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Some aspects on the planning of complex underground roads for motor vehicles in Chinese cities

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ABSTRACT

With the rapid growth of the urban economy and underground space utilization, complex underground roads for motor vehicles are becoming increasingly popular in China. Over the past decade, many Chinese metropolises have adopted this kind of underground transportation system to address the severe traffic problems, protect the environment and save land resources in downtown areas. An integrated planning strategy was also adopted to improve underground space utilization efficiency during the planning. This paper analyzes the planning motivations, characteristics and current challenges of complex underground roads for motor vehicles with typical examples in Chinese cities. Based on the existing cases and planning experience, a 5-step procedure of overall layout planning and an integrated planning strategy are provided and then applied to the planning of the underground road network in Qingdao's core area of Shinan District.

1. Introduction

Urban underground space utilization, which mainly emphasizes constructing infrastructures (e.g., transportation and municipal systems) and specific urban service facilities (e.g., retail, exhibition and catering facilities) beneath crowded urban areas, is a pivotal method for building a more livable and sustainable city and meeting the increasingly higher standards of city life (Durmisevic, 1999; Parriaux et al., 2004; Hunt et al., 2016).

As more than 58.52%[1] of Chinese people lived in urban areas as of 2017, many Chinese cities are confronted with severe traffic problems. The car-choked cities, with terrible noise and emissions pollution, are becoming unsustainable (Yu and Guo, 2006; Broere, 2016). Apart from building elevated roads to extend the road traffic supply, which also separates the original urban fabric and takes up vast land resources (Samuel, 2017; Yu, 2014), it is more suitable to use urban underground space to balance daily convenience, environmental conservation and urban development (Nishi et al., 2000). One measure is, for example, constructing complex underground roads for motor vehicles.

Complex underground roads for motor vehicles are referred to as urban road tunnels with one of the three following features (PIARC, 2016),

(1) Multiple entries and exits that connect surface road networks.
(2) A series of urban road tunnels located close to each other with interactions between them.
(3) Urban road tunnels integrated with each other and providing access to different underground parking lots in a specific zone.

These complex underground roads are buried beneath downtown areas and only accessible to automobiles, especially private cars. They bear a closer resemblance to elevated roads that can shift an enormous amount of traffic from the surface streets rather than conventional road tunnels or urban underpasses. Based on the design speed and service objections (Chinese Code for Design of Urban Underground Road Engineering, 2015), complex underground roads can be classified into two types: (1) underground expressways or arterial roads with a design speed ranging from 40 km/h to 100 km/h, which connect different key areas and mainly serve through traffic, such as the LASER Project in Paris (Lemperiere et al., 1989), and (2) underground parking links with a speed limit less than 30 km/h, which can reduce the surface load of inbound and outbound traffic in central business districts (CBD) or subcenters, such as underground road systems in the Chicago Loop (Robert et al., 1995).

In recent years, complex underground roads for motor vehicles have gained significant popularity among Chinese metropolitan cities (Liu et al., 2014; Qian, 2016). Some of them have already been built and had good effects. Furthermore, an integrated planning strategy, which aims

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at realizing a harmonious vertical arrangement for different underground facilities based on their specific burial depths and functions, is often adopted (Zhang et al., 2011).

In this paper, the development process of complex underground roads for motor vehicles and some related challenges in China are analyzed in Section 2. Subsequently, a 5-step layout planning procedure and an integrated planning strategy are thoroughly presented in Section 3 and then applied to Shinan District, Qingdao, in Section 4. Conclusions are finally drawn in Section 5.

2. Developing processes and current situation of complex underground roads for motor vehicles in Chinese cities

2.1. Development in some developed countries

The origination of complex underground roads is related to the change in urban spatial patterns and the requirement for urban renewals in developed countries (Yu, 2014). Some famous cases and their important technical data are listed in Table 1.

After the mid-1980s, because of booming employment locations in suburbs, the major commuter traffic pattern changed to the suburb-to-suburb pattern, rendering traditional freeway networks or bypasses (designed to serve the suburb-to-CBD traffic mode) unable to cope with the increasing through traffic in city centers (Pisarski, 1987; Schrank et al.,1993). Severe traffic congestions and land shortage problems worsened life quality (Van der Hoeven, 2011). Urban planners were forced to seek more space for people and vehicles. Then, they came up with the idea of building long road tunnels to serve as expressways and arterial roads under the surficial ground, such as the Southern Link Tunnel in Stockholm, the Yamate Tunnel in Tokyo and the famous Big Dig in Boston (Lemperiere et al., 1989; Endo, 1993; Karlsson, 2000; Chandra et al., 2002).

Simultaneously, to avoid similar traffic problems in newly planned subcenters or urban renewal zones, urban planners diverted inbound and outbound traffic off the ground and integrated local underground parking resources. Motor vehicles can travel though the parking link tunnels before entering the core area, creating a more livable and walkable ground space for pedestrians, such as Voie des Bâtisseurs and Voie des Sculpteurs in La Défense, Paris, and the underground parking system at Shinagawa Station, Tokyo (Shen, 2014; Yu, 2014).

According to the experiences of developed countries, some of these complex underground roads are limited to small motor vehicles with a lower tunnel clearance and even double-deck tunnels, which means a smaller tunnel section and total investment. Due to the high cost of underground structures (average cost ranging from US$100 mn to US $500 mn per kilometer by Table 1), the PPP mode (Public-Private Partnership) is often applied (Evenhuis and Vickerman, 2010; Low and Sturup, 2014), by which private capital is entirely or largely invested in the project and gains a long-term franchise of the underground road operation from the government. Accordingly, most of these complex underground roads are toll tunnels. In addition to reducing the traffic on the ground, these underground roads in developed countries also serve the following functions:

(1) They serve as a “missing link” for urban expressway networks and as a “win-win” solution to both satisfy environmental protection and improve the road network (Ishii et al., 1995; Broto, 2006).
(2) They move current traffic below ground and free a large parcel of land for redevelopment and landscape conservation, such as the Big Dig in Boston, which brought 30 acres of new open space in the downtown area (Tajima, 2003).
(3) They reduce emissions (including greenhouse gases) in exhaust by both adopting filtered extraction systems at tunnel ventilation towers and smoothing the traffic flow since the frequent stop-and-go travel mode is reduced (Robert et al., 1995).
(4) They lower the accident rate, as the underground road increases cautiousness and conservative driving behaviors and decreases the impacts of bad weather (Yeung et al., 2013; Lee et al., 2016). It is estimated that the overall accident rate fell by approximately 50% and saved insurance and tax costs of US$9.34 bn after the renovation of M30 in Madrid, Spain (New York City Government, 2012).

2.2. Development in China

As Chinese urbanization accelerated after the 1980s (United Nations, 2018), the shortage of road transport infrastructures could not meet the rapidly growing population and traffic demands. To increase the transport supply and solve or prevent potential congestion problems in the city center, the concept of complex underground roads for motor vehicles was introduced in China in the 1990s as part of the comprehensive underground space utilization for daily life (not for air defense) (Hu et al., 1990; Wang et al., 1994; Qiao and Peng, 2016).

At first, scholars and urban planners thoroughly analyzed construction necessity or feasibility in Chinese cities (Qian, 2004; Tong, 2005; Liu, 2006). Then, further research on planning theory and methodology (Zhang et al., 2007; Hu et al., 2009; Han, 2010; Liu and Peng, 2012; Zhou, 2013), monetary valuation methods of environmental benefits (Cui et al., 2008) and other technical problems, such as alignment designs, road section regulations and tunnel portal distributions (Qin et al, 2006; Yu, 2014), were studied.

After 2006, many Chinese metropolises began to implement the planning of complex underground roads in practice and made great progress, as shown in Fig. 1 (detailed information is summarized in Tables 2 and 3). Some of these cases are known for the large engineering scale and great effects to reduce traffic congestion, which have been rare worldwide, for example, Shanghai “#” Form Underground Road Network of CBD Core Area (Fig. 2), Nanjing Inner Ring Expressway (Fig. 3), urban underground expressways in Hong Kong (Fig. 4) and the underground parking link in Jiefangbei CBD, Chongqing (Fig. 5). Most of these underground roads were built or planned in Eastern China, where the per capita GDP is usually more than US$15,000, and the population in the city center is more than 4 million, per the statistics reported in Fig. 6.

The main functions and benefits of complex underground roads for motor vehicles in Chinese cities are similar to those in developed countries, and the average cost of these underground infrastructures ranges from US$50 mn to US$150 mn per kilometer in China. With regard to high construction costs, complex underground roads should be applied in the most urgent places (Cheng et al., 2012). High population density and great economic strength are two prerequisites for planning. The first index usually indicates more traffic demand, higher environment requirements and fewer land resources in the downtown area, indicating greater necessity for the mega-underground infrastructure. The latter is the basis for local governments to bear the burden of such expensive construction and operation costs. Because the PPP mode is immature in China (Luo, 2016), most of the complex underground roads are non-toll tunnels and are totally invested in by government budget revenues or local urban construction investment corporations (one kind of state-owned company authorized and entrusted by city government). The local government remains the most crucial stakeholder for these projects.

Furthermore, despite the great effects and advantages of metropolises, some scholars and urban planners continue to have a negative attitude toward complex underground roads for motor vehicles in China. Although some related cases, such as SURS (Singapore Underground Road System) in Singapore CBD (Authority, 1996), have been abandoned by the local authorities for their perfect public transportation system and great land use policies, the situation in Chinese metropolitan cities is quite different for the following reasons.

(1) China is still a developing country with rapid growth of private cars. Since 1985, developed countries and regions, such as the