and clarification of traffic volume distribution characteristics in the base year to provide a foundational reference for subsequent predictions. The second step quantifies construction impacts. Based on specific measures such as road occupation scope, speed limit requirements, and closure durations at different construction stages, scientific calculations are made to determine capacity reduction coefficients for mainlines and construction areas, clearly defining changes in road network supply and the extent of construction impact on road network capacity. The third step involves traffic volume generation and distribution. Combining regional economic development trends and vehicle ownership growth patterns, future trend traffic volumes, construction-induced traffic volumes, and transferred traffic volumes are reasonably predicted. Using TransCAD software, a provincial road network model is constructed to allocate future year Origin-Destination (OD) flows reasonably to various road sections within the regional road network. The fourth step calculates transfer volumes and allocates routes. Based on established diversion principles and vehicle type-specific traffic restriction policies, precise calculations are made to determine the scale of traffic volume transfer on each route, clarifying the transfer ratios for long-distance, medium-distance, and short-distance traffic volumes, ultimately outputting traffic volume transfer prediction results for different time periods, road sections, and vehicle types. Throughout the prediction process, dynamic corrections are made to account for the impacts of construction disturbances, adjustments in control measures, and changes in traveler choices, continuously optimizing prediction results to ensure they align with actual on-site operation conditions.

3.4. Evaluation indicators for prediction results

To verify the reasonableness and practicality of traffic volume transfer prediction results, a multi-dimensional evaluation indicator system is established, comprehensively validating prediction results from four core aspects: traffic volume, service level, transfer efficiency, and operational risk, providing a basis for optimizing prediction models and adjusting diversion plans [7].

Traffic volume indicators primarily include total traffic volume transfer, transfer volumes by road section, transfer rates by vehicle type, and peak hour transfer traffic volumes, comprehensively measuring the overall scale and distribution characteristics of traffic volume transfer. Service level indicators cover the V/C ratio (traffic volume to capacity ratio) of construction road sections, service levels of diversion routes, and the overall service level of the road network, with explicit requirements that the service level of construction road sections should not be lower than Level 4 and that of diversion routes should not be lower than Level 3, ensuring basic traffic needs are met during construction. Transfer efficiency indicators include transfer balance, route utilization rates, and increases in detour distances, with the core aim of avoiding excessive load on single routes and achieving balanced distribution of road network traffic volumes. Operational risk indicators include the number of bottleneck road sections, congestion durations, and predictions of accident-prone points, providing precise support for traffic safety control and emergency response during construction. Through comprehensive evaluation using these indicators, prediction model parameters are promptly optimized, and diversion plans are adjusted to achieve optimal allocation of regional road network resources, ensuring safe, orderly, and efficient traffic flow during construction.

4. Conclusion

In the context of the networked development of expressways and the normalization of reconstruction and expansion projects, regional road network linkage has become a core feature of traffic volume transfer, rendering prediction methods from a single-project perspective inadequate for meeting traffic maintenance needs during construction. Through mechanistic analysis, this paper clarifies the multi-level impacts of reconstruction and expansion projects on the road network, identifies the driving factors, route patterns, and spatiotemporal distribution characteristics of traffic volume transfer, and constructs a traffic volume transfer prediction system adapted to regional road network linkage, achieving a transition from single-project to whole-network analysis and from static to dynamic simulation. Research indicates that traffic volume transfer during expressway reconstruction and expansion is the result of the combined effects of construction supply constraints, road network alternative conditions, traveler choice preferences, and traffic control measures, exhibiting significant spatiotemporal imbalances and vehicle type-specific differentiation characteristics. The prediction system, based on the four-stage method and construction disturbance correction, can accurately quantify transfer scales and distributions, providing scientific support for construction traffic organization, road network diversion control, and traffic safety guarantees. Future research can further integrate vehicle-road coordination and real-time traffic sensing technologies to achieve dynamic traffic volume transfer prediction and real-time control linkage, continuously improving the operational efficiency and service levels of regional road networks during expressway reconstruction and expansion, providing replicable and transferable theoretical and practical experience for similar projects nationwide.

Disclosure statement

The author declares no conflict of interest.

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