Study on Underground Logistics System Planning in the Jinan Prior Zone

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Abstract. In recent years, logistics demands in Jinan have shown clear growth trends. By 2020, Jinan city has proposed that the volume of express deliveries will reach 800 million packages, with revenue reaching 7 billion CNY. As an innovative logistics system, an underground logistics system (ULS) can provide new developmental ideas for urban logistics in Jinan. Although there are no actual cases of ULS construction projects in the world at present, as a first demonstration area driven by innovation in Jinan City, the Jinan Prior Zone for Replacing Old Growth Drivers with New Ones (Jinan Prior Zone) will be the first to attempt its implementation, thus providing an advanced model for sustainable development of urban logistics around the world. Based on the urban master plan of the Jinan Prior Zone, the logistics plan of Jinan city and other urban subject plans, this study proposes ULS planning for the Jinan Prior Zone, including demand forecasting, logistics architecture, planning principles, construction forms, and short/long term construction plan. The ULS planning will provide small batch, high frequency, and high timeliness for express delivery services in the central area of the Daqiao Group in the Jinan Prior Zone. In the long term, it will serve 500,000 people, with an average daily logistics volume of 1300 tons. This study views the introduction of ULS into the Jinan Prior Zone will both improve the efficiency of logistics and reduce the pressure of ground traffic and improve the level of green logistics, which is of great significance for the promotion of high-quality development of urban logistics.

1. Introduction
With the rapid growth of new business models such as e-commerce and new retail sales, express delivery has continued to grow in demand as an important support infrastructure for new business models. By the end of 2019, China's express delivery volume was 63 billion packages, an increase of 24% year-on-year [1]. In recent years, the demand for express delivery in Jinan has shown clear growth trends, and will continue its stage of rapid development in future. According to official statistics, express delivery volume in Jinan reached 430 million packages in 2018, an increase of 43% year-on-year (Figure 1). Its growth rate is higher than the national level [2].

![Express delivery volume in China (billion packages)](image)

![Express delivery volume in Jinan (ten thousand packages)](image)

Figure 1. (a) Express delivery volume in China. (b) Express delivery volume in Jinan.
The relevant development policies issued by the Jinan municipal government have put forward higher development requirements for express delivery, with the development goal set for 800 million packages by 2020 [3]. However, the increased demand for express delivery results in various urban problems such as traffic congestion and environmental pollution. For example, with the number of vehicles in Jinan exceeding 2.3 million in 2018, traffic congestion has become a prominent problem, which considerably restricts the development of express delivery in Jinan.

Smart logistics systems can use information technology to integrate urban space resources in the air, ground and underground to support the demand growth of the logistics market and alleviate urban traffic problems caused by freight transportation. The underground logistics system (ULS), as a new mode of smart logistics, aims to become an effective tool for sustainable development of city logistics [4]. In terms of policy conditions, China has proposed the future development direction of its logistics: build a green and efficient modern logistics systems, speed up the development of new business forms and new logistics modes, promote the construction of intelligent logistics terminals, and actively develop autonomous vehicles and ULS for express delivery [5]. ULS, as an important component of urban transportation, represents an important development mode of future urban freight transportation. However, no actual implementation of ULS as yet exists in the world [6]. As a pioneer area driven by innovation, the Jinan Prior Zone for Replacing Old Growth Drivers with New Ones (hereon referred to as Jinan Prior Zone) has the opportunity to be the first ever implementer of ULS.

Based on its regional development characteristics, this study presents planning research of ULS in the Jinan Prior Zone, including demand forecasting, system structure and planning principles, and proposes a preliminary design for the construction form of ULS.

2. Feasibility Study on the Jinan Prior Zone

The key research areas of the Prior Zone are the Daqiao Group and the Cuizhai Group (see Figure 2).

![Figure 2. Key research areas](image)

The Daqiao Group plans for a population of 500,000 by 2035 and mainly develops scientific research, high-technology industries and economy headquarters [7]. Therefore, the logistical activities in the Daqiao Group mainly rely on consumable logistics, with high frequency, small batches and large demand for timeliness. In addition, underground roads and utility tunnels are being planned for the Daqiao Group, making it suitable for the planning and constructing of ULS.

The Cuizhai Group plans for a population of 250,000 by 2035. It mainly develops logistics-related industries such as bonded logistics, cross-border e-commerce logistics, and hydrogen energy industries [7]. The size of its goods primarily comes in the form of containers, adding safety risks in the transportation. Therefore, the logistics in the Cuizhai Group mainly concerns production and manufacturing, which is more suitable for ground transportation.

In view of the above, this paper has carried out ULS planning research for the Daqiao Group in the Jinan Prior Zone.

3. Research on ULS Scheme

To follow the master plan of the Jinan Prior Zone, the ULS scheme’s study period extends up to 2035. The research content includes demand forecasting, logistics architecture and scheme design.
3.1. Demand forecasting

The main types of goods in the Daqiao Group are consumable logistics, including express delivery, less-than-carload logistics, cold-chain logistics, reverse logistics (domestic waste) and instant delivery (take-out food). Among them, the suitable logistics types for ULS are express delivery and less-than-carload logistics.

Based on the forecasting results of ULS demand in the Daqiao Group (see Table 1), ULS mainly targets express delivery, chain supermarket logistics and cross-border express delivery. In 2035, the total demand in the Daqiao Group for ULS is expected at 468,700 tons, which accounts for 30% of the total logistics volume in Daqiao Group. The per capita ULS demand is 2.57 kg per day.

| Categories                  | Subcategories              | 2022  | 2028  | 2035  | 2050  |
|-----------------------------|----------------------------|-------|-------|-------|-------|
| Express delivery,           | Express delivery           | 2.0   | 6.1   | 14.5  | 24.9  |
| Less-than-carload logistics | Chain supermarket          | 5.3   | 14.5  | 32.3  | 45.6  |
| Logistics (ten thousand Tons/year) | Logistics                 | 0.01  | 0.03  | 0.07  | 0.12  |
|                             | Cross-border Express delivery | 0.01  | 0.03  | 0.07  | 0.12  |

**Total demand of express delivery, less-than-carload logistics**

7.31  20.63  46.87  70.62

According to the types and demand of ULS goods, we can study the space scale of the ULS transportation corridor. ULS will mainly deal with express delivery and less-than-carload logistics, which are characteristically multiple batches and small batches of express packages, respectively. To transport the demand of 2.57 kg per day, the scale of ULS corridors needs to ensure that small trucks can travel in two directions. Therefore, the ULS corridors should meet the requirements of two lanes, with a width of 7 m and a height of 3.5 m.

3.2. Logistics Architecture

ULS in the Daqiao Group will adopt a two-level logistics architecture (see Figure 3). In this architecture, logistics facilities can be divided into two levels: logistics center and distribution center, while logistics corridors can also be divided into two levels: trunk corridor and branch corridor. This logistics architecture describes the whole process by which ULS participates in express delivery, i.e. goods are transported from the logistics center using new energy logistics vehicles, moved through trunk corridors to the distribution center, and finally pass through the underground space to end users by deliveryman or robot.

![Figure 3. Logistics architecture of ULS](image-url)
3.3. Scheme design

3.3.1. Logistics Center. The functions of the logistics center include intelligent distribution, storage, sending and receiving, security inspection, container standardization and information processing. The selection of logistics center location follows the following principles:

(1) Convenient for both internal and external traffic. Convenient traffic conditions are required for goods transportation, so selected locations should have efficient expressway access to outside and also convenient urban road connection to inside.

(2) Suitable transportation distance. The location should not exceed 10 km from the core area of city logistics, so that the logistics service will be more efficient, and construction costs of ULS corridors can be minimized.

(3) Flexibility for land use planning. From the perspective of overall and long-term development of the Prior Zone, the functions of the logistics center and service scope will be further improved and expanded. Therefore, based on meeting logistical needs in the Daqiao Group, the location selection of the logistics center must consider the possibility of spatial expansion. For example, in the future, the logistics center will take into account part of the logistical demands of the Cuizhai Group.

Considering factors such as traffic condition, transportation distance, and land use, the Daqiao Group plans to establish a logistics center located in the southeast side of the Daqiao Group, close to the intersection of the Beijing-Shanghai Expressway and Kechuang Avenue with a scale of 24,000 square meters according to logistics demand and level of efficiency (see Figure 4).

![Figure 4. Location of ULS logistics center](image)

3.3.2. Distribution Center. The function of the distribution center is to provide the distribution and loading of goods and to disassemble standard containers of parcels. The selection of the distribution center location should follow the following principles:

(1) Service coverage. According to a 10-min walking range of community-level life circle, the distribution center is laid out according to a service radius of 500 m to reach 70% coverage and 1000 m to reach 100% coverage.

(2) Priority is given to locate the distribution center within public service facilities. As the distribution center belongs to public service facilities in the city, the ownership has public attributes, so the distribution center should be preferentially located in a public service area within the neighborhood.

According to the above principles, there are 22 distribution centers in the bridge group planning, which are divided into underground distribution centers and ground distribution centers (see Figure 5). Among them, there are 10 underground distribution centers, which are located in underground spaces, connected with ULS corridors, and located in the core area for large logistics demand. There are 12 ground distribution centers, which are located on the first floor of buildings, with relatively small logistics demand. According to service scope and total logistics demand, each distribution center has a planned area of 800–2,000 m² and serves 10,000–25,000 people.
Figure 5. Distribution centers

3.3.3. Layout of ULS Corridor. Guided by the principles of sharing, this paper adopted the following principles to plan ULS corridors:

1. The layout of ULS corridors requires intensive construction in the interest of ensuring service level. The ULS corridor should be located in an urban area with large logistics demand, so as to maximize the service level of the corridor. Moreover, the construction scale of the corridor should be reasonably controlled.

2. Coordination with ULS facilities. The ramp exit of corridors should be on the same side as the location of ULS logistics and distribution centers, to avoid unnecessary overhead crossing and save construction cost.

3. Integration and sharing with other infrastructures. By integrating the space with other facilities in the underground space, spare underground resources can be comprehensively utilized and connectivity of the ULS network enhanced.

Based on the above principles, ULS corridors with "one ring and one branch" are planned for the Daqiao Group, located at the north extension of East 2nd Ring Road, north extension of Fenghuang Road, S101 and Kechuang Avenue, with a total planning length of about 16.4 km (Figure 6).

The distribution centers (shown in Figure 5) are located inside the building site. Therefore, the branch corridors between the distribution centers and end users will be designed by the building developer in the future. Usually, branch corridors use an underground garage connection road or ground passageway.

3.3.4. Construction Forms of ULS Corridor. One difficulty in the study of ULS corridors concerns their construction form. The choice of ULS corridors not only takes into account the layout of logistics facilities and spatial distribution of logistics demand, but also the spatial distribution of other underground infrastructures. Underground infrastructures in the Daqiao Group include utility tunnels.

| Number | ULS Corridor | Road                                 | Length (km) |
|--------|--------------|--------------------------------------|-------------|
| 1      | E1           | north extension of Fenghuang Road    | 3.8         |
| 2      | E2           | Kechuang Avenue                      | 4.0         |
| 3      | E3           | Kechuang Avenue                      | 1.9         |
| 4      | N1           | S101                                 | 3.7         |
| 5      | N2           | north extension of East 2nd Ring Road | 3.0         |
and underground roads. Integration with only a single kind of underground infrastructure prevents the formation of a systematic ULS network. Therefore, this paper adopts a multi-mode construction form, and for mode selection comprehensive consideration is given to factors such as line layout, road red line width, construction sequence and facility construction standard. When determining the construction form of ULS, in the case of underground roads or utility tunnels along the ULS transportation corridor, priority should be given to their joint construction. At the same time, the restrictions of construction should be considered. For example, considering the width of red lines including the underground logistics channel width of 7 m, when the ULS and underground infrastructure are jointly constructed it is necessary to determine whether the ULS corridor is horizontally or vertically joined or other conditions for joint construction exist.

The construction forms of each section in the Daqiao Group are as follows: The construction form of Section E1 at the north extension of Fenghuang Road is joint construction of ULS and utility tunnels. The width of the red line of Section E1 is 42 m, and has sufficient construction space. The cabin of the utility tunnel is independently arranged in this section, allowing favorable conditions for joint construction with ULS. Considering that the power cabin of the utility tunnel cannot be located under the pressure cabin, the ULS and the pipeline cabin are arranged together vertically (Figure 7).

Section N1 at S101 adopts the construction form of independent construction. The west side of the underground space is planned to house a branch line of the utility tunnel. However, there is no construction space under the bicycle lane on the east side. Moreover, for the construction sequence, the utility tunnel is constructed in advance and ULS arranged during long-term construction. There are no conflicts in time sequence and spatial relationship between ULS and the utility tunnel. Therefore, the ULS corridor of Section N1 can be constructed independently under the road’s central green belt over the long term (Figure 8).

Section E2 at Kechuang Avenue (west of interchange) adopts the construction form of independent construction. The underground road and rail transit of E2 will be constructed and implemented in the near future. Considering the construction period, the feasibility of joint construction is low. At the same time, if the ULS corridor and the underground road are built together, it will overlap vertically
with the buried pipeline on the north side of the road. Therefore, the ULS corridor is planned to be build in deep underground space. In the future, a shield with a diameter of 8.5 m will be used for construction, and a 1D distance from the underground road will be reserved (see Figure 9) to ensure construction safety.

![Figure 9. The construction form of Section E2](image-url)

Section E3 of Kechuang Avenue (east of interchange) is jointly constructed with the underground road. Because there are many types of underground infrastructure in this section, the convenience of an on/off ramp for the corridor should be given priority, and so is chosen to be built together with underground road in the north side. The bottom elevation of its structure is consistent with that of the underground road (see Figure 10).

![Figure 10. Construction form of Section E3](image-url)

Section N2 in the north extension section of the East 2nd Ring Road is built in conjunction with the utility tunnel. The width of the red line of the road is 42 m, and a 60 m wide green belt exists to the east, so space for the horizontal expansion of the utility tunnel is sufficient. Therefore, the ULS corridor can be horizontally combined with the utility tunnel (Figure 11).

![Figure 11. Construction form of Section N2](image-url)

3.3.5 Future Development of ULS. In the future, with the increase of logistics demand, intelligent transportation organization can be used to optimize ULS transportation volume instead of expanding its physical scale. Moreover, ULS requires cooperation with ground logistics and even air logistics. In
the case when ULS cannot bear excessive logistics volume, it can be shared with ground and air logistics.

4. Conclusions
ULS is a new intelligent logistics mode. In the face of rapid growth of express delivery and increasingly severe traffic congestion on the ground, planning and construction of ULS can provide new ideas for efficient and sustainable development of urban logistics.
In this paper, the planning for ULS is presented for the Jinan Prior Zone. First, the feasibility of ULS planning and construction in the Daqiao Group is determined. After express delivery is confirmed as the main transportation target of ULS, it is predicted that in 2035 the total demand in the Daqiao Group for ULS will be 468,700 tons, with a per capita demand of 2.57 kg per day. According to the logistics demand, this study proposes a logistics center with a scale of 24,000 m², and 22 distribution centers with a scale of 800–2000 m². The planned ULS corridor is 16.4 km, of which three corridors are built jointly with the utility tunnel or underground road.

References
[1] State Post Bureau of The People’s Republic of China 2019 The State Post Bureau announced the operation of the postal industry in 2019
[2] Statistics bureau of Jinan 2019 Statistical Bulletin on National Economic and Social Development of Jinan City in 2019
[3] Jinan Municipal People's Government 2016 The 13th Five-Year Development Plan of Postal Industry in Jinan City (Jinan: Jinan municipal people's government)
[4] Guo D, Chen Z, Qian Q 2005 Discussion on Developing Underground Logistic System in Beijing Chinese Journal of underground space and Engineering 01 37–41
[5] Central People's Government of the People's Republic of China 2019 Outline for building a transportation power (Beijing: People's Publishing House)
[6] Qian Q 2004 Construction of underground expressway and underground logistics system, a new idea for solving the traffic problems in chinese mega cities Science & Technology Review 22(0404) 3–6
[7] Planning Bureau of Jinan 2018 Master Plan of Jinan Prior Zone For Replacing Old Growth Drivers With New Ones(2018-2035) (Jinan: Planning Bureau of Jinan)