Social benefit assessment of urban utility tunnels planned in unbuilt new area: a case study of Xiong’an New Area

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Abstract. Urban utility tunnels (UUTs) have the social benefit of providing careful management and keeping maintenance and repair work underground, avoiding causing disruption or damage to the aboveground environment which is always the case with directly buried pipelines. Previous studies have developed several methods for valuating those benefits with high demand on data and field surveys. Problems therefore arise when UUTs are planned to be built in unbuilt new areas where there is a lack of data required and practicality in doing surveys. This paper provides adapted valuation methods and instructions for calculating social benefits of UUTs under this circumstance, by taking the UUT project in Xiong’an New Area, China as an example. Though bearing inevitable uncertainties, the method is useful for making a quick and workable estimation. Some suggestion is then given on further improvement and development.

1. Introduction
Urban utility tunnels (UUTs) as quasi-public goods possess vast social benefits. With different urban pipelines integrated together in the easily accessible tunnel space of UUTs, traditional aerial cables and directly buried pipelines can be replaced. Routine maintenance and repair work can be carried out inside the tunnel without repeated excavation and rehabilitation (E&R) procedures in the road which not only cause service life reduction of pavement, dust and noise pollution, business loss in the vicinity and traffic interruption, but also bear a high risk of damaging the adjacent pipes by accident. Furthermore, the strengthened monitoring system in UUTs enables pipeline failures to be identified as soon and precisely as possible and initiates emergency measures at once, mitigating the consequences of pipeline failures drastically. However, the huge initial investment of UUTs usually makes it difficult to be approved by the local authority or private sectors. To cope with the situation, researches are then done taking externalities of UUTs into account to provide comprehensive economic comparisons between UUTs and directly buried pipelines, showing that UUTs are not so costly as people generally regard.[1]

In China, central government initiatives have promoted the utilization of large infrastructures such as UUTs to a certain degree [2], yet the initial investment remains a heavy burden. To improve the efficiency of urban construction and to support the high initial investment, varied financing modes and diversified social capital investment are needed. Naturally, external benefits of UUTs ought to be made clear ahead of time so as to provide detailed information for improving decision making as well as resource allocating. Existing researches and approaches can be applied to most of the cases while new problems arise when UUTs are planned to be built in unbuilt new areas. Most data and information required for valuating social benefits are inaccessible in new areas, and there is no
available instruction on adaption of the valuation methods. This paper intends to provide adapted valuation methods and instructions for calculating social benefits of UUTs in unbuilt new areas, by taking the UUT project in Xiong’an New Area, China as an example.

2. Project background

Xiong’an New Area of China, established in 2017 at the center of the triangular area formed by Beijing, Tianjin and Baoding, is another new area of national significance and aims at relieving Beijing of functions non-essential to its role as China’s capital. With strategic significance as such, strong support of policies and resources are provided for Xiong’an, confirming an unconventional urbanization for the area. Many of the construction standards of Xiong’an are the same as that of Beijing. The new area consists of three undeveloped counties and the region around, covering an area of about 2000 km² in total, of which 198 km² where locates the main functions of the new area is planned as the starting area and is under construction initially. It is expected that the central downtown of the starting area will be completed around 2035, together with advanced infrastructures.

As suggested by the regulatory detailed plan for starting area of Xiong’an New Area (2020-2035), an eco-friendly and livable urban area is going to be built and accommodate a population density of 10,000 per square kilometer of construction land, and urban infrastructures such as UUT of high quality and intellectualization are planned to lay a solid foundation for promoting green and low-carbon lifestyle and mode of production. According to the special planning for urban utility tunnels of Xiong’an New Area, as of 2035, there will be 90 km of UUT mainline and 100 km of branches lying beneath sidewalks and greenbelts of arterial and sub-arterial roads all over the city, with a service life of 100 years. Most of the municipal pipelines are going to be accommodated into UUTs, except for the storm water sewer due to its excessive cross-sectional area.

3. Social benefits of UUT in Xiong’an New Area

3.1. Avoiding traffic delays

By keeping maintenance and renovation work underground, UUTs get free from disrupting traffic which can results in extended travel time, more vehicle wear and tear and increased petrol consumption. Since directly buried utility pipelines that can be integrated into UUTs are arranged underneath sidewalks or roadways or both, varying from city to city and case to case, the extended travel time can happen to either vehicle passengers or pedestrians or both, so the annual benefit of avoiding traffic delays for UUTs is expressed in three kinds of combination of two broad categories: \( B_{pd} \) for avoiding pedestrian delays and \( B_{vd} \) for avoiding vehicle delays.

\[
B_{td} = \begin{cases} 
B_{vd} \\
B_{pd} \\
B_{vd} + B_{pd}
\end{cases}
\]  

(1)

Most of the pipelines that can be integrated into UUTs are required to be laid underneath sidewalks or green belts in China to minimize potential obstruction to traffic. Therefore, here we mainly focus on the calculation of \( B_{pd} \), while \( B_{vd} \) can be calculated on the analogy of that. Value of avoiding traffic delay is commonly represented by the total value of travel time savings (VTTS) for pedestrians as shown in the equation below:

\[
B_{pd} = t_{p} \cdot N_{pd} \cdot P_{pd} \cdot D
\]

(2)

where \( t_{p} \) is the extra time added for a pedestrian to pass through the area (often of minute level and needs to be translated into hours); \( N_{pd} \) is the average number of pedestrians affected per day; \( P_{pd} \) is the local VTTS for walking; \( D \) is the number of pipelines E&R days per year which can be eliminated by adopting a UUT.

First of all, a conservative assumption that only in rush hours (which consists of two hours in morning and two in evening) is there extra passing time needed is made. Then the average rush-hour
volume of pedestrian traffic in Beijing is used directly here. Though Xiong’an New Area is planned with limited density of population, primary functions it is going to undertake from Beijing are all kinds of enterprises and institutions, making it hard to predict the commuting condition, so no crude estimate is made for correction here. \( N_{pd} \) of each street section is therefore 8000 people per day.

Researches in the field of transportation have developed many effective but complicated traffic models that can be used to calculate delay time or evacuation time. As most data of cases in unbuilt new area are based on estimation, it is more reasonable to predict delay time or evacuation time simplistically. Hence, supposing a street section of 500 metres is adversely affected by an E&R construction, with a site of 50 meters long and leaving one meter wide for pedestrians to pass through. The prolonged passing time through a street section like this is usually between 10 and 12 minutes, while normally it only takes one 5 to 7 minutes, so \( t_p \) is estimated at 0.083 hour per person.

VTTS varies widely in different regions. Many countries such as the UK, the US and the EU countries have developed their official instructions on assigning VTTS based on large complicated surveys. For estimation of VTTS in developing countries where there is usually a lack of availability of data and resources, some generalized methods (shown in Table 1.) have also been provided by the World Bank.[3] VTTS here is calculated using the base approach. Average wage rate of employees in Beijing is directly adopted which is approximate 53 CNY per hour estimated with data from Beijing Municipal Human Resources and Social Security Bureau.

The 90 km mainline and 100 km branches of UUTs lies under a total of 380 street sections in approximation. Supposing buried pipes under each street section require an emergency repairing of two days each year and a maintenance of 12 days every two years based on experience, which is 8 days per year for each street section. Eventually the annual benefit of avoiding traffic delays for UUTs is obtained, which is 142.29 million CNY (price in 2020).

### Table 1. Methodologies for VTTS recommended by the World Bank.

| Approach to be adopted | For work time | For non-work time |
|------------------------|---------------|-------------------|
| Base approach          | Option 1: national average wage rate adjusted by observed adjustment factors | Adults: 0.3 × household income (per head) |
|                        | Option 2: 1.33×wage rate (adjusted by shadow wage rate) | Children: 0.15 × household income |
| Ideal approach         | Adjusted from observed wage rate using observed adjustment factors such as overheads and shadow wage rate | Revealed and Stated Preference methods for VTTS and modifiers with results adjusted to price base |

* VTTS for walking during work time is the same as that of in-vehicle travel, and VTTS for walking during non-work time is modified as 1.5 × corresponding value for in-vehicle travel.

#### 3.2. Avoiding loss of onsite business

According to existing researches and case studies, there is great local business loss incurred by constructions in the road which block access to stores and deteriorate environment around, making stores less appealing. With UUTs utilized instead, those constructions together with business loss can be circumvented. The benefit of avoiding loss of onsite business (\( B_{ob} \)) is usually taken into consideration by the equation below:

\[
B_{ob} = P_{b} \cdot D
\]

where \( P_{b} \) is the daily business loss in pipelines E&R affected area if directly buried pipelines were built rather than a UUT; \( D \) is the same as aforementioned.

For projects in built-up areas, information about the local business to be affected is basically confirmed. Hence the daily business loss in pipelines E&R affected area can be estimated based on surveying affected businesses by category since businesses are impacted to different extent in terms of
their types and locations and so are their percentages of turnover loss. While for UUT projects planned in new urban area, with trouble in doing surveys, data should be adapted from elsewhere and be simplified. The business loss of a market or mall can be taken as a conservative proxy for total business loss on a whole street section. For Xiong’an, turnover data can be derived from national average with a moderate increase based on the data of Beijing, which is estimated at 500 million CNY each mall or market every year. Existing researches have discovered that construction work can cause loss of onsite business between 10% and 60%, and case study of Ferguson in Texas shows that about 70% of onsite businesses claim to have experienced sales reduction mainly by 20% to 30%.[4] Therefore, daily business loss on a street section in Xiong’an is estimated to be approximately 17.5% (70%*25%) of 500 million CNY.

According to the layout of land usage depicted in the regulatory detailed plan for starting area of Xiong’an New Area, land for commercial and business facility is set along about one sixth of the road network, so the number of street sections suffering business loss caused by pipeline constructions is estimated at 63. Therefore, the annual benefit of avoiding loss of onsite business is 121.46 million CNY (price in 2020).

3.3. Conserving service life of pavement

Except for onsite business loss and traffic delays, repeated E&R procedures of directly buried pipelines can also do irreversible damage to the pavement, leading to replacement expenditure and premature deterioration. While the pavement replacement expenditure which, as part of maintenance construction cost, is usually included in the internal direct cost of directly buried pipelines and excluded in that of UUTs, the value of pavement service life reduction avoided by adopting the UUT ($B_{psl}$) needs to be considered as part of its social benefit.

The study of Tighe et al. in Ontario indicates that a new road subjected to an open excavation will suffer an approximate 30 percent reduction in its service life.[5] This conclusion was then used widely in valuating pavement service life loss by life cycle costing method and replacement cost method which take the original construction cost of the pavement as a substitute of the value of pavement designed service life. It is also suggested by Tighe et al. that an older road suffers less than a new road because of the existing distresses in structure due to aging. However, the quantitative relationship between road ages and percentage of pavement life loss has not been made clear. Neither has the effect of a second or third E&R on the same spot on pavement. So, for a simple and rapid estimation of $B_{psl}$, it is first calculated by assuming that each E&R procedure happens on a different spot on the pavement of a new road, and then corrected by a factor as shown in the following equation:

$$B_{psl} = \alpha P_{pm} \cdot A_{E&R} \cdot \left[ \frac{1}{L_{pm}} + \frac{1}{1+(k-1)(L_{pm}-1)} \right] \cdot T$$

where $P_{pm}$ is the original construction cost of pavement per square metres, which is used as a proxy for the value of pavement service life; $A_{E&R}$ is the average area of construction site for a pipeline E&R procedure; $L_{pm}$ is the designed service life of the pavement; $k$ is the percentage of pavement service life loss when pavement of a new road is under E&R for the first time, which is taken as 0.3; $T$ is the frequency of pipelines E&R (per year) which can be eliminated by adopting a UUT, and should be noticed that it is different from $D$; $\alpha$ is the correction factor considering that not all the E&Rs happen on different spots of roads newly built, which is taken as 0.8.

Average pavement construction cost of sidewalks is about 200 CNY per square metres according to budget quota of municipal engineering in Beijing, including cost of materials, equipment, labour and etc. As is proposed above, the average area of construction site for a pipeline E&R procedure is supposed to be 3 meters wide and 50 meters long, which is 150 square metres. Common service life of sidewalk pavements can be either 10 years or 20 years according to the relevant design code, so an average of 15 years is taken. Therefore, the value of pavement service life reduction caused by each E&R procedure is 622.2 CNY.
unit value of $BP_{sl}$ = $0.8 \times 200 \times \frac{CNY}{m^2} \times 150 m^2 \times \left( \frac{1 yr}{15 yrs} + \frac{1 yr}{1 yr + (1-0.3) \times 14 yrs} \right) = 622.2 CNY$

As assumed above, approximate 1.5 times of E&R construction are imposed on each street section. Consequently, final value of pavement service life conserved annually is 0.35 million CNY (price in 2020), which is rather small compared with the other social benefits of UUTs.

3.4. Reducing serious accidents of urban pipelines

As suggested by investigations of many government departments and organizations like Pipeline and Hazardous Materials Safety Administration of the U.S. (PHMSA), European Gas Pipeline Incident Data Group (EIGIG) and United Kingdom Onshore Pipeline Operators Association (UKOPA), most of the pipeline accidents are caused by careless excavation or other outside force damage that can be prevented when UUTs are in place of directly buried pipes. A large proportion of those accidents are gas pipeline accidents, arousing great concern and consequently getting more detailed records. Statistics provided by Underground Pipeline Committee of China Association of City Planning indicate that from 2009 to 2013 gas pipeline accidents account for 54.6% of all massive pipeline accidents in China. Therefore, the annual benefit of reducing serious pipeline accidents ($B_{sa}$) is estimated based on gas pipeline accidents in the case of Xiong’an as expressed by the following equation:

$$B_{sa} = \frac{1}{p} (P_{pt} + P_{c})$$  \hspace{1cm} (5)

where $p$ is the proportion of gas pipeline accidents in all of the urban pipeline accidents; $P_{pt}$ is the value of annual public property loss due to gas pipeline accidents in the project service area if directly buried pipelines were built rather than a UUT and $P_{c}$ is the cost of human casualties incurred by gas pipeline accidents in the project service area.

The number of gas pipeline accidents is mainly associated with the climate and management level of cities. Xiong’an bear a resemblance in both these two aspects with Beijing, so the average number of gas pipeline accidents per unit length of pipe in Beijing is adapted in this case, which is 0.015 case per kilometre every year. Gas pipelines are planned to be accommodated only in UUT mainlines (90 km) in Xiong’an. Therefore, it is estimated that approximately 1.35 cases of gas pipeline accidents can be prevented in the UUT mainline service area in Xiong’an annually. Conclusions can be drawn from years of accident reports in Beijing that gas pipeline accidents usually lead to hundreds of thousands of direct economic loss and sometimes cause millions or more in severe cases, so an average of 0.5 million CNY loss per case is taken here. Eventually, the value of annual public property loss that can be avoided ($P_{pt}$) is 0.675 million CNY.

The value of reducing human casualties ($P_{c}$), which is not goods and has no market price to refer to directly, should be calculated in monetary terms with the help of human capital methods. The modified human capital method valuates premature death as loss of contribution to the society for a certain period of time using the product of local GDP per head and the years of life lost, while the human capital method can be used to valuates loss of labour due to human injury by multiplying local average wage rate and the duration of convalescence.

GDP per head of Beijing is 1.64 million CNY in 2019 and has maintained an average annual growth rate of 10% in the past five years, so GDP per head of Xiong’an New Area in 2020 is estimated to be around 1.8 million CNY. The years of life lost is simply estimated as half of local average life span for accidental deaths caused by gas pipeline accidents. For Beijing, latest report from Beijing Municipal Health Commission suggest local average life span to be 82.2 years. Data show that, from 2012 to 2015 in Beijing, approximately 9 people dies of gas pipeline accidents annually, averaging 0.025 deaths each case. The number of injuries is not provided, but according to national data it is usually more than ten times of that of deaths. Average duration of convalescence is taken as 6 months. Therefore, the annual cost of human casualties that can be avoided ($P_{c}$) is 2.516 million CNY.

At last, $B_{sa}$ is a total of 5.84 million CNY each year (price in 2020).
4. Discussion and conclusions

For assessing social benefits of UUTs planned in unbuilt new areas, it is crucial to choose the proper source to adapt data from. Development strategy and direction, geographical conditions, climate and etc. are all needed to be considered. While there is a very slight chance to encounter source matches perfectly, differences in conditions should be taken into account in the adaption process. Basic information such as construction scale, expected population density and layout of transportation network and land usage that is usually provided in planning documents can be used to make direct quantitative adaption, while descriptions of development strategy and direction need to be interpreted first. It is more dependable and convenient to choose source bearing the similar strategic significance while making simplified adjustment in scale, though uncertainty is bound to exist. Additionally, numbers of parameters also ought to be limited to reduce uncertainty.

| External benefit category | Description                                      | Annual value (CNY mn.) | Proportion  |
|---------------------------|--------------------------------------------------|------------------------|-------------|
| \( B_{pd} \)              | Avoiding traffic delays                          | 142.29                 | 52.71%      |
| \( B_{ob} \)              | Avoiding loss of onsite business                 | 121.46                 | 45.00%      |
| \( B_{psl} \)             | Conserving service life of pavement              | 0.35                   | 0.13%       |
| \( B_{sa} \)              | Reducing serious accidents of urban pipelines    | 5.84                   | 2.16%       |
| **Total**                 |                                                  | **269.94**             | **100%**    |

In this paper, adapted valuation of social benefits of UUTs in unbuilt new areas is demonstrated in Xiong’an New Area, China. The benefit of avoiding traffic delay makes up more than half of the total amount, which accords with the conclusion of previous researches. To improve calculation and verification, further study is still needed, but the method demonstrated herein is useful for making a quick and workable estimation. It is noteworthy that those annual value of social benefits cannot be used directly to obtain a total value throughout service life for UUTs (100 years in this case). The time value of money should be considered by adopting social discount rate and annual growth rates of parameters. It is predictable that adaption and simplification is also needed in this process.

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