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Transportation Engineering Under the Environment of Cooperative Vehicle Infrastructure System

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Abstract: Transportation engineering focuses on the interaction between people, vehicles, and infrastructures to improve efficiency, safety, and environmental friendliness. Technologies associated with the cooperative vehicle infrastructure system (CVIS), are based on intelligent vehicles, vehicle-to-vehicle communication, and vehicle-to-infrastructure communication. This will eventually transform the transportation system configuration from human–vehicle–road coordination to vehicle–infrastructure cooperation, thereby significantly improving traffic efficiency and safety. In the CVIS environment, conventional human factors have a minimal impact and the intersection of people, vehicles, and roads is enhanced. Traffic systems can be controlled and evaluated effectively, and randomness can be reduced to a large extent. Perception, decision-making, and control are managed by robots instead of people, which could lead to numerous changes and challenges in fundamentals of traditional transportation engineering. In this paper, we will mainly discuss the influence of CVIS on transportation engineering, and the associated scientific issues.
Keywords: transportation engineering; cooperative vehicle infrastructure system; development trend

1 Introduction

Traditional intelligent transportation systems help achieve the integration of transportation elements through perception, transmission, knowledge, and implementation. This guarantees the orderly operation of road traffic. With the progress of information technology, vehicles have followed an emerging trend from driving assistance to cooperative intelligence. As an important technical means to solving traffic safety issues and improving traffic efficiency, CVIS has received increasing attention by domestic and foreign scholars as well as the transportation industry management departments [1]. The development of CVIS will further change the organizational form, operation pattern, and running mode of transportation systems, triggering a series of transformative developments in transportation system technologies. The development of a new theoretical system and establishment of a new technical framework in this new environment are essential in the field of traffic engineering.

2 The transportation system is a complex system associated with people, vehicles, and roads

The transportation system includes numerous elements, e.g., carrier, infrastructure, operation services, and so on, and covers planning, design, construction, maintenance, and operation. It aims at achieving the goals of high efficiency, safety, environmental friendliness, and so on. The content of transportation engineering has become increasingly extensive and divergent, but all transportation technologies must adhere to systematic engineering concepts. The transportation system is a complex system, which is composed of traffic elements such as humans, vehicles, and roads. All behaviors in this system are the result of the interactions between these elements, and any goal is closely related to these interactions. Therefore, we should not ignore the interactions, but rather we should discuss transportation engineering from the perspective of the system.

The interaction between humans, vehicles, and roads is first

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manifested in driving behavior. Driving behavior is embodied in the driving process, which can be divided into three stages, i.e., path planning, trajectory planning, and trajectory control. Path planning involves the driver's route choice, macroscopic road network planning, and matching vehicles to routes. Drivers are accustomed to choosing familiar routes according to the traffic status of the road network, which is constrained by the coupling between humans and the road network. Different vehicles need to choose different roads: the route selections of drivers of large vehicle drivers are affected by height limits, and this is an example of limits imposed by the coupling between vehicles and roads. Therefore, the interaction between traffic elements such as humans, vehicles, and roads significantly affects the process of path planning. Trajectory planning and control are more microscopic than path planning, involving specific movements of the vehicle during operation, such as changing lanes, and following and overtaking cars. The coupling of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) coordination places certain constraints on trajectory planning, and the coupling of human-to-vehicle and V2I coordination also affects the driver's handling of vehicles.

The interaction between humans, vehicles, and roads is also reflected in the characteristics of traffic flow. For example, the capacity of a single lane largely depends on the driver's choice of time headway, which is the result of human–vehicle–road interaction. Lane changing behavior affects the stability of traffic, which is the result of the V2V interactions. These affect the characteristics of traffic flow, and thus affect road capacity and service level.

The coupling between humans, vehicles, and roads is also the basis of traffic design and organization. For example, when designing sight distance, it is essential to consider the behavioral characteristics of drivers with the parameters of vehicles and roads to achieve mutual coordination. The geometric design of ramps, bends, and bridges must also take into account the V2I interaction. The signal control and traffic flow of road traffic are inseparable from the interaction between humans, vehicles, and roads. Only by taking human–vehicle–road interaction as the basic element of the transportation system can we have more flexibility in traffic design and organization.

3 From V2I coordination to V2I cooperation

The current transportation system is mainly designed from the perspective of human–vehicle–road coordination, and the development route of the transportation system may lean toward human–vehicle–infrastructure cooperation in the future.

3.1 China's traffic development has entered a new stage

At present, the development of China's road system has entered a new stage. China's expressway area density has reached 1.4 km/100 km^2, higher than that of the United States of 1.1 km/100 km^2, but lower than that of Japan of 2.2 km/100 km^2. Furthermore, the highway mileage per 10 000 vehicles has surpassed that of the United States and Japan. Around 2020, the large-scale expansion of road infrastructure will be finished for the most part. The main tasks will be to improve facilities and services. Thus, improving the utilization of existing resources to enhance the service level must be considered. Using new technologies to improve the service capacity of existing infrastructure is an important solution.

3.2 New technologies release traffic system capabilities

After 2030, the transportation system will combine more modern technologies to enhance the experience of transportation and provide diversified travel services. It is predicted that the application of intelligent transportation technologies could increase the capacity of the transportation system by a factor of 1.5. At present, the development of traffic technologies shows the following trends: rapid development of intelligent transportation tools, deep integration between traffic and information technologies, and cooperative operation of the traffic system. In recent years, the study of a vehicle–road collaboration system has attracted wide attention [3].

3.2.1 Intellectualization of the transport facility

The development speed of intelligent vehicles has exceeded expectations. Unmanned vehicles have been at the forefront of the transportation industry in recent years, and have become a favorite of universities, enterprises, and the media. Unmanned vehicles, as the next major mobile internet terminal after the smart phone, will be an important trend in future developments of the automotive industry [4]. The National Highway Traffic Safety Administration (NHTSA) divides automobile intelligence into five levels. Of these, Level 0 is for manual driving; Level 1 is for intelligence with special functions; Level 2 is for intelligence with multiple functions; Level 3 is for unmanned driving under limited conditions; Level 4 is for fully unmanned driving without limiting conditions. At present, many middle-to-advanced vehicles already have a Level 1 to Level 2 vehicle intelligence. Level 3 unmanned driving is a technological bottleneck that is being broken through, and is being tested and verified around the world. However, the realization of automatic driving with the vehicle as the main driver-agent requires strong artificial intelligence technology and high cost, thus its timeline is difficult to predict. At present, there are still significant limitations on the safety and reliability of the technology, thus it would be difficult to apply in the near future and on a large scale. To achieve overall optimization of the system, the integration and cooperation of various traffic elements must be realized with complete vehicle-road interaction. The development of vehicles and roads is actually a process of mutual promotion. After the emergence of unmanned vehicles, traffic facilities will also need to make corresponding changes to adapt to this development. The intellectualization of vehicles has generated new demand for the intellectualization of transportation infrastructure.

3.2.2 Deep integration between information technology and transportation

Information technologies such as mobile internet technology, artificial intelligence, and big data have revolutionized transportation engineering. The deep integration between them has created many new business models in the transportation industry [5]. For example, the application of mobile internet technology in the rental industry has produced car sharing services; the integration of big data and the transportation industry has a far-reaching impact on the collection, analysis, and prediction of traffic information. With the deep integration of information technology and transportation, new business models and operating modes are constantly emerging. CVIS has also been greatly anticipated by domestic and foreign experts.

3.2.3 A cooperative operational trend in transportation systems

To adapt to the existing traffic system, traditional autonomous vehicles tried to become much more intelligent in the early stages of development, and continue to do so even at the present stage, such as by using machine vision to identify road markings. However, this increases the calculation load to a certain degree while reducing reliability. With the development of mobile communication, the interconnections of V2V and V2I have increasingly attracted attention. If the transportation system can make some minor changes, the actual effect may be to achieve twice the result with half the effort. For example, marking and signing information can be sent directly to the vehicle after being digitized, which will be a revolutionary change in the design of automatic driving. Therefore, future transportation systems will not only include the intellectualization of vehicles, but also cover the interconnection and interoperability of humans, vehicles, roads, and other objects [6].

In summary, the traditional traffic system can achieve high efficiency, safety, and environmental friendliness through the design of horizontal and vertical curves, sight distance, and roadside environment. However, in future transportation systems, highly intelligent vehicles will become the main traffic elements. In addition, the information exchange between V2V and V2I will be enhanced. Vehicles may adjust their behaviors according to road information, and roads may also adjust their status according to vehicle behaviors. Therefore, in the future, a dynamic CVIS will be built to make the entire transportation system more efficient, safer, and more environmentally friendly.

4 Transportation engineering changes brought by CVIS

In an ideal CVIS environment, vehicles have a high degree of automated driving ability. The human factors of the traditional transportation system become weakened, and may even be removed, thus related transportation modes will change. For example, the perception mode changes from driver perception to vehicle perception; the decision-making mode changes from driver decision to machine decision, and the control mode changes from traffic guidance system to vehicle active control. Traditional transportation systems are time-varying, strongly nonlinear, discontinuous, uncontrollable, and unmeasurable. There is no theoretical solution for controlling vehicles on the road under such conditions. However, CVIS may transform these problems to controllable and solvable problems through model deconstruction, which marks a return to physics [7].

In the *Handbook of Transportation Engineering*, transportation engineering is defined as a technical science for studying the interaction between humans, vehicles, roads, and environment, exploring the rules of road traffic, establishing the theory and methods of traffic planning, design, control, and management, as well as related facilities, equipment, laws, and regulations, in order to make road traffic safer, faster, and more efficient and comfortable. Transportation engineering textbooks cover traffic surveys, traffic flow theory, traffic capacity, service levels, traffic planning, and so on. Thus, the changes that could be induced in transportation engineering by CVIS should be investigated.

Traffic investigation will change first. Methods of collecting traffic parameters will change from traditional manual observation and geomagnetism to multi-sensor systems and full time-space automated collection, which will basically solve the traffic measurability problem. Analytical methods will change from statistics for questionnaire survey data to multi-sensor data fusion, and the data granularity will also change from cross-sectional and local to precise full time-space trajectory data.

For traffic flow theory, the traditional theory is mainly based on dynamic analysis where the individual is relatively independent and passive. However, under a CVIS environment, information interaction and cooperation are favored, and the individual will be driven through complete data.

By fully tapping the resources of the existing transportation system based on CVIS, service level and capacity could be improved, while the transportation system could become more flexible. At present, mature electronic toll collection (ETC) technology could greatly improve service level at the entrances and exits of freeways. The development of CVIS could not only greatly improve the toll collection system, but also realize applications, such as electronic road tickets and mileage charges, which cannot be achieved by current ETC technology. Traditional tidal lanes are generally controlled by fixed signs and lines. However, the number and direction of tidal lanes could be adjusted by real-time traffic conditions under a CVIS environment.

For traffic planning, it is well known that there are many problems that are difficult to solve in the traditional traffic origin-destination survey (OD survey). Big data technology under a CVIS environment will bring revolutionary change to the modeling and simulation of urban traffic planning.

Changes in traffic management and control involve multiple sources and dynamic data, real-time situation analysis, and refined traffic control. This mainly covers the changes in traffic information collection from section information to trajectory holography; changes in traffic management methods from field and manual operation to remote information management; and changes in traffic control methods from group traffic flow control to individual vehicle control.

Traditional traffic safety issues are more concerned with drivers, and focus on improving the safety of drivers for vehicle control. These will more likely focus on system reliability in the future. The cooperation of vehicle–vehicle and vehicle–infrastructure will break through the traditional sight distance restrictions to enable oversight warning control. In addition, the control mode of the driving process will change from driver control to human–machine co-control, which may cause safety problems during human–computer interaction.

Transportation facilities will tend towards digitalization, intellectualization, and sharing in the future. The current traffic facilities are mainly designed to adapt to the driver. Whether the future traffic facilities can adapt to human–machine co-driving, cooperation of vehicles and infrastructure, automatic driving, and the control of intelligent vehicles are the problems that should be solved readily.

5 Scientific problems to be solved

Under a CVIS environment of CVIS, many basic theoretical methods in transportation science are confronted with the process of reconstruction [8].

(1) Operation rules for transportation system elements under a CVIS environment. The operating rules of the transportation system elements under a CVIS environment are obviously different from the traditional ones wherein vehicles are driven by humans, including the V2V/V2I coupling mechanisms under the CVIS environment and the cooperative operation mechanism between group vehicles and road facilities.

(2) The balance mechanism of individual service and group control. Under ideal fully-automatic driving conditions, it is theoretically possible to precisely control each vehicle and serve everyone. It is also crucial to balance this precision service with group optimization when faced with a conflict between individual optimization and system optimization.

(3) Theory and methods for building new intelligent infrastructure for CVIS. On the one hand, with the maturity of intelligent vehicles and automatic driving, roads need to adapt to the changes in vehicles. On the other hand, optimizing the digital road system that vehicles sense could make environmental perception much more reliable and accurate.

(4) Traffic design for mixed vehicles with different intelligence levels. The goal of unmanned driving will not be achieved overnight, and the development process is bound to undergo a period where mixed vehicles with different levels of intelligence co-exist. The traffic system will be in a state of human–machine co-driving for a long time. Therefore, finding a way to carry out traffic design to optimize the system under such conditions is also a problem that needs to be solved.

(5) The coupling between the intelligent connected transportation system and the external environment. Transportation itself is not an isolated system, and the development of CVIS will continuously strengthen the coupling between the future transportation system and the external environment, such as, for example, the coupling of intelligent connected transportation and energy networks, information networks, payment networks, and traffic networks, involving electronic charging, environmental pollution, urban congestion, and so on.

6 Conclusions

To summarize, the transportation system is a system that connects people, vehicles, and roads as a whole. The planning and design of transportation engineering must consider the coupling and interaction between these elements of the system. At present, the road traffic in China is shifting from expansion to stock optimization. CVIS will be an inevitable trend in future traffic development. Therefore, the development of the transportation engineering discipline should also adapt to this new trend in traffic development, studying and solving the basic scientific problems of this trend from a forward-thinking perspective.

The transportation engineering reconstruction of CVIS needs comprehensive and deep integration in the fields of automobiles, transportation, and communication. As a cross-industry and cross-domain project, it should be regarded as a systematic “national project” that combines multiple elements such as national laws, Chinese standards, national scientific and technological innovation, intelligent manufacturing, and social services under the market economy mode. In accordance with the trinity organization of “firm national will, active scientific and technological force, serious market economy,” we should make an effort to consolidate control and perception hardware, core software, reliable communication, core platform and other technical evolution, and industrialization projects, and strive to promote project development and industrial integration. It could first be demonstrated and applied in the country’s major landmark projects and major cities. Then, a new national economic growth level of a trillion yuan could be attained by completing the transformation from existing transportation engineering patterns, and by promoting industrial reform in the next decade.

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