Research on the Impact of Urban Traffic Development on Municipal Road and Bridge Design and Countermeasures

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Abstract: Against the backdrop of the continuous acceleration of urbanization, the sustained growth of urban traffic volume, changes in travel modes, and adjustments in traffic planning have posed numerous new challenges to the design and construction of urban traffic infrastructure. In this context, municipal road and bridge design should actively respond to various impacts and challenges brought about by urban traffic development and select reasonable design strategies to avoid functional defects and resource waste caused by design disconnections. This paper analyzes the impact of urban traffic development on municipal road and bridge design and summarizes a series of practical countermeasures for implementation, aiming to promote the stable development of China's urban transportation industry.

1. Introduction

At present, the population and industries are gradually concentrating in urban areas, leading to an explosive growth in urban traffic demand. According to data from the Ministry of Transport, in 2024, China's urban passenger volume reached 64.5 billion person-times, a year-on-year increase of 5.2%. The emergence of travel modes such as shared bicycles and online ride-hailing services has facilitated a gradual transition towards a people-oriented and diversified travel model. To improve the overall traffic operation efficiency in cities, various regions have optimized traffic planning based on actual conditions, aiming to establish a multi-modal, efficient, and convenient traffic transfer system. However, municipal road and bridge designs in many areas have exposed problems such as single functionality or outdated concepts, seriously affecting the full utilization of their functions. Therefore, how to effectively respond to the challenges brought about by urban traffic development and optimize municipal road and bridge design has become a hot topic in the field of urban transportation.

2. The Impact of Urban Traffic Development on Municipal Road and Bridge Design

Urban traffic development is a progressive evolutionary process, with changes in modes and volumes. In the new era, it is necessary to focus on several major changes, including the diversification of travel modes, the continuous growth of traffic volume, and adjustments in traffic planning, and analyze their impacts on municipal road and bridge design from multiple perspectives to provide reference support for the subsequent optimization of municipal road and bridge design. The specific impacts are shown in Table 1.

Table 1 The Impact of Urban Traffic Development on Municipal Road and Bridge Design

Influencing Factors	Main Challenges	New Requirements for Road and Bridge Design
Continuous Growth of Traffic Volume	Structural overload and insufficient capacity	Three-dimensional design, standard upgrades, etc.
Traffic Planning Adjustments	Dynamic design premises and complex multi-objective integration	Multidisciplinary integrated design, flexible and adaptive design
Changes in Travel Modes	Conflicts in road right allocation and increased transfer demands	Integrated supporting facilities, optimized cross-section design, and

2.1 Impact of Continuous Growth of Traffic Volume

With the construction and development of cities in various regions, the number of motor vehicles and travel volume have increased simultaneously. According to data from the Ministry of Public Security, the number of motor vehicles in China has reached 453 million, and the number of drivers has reached 542 million. In major cities such as Beijing and Shanghai, the average daily urban road traffic volume exceeds 100 million vehicle-times. Moreover, the cross-regional traffic volume in cities continues to grow, especially within urban agglomerations such as the Yangtze River Delta and the Beijing-Tianjin-Hebei region, where the proportion of cross-city commuting traffic has significantly increased, and even tidal congestion occurs during morning and evening peak hours. The growth in traffic volume has brought new challenges to the traffic capacity and load-bearing capacity of municipal roads and bridges [1]. Due to the unexpected growth in traffic volume, some roads and bridges built a long time ago in cities are operating under excessive loads, directly causing diseases such as bridgehead jumps and pavement cracks. This requires an increase in traffic volume prediction cycles and load standards in road and bridge design, especially the optimization of bridge deck paving materials and bridge main girder structures based on some cross-regional travel demands to improve the durability and fatigue resistance of roads and bridges.

2.2 Impact of Changes in Travel Modes

At present, urban transportation travel is gradually transitioning from a model dominated by public transportation and private cars to a diversified and integrated model. The emergence of shared bicycles, online ride-hailing services, and the concept of green travel has led to significant changes in travel modes [2]. Shared bicycles or shared electric bikes have become important means of transportation for short-distance travel due to their low cost and ease of operation, especially in first- and second-tier cities where the number of shared bicycles has been increasing year by year. The popularity of online ride-hailing services has quickly seized the market share of public transportation and taxis due to various coupons and high-quality service advantages, becoming one of the main travel modes for the general public. In the future, with the widespread application of autonomous driving technology, the intelligence level of travel modes will be further improved, posing more requirements for the functionality of road and bridge design [3].

2.3 Impact of Traffic Planning Adjustments

Currently, urban traffic planning mainly aims to build a comprehensive transportation system and focuses on three aspects of transformation: First, optimize and adjust the spatial layout, break the traditional model of wide roads and sparse road networks, and increase urban traffic capacity. Second, coordinate and adjust travel modes, focusing on strengthening the connection and transformation between rail transit and ground transportation to achieve comprehensive coverage of various travel modes and seamless transfer for citizens. Third, conduct ecological planning adjustments, incorporating green and low-carbon concepts into existing traffic planning, minimizing the damage to the ecological environment caused by road and bridge construction, and improving supporting facilities such as noise protection and rainwater recycling. In response to the characteristics of traffic planning adjustments, road and bridge design needs to break away from the limitations of traditional long-distance and large-span layout concepts and promote a multi-node and small-span collaborative layout. For example, in a certain area, the main road is 40 meters wide. Under the planning of narrow roads and dense road networks, 3-4 secondary roads with a width of approximately 20-25 meters are added, along with multiple branch roads, achieving collaborative optimization of road and bridge design.

3. Optimization Strategies for Municipal Road and Bridge Design under Urban Traffic Development

3.1 Optimize Traffic Volume Design

To effectively respond to the impact of urban traffic development, municipal road and bridge design should be adjusted synchronously to improve the dynamic traffic volume adaptation capacity of roads and bridges. By accurately predicting traffic volume and dynamically allocating traffic resources, municipal roads and bridges can effectively meet the challenges brought about by traffic volume growth. The specific manifestations are as follows:

3.1.1 Establish a Long-term Dynamic Traffic Volume Prediction System

With the continuous growth of urban traffic volume, the drawbacks of previous static short-term traffic volume prediction methods have become increasingly apparent. In the new era, a long-term dynamic update prediction system driven by multi-dimensional data should be established. Integrate urban population census data, motor vehicle ownership data, and industrial layout planning information from multiple channels, and connect with ETC toll data and traffic monitoring data collected by intersection cameras. Build an LSTM neural network model to accurately predict traffic volume by region and time period for the next 15-20 years. Taking the cross-city commuting corridors in urban agglomerations as an example, predict the future proportions of heavy trucks and small passenger cars based on big data analysis models, and these data can provide quantitative support for the load design of municipal roads and bridges. At the same time, the traffic volume prediction model should be dynamically updated, and the prediction model should be revised every 3-5 years to match changes in urban traffic volume and avoid prediction instability affecting design accuracy [4].

3.1.2 Promote Dynamic Flexible Lane Design

In view of the tidal characteristics of traffic volume in many cities, it is necessary to promote dynamic flexible lane design to achieve effective allocation and utilization of traffic resources. Specifically, reserve tidal adjustable lanes in the design of urban main roads and cross-regional bridges, such as the movable design of central isolation barriers, to dynamically adjust the number of lanes between 3 and 4 according to the direction of traffic volume during morning and evening peak hours, and automatically and intelligently switch lanes based on traffic volume. For some urban bidirectional 6-lane roads, add variable-function lanes, which can be used as ordinary lanes for private car travel during peak hours and as bus lanes during non-peak hours, leaving emergency flexibility space for changes in urban traffic volume and enhancing the emergency response capacity of roads and bridges.

3.1.3 Implement Efficient Node Diversion Plans

For areas prone to congestion, innovative design methods should be adopted to improve traffic efficiency. At road intersections in urban core areas, a combined design of underpasses and ground roundabouts should be implemented, introducing straight-traveling vehicles into the underpass and diverting left-turning and right-turning vehicles on the ground roundabout; an adaptive traffic signal system should be set up to dynamically adjust the duration of traffic lights based on real-time traffic volume changes. For example, the roads around Beijing Financial Street have adopted this design plan, effectively alleviating node congestion problems. Moreover, at the connection points at both ends of cross-railway bridges, set up vehicle flow distribution buffer zones, and set up transition lanes with a length of 50-100 meters in the road and bridge entrance areas to guide vehicles to enter the main lanes in an orderly manner; set up distribution plazas at the exit areas to connect surrounding secondary roads and branch roads, effectively avoiding traffic congestion caused by a large number of vehicles entering the main lanes.

3.2 Reasonably Plan Road and Bridge Layout

Strengthening the planning of road and bridge layout focuses on the multi-faceted collaborative integration of roads, bridges, and urban transportation systems to improve the overall layout rationality of roads and bridges under multi-modal connections. Based on diversified travel demands, create humanized functional spaces for the travel demands of motor vehicles, non-motor vehicles, and pedestrians. In the layout of road space, the road network density in newly built urban areas should be more than 8 kilometers per square kilometer, and motor vehicle lanes, non-motor vehicle lanes, and sidewalks should be reasonably divided in each road. Physical isolation such as green belts or guardrails should be set up to separate different traffic flows and avoid mutual interference among lanes. To meet the travel demands of citizens for shared bicycles, dedicated parking areas with a width of 1.5-2.0 meters can be planned on both sides of roads and bridges or at bus stops, equipped with intelligent parking guidance systems to meet people's travel demands and effectively avoid random parking [5].

In response to the development demands of urban rail transit in some cities, attention should be paid to the seamless connection planning with bus, private car, and shared bicycle travel modes to build a complete and reasonable comprehensive transportation system and improve travel efficiency. Plan connection areas for different travel modes within a 500-meter radius of rail transit stations. Establish covered walkways at subway exits to connect with shared bicycle parking areas or bus stops, and set up bus priority lanes around the roads; for intercity railway stations, plan fast connecting roads to connect with urban expressways and highways to provide convenient travel services.

In the planning of road and bridge layout, incorporate landscape creation and environmental protection concepts, and strive to build environmentally friendly transportation projects. For ecologically sensitive areas such as nature reserves and mountainous areas, adhere to the principle of minimum intervention and adopt a small-span and multi-span bridge layout to avoid bridges blocking river ecosystems. In the overall layout design of mountain roads, adhere to the design concept of following the terrain to avoid large-scale excavation of mountains and damage to the local ecological environment. In addition, reasonable planning and design can transform roads and bridges into scenic spots with urban characteristics. For example, the Lupu Bridge over the Huangpu River in Shanghai adopts an arch structure and lighting design, paired with transparent guardrails, becoming a characteristic landscape landmark of the city.

3.3 Introduce Intelligent Design

Introducing intelligent concepts into municipal road and bridge design breaks away from the constraints of traditional engineering thinking and builds an integrated intelligent road and bridge system with the support of intelligent technologies to improve traffic operation efficiency. Establish a full-life-cycle intelligent monitoring system for roads and bridges to achieve full-life-cycle management and control of roads and bridges under real-time monitoring by intelligent technologies. In the design stage of roads and bridges, reserve installation spaces for intelligent monitoring equipment in advance, embed displacement, strain, and temperature and humidity sensors in bridge piers, main girders, and other areas to monitor the stress and deformation of bridge structures; embed temperature sensors and piezoelectric sensors below roads to monitor vehicle loads and road surface water accumulation; and install high-definition cameras along roads and bridges to monitor traffic volume, violations, and structural diseases. Most disease problems can be detected and disposed of in a timely manner, reducing the likelihood of safety accidents.

To effectively respond to the challenges posed by the development of intelligent connected vehicles and autonomous driving, when introducing intelligent concepts and devices into road and bridge design, it is necessary to connect with existing intelligent transportation systems and establish an integrated communication network to achieve real-time transmission and sharing of communication data. In road surface design, set up reflective markings or flexible road surfaces with built-in RFID chips in appropriate areas to provide accurate road condition information support for autonomous driving. Install roadside units at key nodes such as bridge entrances to achieve real-time data interaction between roads, bridges, and vehicles, enabling vehicles to learn about traffic congestion or speed limits in advance and adjust their driving strategies in a timely manner. In addition, introduce BIM technology to assist road and bridge design, collect data parameters such as construction records, material parameters, and design drawings, establish digital models, visually present road and bridge structures, and accurately locate diseases if any to formulate reasonable maintenance plans based on this.

3.4 Strengthen Green and Environmentally Friendly Design

Incorporate green and environmentally friendly concepts into road and bridge design, introduce environmentally friendly and renewable materials, and minimize pollution and damage to the ecological environment. Promote the use of materials such as recycled asphalt concrete and permeable asphalt in road surface paving design. Rainwater can quickly penetrate into the ground, improving urban waterlogging problems while replenishing groundwater sources. Recycled asphalt concrete, as a new type of material, recycles waste asphalt pavement raw materials and adds other additives to become a reusable asphalt material, reducing the discharge of construction waste. At the same time, promote the application of lightweight and high-strength green steel bar materials, and introduce slag concrete or fly ash concrete. These materials are not only energy-saving and environmentally friendly but also reduce the emission of harmful substances and unnecessary resource consumption.

Adhere to the principles of resource recycling and energy conservation and consumption reduction to optimize road and bridge design and effectively improve the utilization rate of various resources. Install solar power generation systems at positions such as bridge guardrails or toll station canopies to store the collected solar energy and provide energy for the operation of monitoring equipment and road and bridge lighting; introduce natural light systems in tunnel design, using reflective devices to introduce natural light into the tunnel interior, effectively reducing lighting resource consumption.

4. Conclusion

In conclusion, the rapid development of urban traffic has brought various impacts on municipal road and bridge design. To meet the needs of urban development, municipal road and bridge design should conform to trends such as the complexification of traffic structures and the increase in traffic volume, continuously optimize design concepts and methods, and introduce intelligent and environmentally friendly technological means to design municipal roads and bridges that better meet the needs of modern urban development and promote sustainable urban development.

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