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

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Abstract: With the gradual deepening of urbanization process, long-term growth in urban transport volume for any place, travel changes form and traffic planning adjustments have brought forth a great many new challenges for urban traffic infrastructure design and construction. According to the challenge brought forward by urban traffic development, municipal road and bridge design need to make an active response in order to choose proper design strategies which prevent functional defects and resources waste caused by utility-oriented disconnected designs. This paper analyzes the influence of urban traffic construction on municipal road and bridge design, summarizes a series of practical countermeasures for implementation in order to promote stable development of China′s city transportation cause.

1. Introduction

Currently, population and industries are more and more aggregating in cities, which is resulting in a rapid increase of urban traffic demand. Statistics from the Ministry of Transport show that in 2024, China's urban passenger volume was 64.5 billion person-times, an increase of 5.2% year on year. New travel modes, such as shared bicycles and online ride-hailing services, have been gradually promoting the transformation of the whole society from motor vehicle-oriented development to people-oriented and diversified travel model. The overall efficiency of traffic operation in cities varies as many regions are more intelligentized and orderful planning according to real situation work for multi-mode efficiency convenient traffic transfer system. Nonetheless, the designs of municipal road and bridge in many areas exposed problems such as features single or outdated concepts, which seriously affects the full play of their functions. Hence, how to cope with the challenges posed by urban traffic development and optimize municipal road and bridge engineering has become a research hot spot in the field of transport.

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

Traffic development in an urban area, is a gradual and evolutionary process where modes as well as volumes are alterted over time. In the new era, we need to concentrate on three significant changes: the diversified travel modes, traffic volume steadily increase and adjust planning of traffic. Then view influence from various fields with this background and propose reference value for follow-up municipal road bridge design optimization. Table 1 exhibits the impact in detail.

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 human-centered design

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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, as autonomous driving technology is applied extensively, there will be a new level of intelligence in travel modes and therefore new functional demands on road and bridge design [3].

2.3 Impact of Traffic Planning Adjustments

At present, the state urban traffic planning focuses on improving the construction of a comprehensive transportation system and mainly consists of three transformations in space; First, from optimizing layout, it breaks through the original model- wide roads but sparsely arranged road network which greatly limit scene provide erti apacity. Second, to coordinate the organization and further adjustment of travel mode, so as to focus on building a seamless connection transforming stage in which rail traffic will be closely linked with ground transportation to realize full coverage of various ways of travel modes and smooth transfer for citizens. Third,implement ecological planning adjustment,integrated concept of green and low carbon is introduced into the original traffic plan,reducing impairment to the ecological environment by construction road and bridge. Based on the adaptation and change of characteristics of traffic planning, the design of road and bridge should abandon envelope combination between long-distance and large-span, advocate multi-node 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. Configure the connecting areas of travel modes, where the distance between rail transit stations and their surrounding traffic facilities cannot exceed 500m. Set up covered cycle lanes at subway exit connections with shared bike parking spots or bus stations, and set up public transport priority lanes around the roads; for the intercity railway station, fast transfer channels should be designed to connect to urban expressway, interstate highway to serve convenient trip.

Integrate the ideas of landscape creation and environmental protection into road and bridge layout planning, and promote environment-friendly transportation engineering construction. For ecologically sensitive areas, such as nature reserves and mountainous areas, stick to the minimum intervention principle and implement a small-span and multi-span bridge form instead of bridges blocking river ecology. The overall layout design of mountain roads should adhere to the principle of following the terrain, and large-area excavation of mountains or destruction of local ecological environment must be avoided. Moreover, through the use of reasonable planning and design, roads and bridges can be built as urban landscape spots. Such as the Lupu Bridge over Huangpu River in Shanghai with an arch structure and lighting design, and transparent guardrails, which has become a characteristic landscape landmark of the city.

3.3 Introduce Intelligent Design

The use of intelligent concepts on municipal road and bridge design breaks away from traditional engineering thinking and lays the foundation for building an integrated intelligent road and bridge system that uses supporting intelligent technologies to improve traffic operation efficiency. China and the United States have invested a lot of human resources and funds in the raw materials industry, such as roads and bridges; Establish full-life cycle intelligent monitoring and control system for road bridges under real-time monitoring of intelligent technologies to achieve full-life cycle management and controlling. Engineering and construction: In the design stage, set aside reserve installation spaces for intelligent monitoring equipment, embed displacement sensor, strain sensor to monitor the steel bar inside girders, temperature and humidity sensor to monitor bridge piers; Place temperature sensors and piezoelectric sensors below roads so as to monitor vehicle loads and road surface water accumulation; Install high-definition cameras along roads and bridges so as to provide effective data supplement for traffic volume counting, violations analysis process control, and monitoring of structural diseases. Most of the disease problems can be diagnosed and removed in good time, and the safety accident probability will be reduced.

In order to deal with the challenges brought by intelligent connected vehicles and autonomous driving, when adopting intelligent ideas and carrying devices in road and bridge design, they need to connect with existing intelligent transportation systems and form an overall communication network, aiming at the real-time transmission and sharing of communication data. Set up reflective roads or flexible road surfaces with productive RFID chips in dedicated areas to offer real-time accurate road condition information support for autonomous driving in the field of road surface design. To reach real-time interaction of data between roads and bridges or bridge to vehicle, set the roadside units at key nodes such as road entrances (e.g. ingress and egress bridges) so that vehicles can learn about vehicle's traffic congestion or speed limit through unplanned time in advance, timely adjust their strategies of suspension driving according to data feedback. Moreover, use BIM technology to help in road and bridge design, collect data parameters such as construction record, material parameters and design drawings of the project, build digital models that are able to

intuitively show road and bridge structures visually, identify diseases at a specific position if there is any disease present so as to develop reasonable maintenance plans based on it.

3.4 Strengthen Green and Environmentally Friendly Design

To introduce new green and environmentally friendly concepts in the design of roads and bridges, to develop some environmentally friendly, renewable materials will inevitably cause certain pollution on the ecological environment, renewal with recyclable materials that damage limited. Encourage the use of recycled asphalt concrete, permeable asphalt and other materials in surface-greening design of expressway pavements. Rainwater can easily infiltrate into the ground, not only alleviating urban waterlogging trouble but also supplementing groundwater resources. 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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