Multi-Criteria Spatial Analysis of Multi-Purpose Utility Tunnels

Yisha Luo

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This is to certify that the thesis prepared

By: Yisha Luo

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____ Chair

Dr. Osama Moselhi

____ Examiner

Dr. Fereshteh Mafakheri

____ Examiner

Dr. Mazdak Nik-Bakht

____ Examiner

Dr. Osama Moselhi

____ Supervisor

Dr. Amin Hammad

Approved by ____

Dr. Michelle Nokken, Graduate Program Director

December. 10 2019 ____

Dr. Amir Asif, Dean, Gina Cody School of Engineering and Computer Science

ABSTRACT

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Yisha Luo

Repeated excavations of buried utilities cause road congestion and maintenance conflicts. Besides, the interference of buried utilities in limited underground spaces does not meet the requirement of sustainable urban underground development. Multi-purpose utility tunnels (MUTs) integrate all utilities together in one tunnel and can be accessed by humans. MUTs reduce the excavation needs and costs and avoid the traffic congestion caused by excavations. MUTs also provide easy access for inspection and maintenance of all types of utilities inside the tunnel. MUTs have been in existence since the 19th century. MUTs in Europe and Japan were developed rapidly especially during the period 1961 to 2000. However, the development of new tunnels in recent years is limited and lacks long-term planning. MUT projects in North America are mainly in university campuses. On the other hand, China is making a big progress in MUT planning and construction because the Chinese government is taking MUT construction as an important urban infrastructure development. Focusing on China, the experience of MUT planning, construction and management in China can be very useful for other countries to examine the potential of MUTs as a sustainable option for future municipal asset rehabilitation projects. MUT planning is a key factor of urban underground space planning, which is an important part of urban planning. Previous research focused on MUT technologies; however, few researches focused on MUT planning. Location selection for MUTs is an important phase for MUT planning and it is complicated because it depends on several criteria, such as traffic volume and the density of the utilities. This research provides a general method for MUT location selection at different urban scales (e.g. street, district, borough) using Geographic Information System (GIS) spatial analysis. Multi-criteria

decision making (MCDM) is used in this research to select potential MUT locations. The weights of the criteria are calculated using the Analytic Hierarchy Process (AHP) method. Several cases studies are used to demonstrate the feasibility of the proposed method. The specific objectives of the research are: (1) Review the history and recent development of MUTs in the world; (2) Carry out a cost analysis based on the project information to find out the relationship between cost and MUT cross section dimension, etc.; (3) Provide a general method for MUT location selection based on GIS spatial analysis.

The conclusions of this research are as follows: (1) The experience of MUT planning and construction in Asia especially in China provides an alternative method for underground utilities, and is very useful for other countries to examine the feasibility of applying MUTs for future municipal asset rehabilitation projects. (2) Based on the AHP results, among the eight criteria used in the questionnaire, the most important criteria for MUT location selection are Annual Average Daily Traffic, utility density, expected number of excavations and future underground development projects. (3) The general method to select potential MUT locations using GIS spatial analysis is feasible.

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In addition, I would like to thank my colleagues Mr. Ali Alaghbandrad and Mr. Tersoo K. Genger for their work on the same project. I also thank them for permission to include Section 2.2 and 2.3 which was originally their work.

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CHAPTER 1 INTRODUCTION

1.1 General information

Most of municipal and private utilities (e.g. water and sewage pipes, electrical and telecommunication cables, etc.) are buried within the right of way under the roads. Different studies have reported that a large portion of underground utilities infrastructure in developed countries has aged and reached their service lives (Gagnon, Gaudreault & Overton, 2008; Ormsby, 2009). Therefore, to access aging buried utilities for repair, maintenance, and renewal activities, repeated excavation and street cuts are needed, which increase the maintenance costs and is a common cause for road congestion or closure. Furthermore, the buried utilities can be damaged by being directly exposed to the underground environment (e.g. soil and humidity) or being accidentally hit by excavation equipment. Frequent excavation for different utilities is a waste of money for public and private utility providers in addition to the impact on citizens and local businesses (i.e. social cost) (Oum, 2017), especially if the repair activities are not synchronized (Hunt & Rogers, 2006). In addition, the limited shallow underground spaces are sometimes not enough for all the conduits in some narrow streets which can cause utilities interference (Cano-Hurtado & Canto-Perello, 1999). In short, buried utilities are becoming un-economic, unsustainable and they increase social costs.

A utility tunnel refers to "any system of underground structure containing one or more utility services, which permits the placement, renewal, maintenance, repair or revision of the service without the necessity of making excavation; this implies that the structure is traversable by people and, in some cases, traversable by some sort of vehicle as well" (APWA, 1997). Multi-purpose utility tunnels (MUTs) refer to more than one utility pipes or cables in one single underground structure system (Su, 2007). MUTs reduce the excavation needs and costs, and consequently reduce traffic congestion caused by excavation. MUTs protect utilities from damages and corrosion as well as decrease the impacts on the environment (Canto-Perello & Curiel-Esparza, 2013; Hunt, Nash, & Rogers, 2014). Moreover, MUTs are easily accessible for maintenance. MUTs provide enough shallow underground space, especially vertical space, to avoid utility interference and enough space for new utilities, which meets the sustainable development requirements of underground space (Cano-Hurtado & Canto-Perello, 1999).

1.2 Problem statement

MUTs have been in existence since the 19th century. MUTs in Europe and Japan were developed rapidly especially during the period 1961 to 2000. MUT projects in North America are mainly in university campuses. However, the development of new tunnels in recent years is limited. Only a few countries including China are making progress in MUT planning and construction. In addition, most researches are focusing on technologies of MUT construction, while few researches are focusing on the long-term planning of MUT construction especially MUT location selection.

1.3 Research objectives

The objectives of the present research are the followings:

1) Review the history and recent development of MUTs in the world especially in Asian countries.
2) Conduct a cost analysis to find out the major factors affecting the costs.

3) Conduct a multi-criteria decision making (MCDM) model for MUT location selection based on GIS data.

1.4 Thesis structure

This thesis will be organized as follows:

Chapter 2 Literature Review: This chapter reviews the benefits and disadvantages of MUTs. The history and recent development of MUTs in the world are also reviewed. Moreover, regulations and standards of MUTs are reviewed in this chapter. In addition, smart MUT systems including sensor monitoring and controls are reviewed. At last, Multi-criteria decision making for MUT planning including MUT location selection, utility selection and MCDM method is reviewed.

Chapter 3 Cost Analysis and Smart MUT System: A cost analysis is conducted based on the information of several MUT projects in China to analyze the factors affecting the costs. Moreover, a smart MUT system is proposed in this chapter.

Chapter 4 Multi-criteria Decision Making for MUT Location Selection: This chapter proposes a MCDM model for MUT location selection. The MCDM model is conducted using GIS data based on the Analytic Hierarchy Process (AHP) method.

Chapter 5 Cases Studies: Ten locations are selected for manually selecting the best location in Montreal using the MCDM model in the previous chapter.

Chapter 6 Conclusions and Future Work: This chapter summarizes the present research work. Additionally, the limitations and some recommendations for future work are discussed.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

There have been several detailed studies about MUTs around the world. In the UK, Hunt et al. (2014) analyzed the cost of MUT and compared that with the cost of buried utilities. In France, Clé de Sol (2005) provided a guidelines about different aspects of MUT, such as cost and financing, management, security, technical issues, etc. In Germany, Laistner & Laistner (2012) compared construction and operational costs, and life expectancy of utilities in buried and MUT methods. The University of Washington provided a design guide for utility tunnels and trenches (UW, 2008) and the University of Oregon published the manual of "Utility Tunnel Safety Program" (UO, 2015).

In Spain, Canto-Perello et al. (2016) developed a model of analysis for MUT planning in urban areas based on Strengths, Weaknesses, Opportunities, and Threats (SWOT) and Analytic Hierarchy Process (AHP). Canto-Perello & Curiel-Esparza (2003) analyzed the risks and potential hazards of utility tunnels in urban areas. In Korea, (Y. K. Kang & Choi, 2015) used cost-benefit analysis for studying the economic feasibility of MUTs. Comprehensive books about MUT were published in Japan (Society of civil engineers, 2010) and Germany (Stein, 2002).

MUTs can be also referred to as Utility Corridors, Utilidors, Common Service Tunnels, Common Utility Tunnels, and Common Utility Ducts (Curiel-Esparza et al., 2004). MUTs can be classified into three types based on depth: (a) flush-fitting MUTs which have 0 m cover, (b) shallow MUTs which have 0.5 to 2 m cover, and (c) deep MUTs which have 2 to 80 m cover (Hunt & Rogers, 2006). In addition, MUTs can be classified into three types based on accessibility: (a) searchable MUTs are tunnels that can be accessible in a selective form by removing the cover, but it cannot be fully accessed because of the reduced cross-section area, (b) visitable MUTs are tunnels that can be fully accessed by man and in the whole length, (c) compartmentalized MUTs provide barriers between each utility type for protection (Canto-Perello & Curiel-Esparza, 2001; Hunt & Rogers, 2006).

For the design and construction of MUTs, cast-in-place concrete, prefabricated concrete/fiber glass segments (AKpipe, 2017; Clé de Sol, 2005; Ramírez Chasco et al., 2011) and trenchless jack and bore (BYU, 2015) are three main methods considered with advantages and disadvantages. For example, although the cast-in-place concrete method is simple with high flexibility in execution, it needs longer duration. The prefabricated concrete/fiber glass segment method is faster with higher quality, but there are issues related to transportation of segments and possible weakness in joints (Clé de Sol, 2005) . Trenchless jack and bore construction reduces the need to excavate along the roads; however this method is much more expensive than the two abovementioned methods (BYU, 2015). If utilities are already buried underground, then the jack and bore system cannot be applied and the open-cut method is needed to remove the buried utilities, before building the new tunnel.

2.2 MUT Benefits and Disadvantages

The benefits of MUTs to utility providers are mainly: (1) significant reduction of repeated excavations for maintenance and repair (Cano-Hurtado & Canto-Perello, 1999b; Hunt & Rogers, 2006; A. Laistner, 1997a), (2) weather independent inspection and maintenance (mainly preventive) of utilities (Julian Canto-Perello & Curiel-Esparza, 2013; Clé de Sol, 2005; Hunt et al., 2014b), (3) reduction of damage and corrosion of utilities (e.g. electricity cables from above-ground to MUTs for protection) (Canto Perello, J. & Curiel Esparza, 2003; Julian Canto-Perello & Curiel-Esparza, 2013), (4) facilitated development and upgrade in future (Clé de Sol, 2005; Y. K. Kang & Choi, 2015), (5) decreased labor accidental injury and death (Clé de Sol, 2005; Ormsby, 2009b), (6) decreased municipal revenue loss (De Marcellis-Warin et al., 2015; Ormsby, 2009b), and (7) improved planning of underground space (Sterling et al., 2012). The utility users and citizens benefit from MUTs mainly in the form of social benefits: (1) decreased traffic congestion (Clé de Sol, 2005; Gilchrist & Allouche, 2005; Ormsby, 2009a), (2) health, environment, and safety improvement (CERIU, 2010; Gilchrist & Allouche, 2005; Najafi & Kim, 2004; Ormsby, 2009a), (3) improved utility services and customer satisfaction (Cano-Hurtado & Canto-Perello, 1999b; Julian Canto-Perello et al., 2009b; A. Laistner, 1997b), (4) decreased local business loss (Manuilova, A. Dormuth, D. W. & Vanier, 2009; Ormsby, 2009a), and (5) reduced damage/temporary closure of recreational facilities (e.g., parks) (Ormsby, 2009a).

The main disadvantages of MUTs include: (1) high initial investment cost for construction (Rogers & Hunt, 2006), (2) less-known construction methods (Hunt & Rogers, 2006), (3) disruption of services for decommissioning and construction of new MUTs (Cano-Hurtado & Canto-Perello, 1999b; Hunt & Rogers, 2005), (4) compatibility and safety issues between utilities (Cano-Hurtado & Canto-Perello, 1999b; Hunt & Rogers, 2005), (5) security risks related to human attacks (Julian Canto-Perello & Curiel-Esparza, 2013), and (6) coordination issues between utility companies and the utility users (Julian Canto-Perello et al., 2009b).

2.3 MUT history and development in the world

MUTs have been in existence since the 19th century. An MUT was built in France in 1861, which integrated the sewage system and water pipes with a huge cross-sectional area (Cano-Hurtado & Canto-Perello, 1999; Canto-Perello & Curiel-Esparza, 2001). Subsequently, a tunnel was built in England in 1866, to host foul and drinking water. This MUT allows man-access and is still in use. Germany (1893) was also among the countries that first implemented MUTs as shown in Figure 2-1 (a). There was a lag from 1893 to about 1920 in the construction of MUTs. Figure 2-1 (b) shows that between 1921 and 1960, several MUTs were constructed in parts of North America (Alaska), Asia (Japan) and Europe (France, Germany, Czech, etc.). Figure 2-1 (c) shows that from 1961 to 1980, there was a rise in the construction of MUTs with a total of about 30 MUTs constructed. During this period, about 50% of the world's MUTs were built in France in cities like Angers, Paris, Rouen, Lyon, etc. Following the Utility Tunnel Law passed in 1963, Japan was able to build approximately 2000 kms of utility tunnels in 80 Japanese cities (Wang, Tan, Xie, & Ma, 2018). Countries like Belgium, Czech Republic, Germany, Switzerland, etc., were also involved in the construction of MUTs. Subsequently, between 1981 and 2000, the Czech Republic increased the construction of MUTs with a total of 10 out of a total of about 36 MUTs constructed worldwide during this period. These MUTs were built in cities like Prague, Brno, etc. Japan increased construction of MUTs during this period to about 30% of the world MUTs. However, countries like France and Germany continued to build MUTs. This period also saw the construction on MUTs in countries like Norway, Spain, China and USA as shown in Figure 2-1 (d). The 21st century has seen a relative increase in the construction of MUTs in Asia. 80% of the world MUTs are currently being constructed in China as shown in Figure 2-1 (e). Countries like Israel, Malaysia, India, Qatar, Singapore and Canada have also implemented MUTs, while countries like Czech Republic, England, USA, have continued to construct MUTs with the latter two having MUTs constructed mainly on university campuses, hospitals, private establishments, and military installations. References regarding the year of construction, utilities hosted, the location of MUTs and other information regarding MUTs used in the generation of Figure 2-1 can be found in Table 2-1. However, some information is unavailable (e.g., the utilities hosted, date of construction, length, and shape of the MUTs).

Figure 2-2 shows some MUTs constructed in Europe, depicting the utilities hosted as well as the shapes of the MUTs. The color of each segment represents the different utilities present in the

MUTs. The map shows the different shapes of the MUTs ranging from rectangular and circular to the arch-topped shape (Cano-Hurtado & Canto-Perello, 1999; Canto-Perello & Curiel-Esparza, 2001; Laistner & Laistner, 2012; Makana, Jefferson, Hunt, & Rogers, 2014; Rogers & Hunt, 2006; Yang & Peng, 2016). The location and size of each segment used in representing the MUTs on the map do not represent the precise locations or actual dimensions of the utilities in the MUTs.

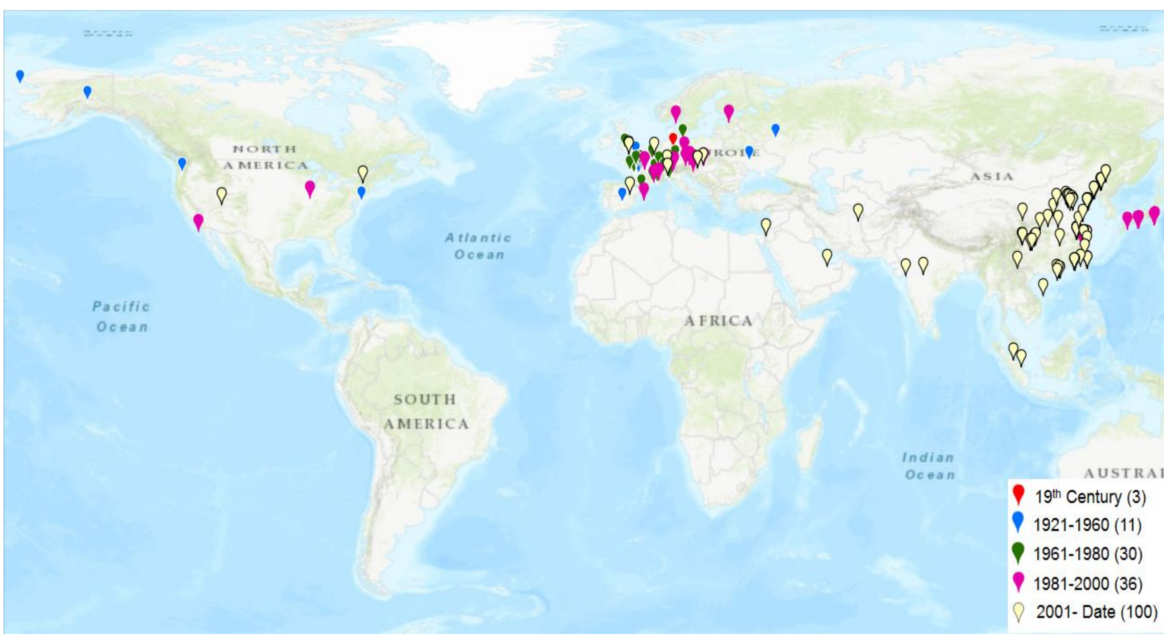
Figure 2-3 represents the relative lengths of the MUTs constructed in Europe. Spain and Russia have implemented the longest MUTs of about 100 km built in 1940 and 1943, respectively. Figure 2-4 shows the utilities commonly hosted in the MUTs in Europe. Focusing on eight of the most commonly hosted utilities, namely gas, water, refuse, district cooling, district heating, sewage/rainwater, communication, and electricity. Figure 2-4 also shows that electrical cables, water pipes, and communication cables are the most frequently hosted in MUTs across Europe, followed by sewage, district heating, and gas pipes. Compared to the other utilities, refuse and district cooling are the least hosted of all the eight utilities. There are more MUTs in Europe that host water pipes as compared to sewage pipes because, unlike water, the slope of the sewage pipes is important. Due to the climate in Europe, district heating is relatively more important than district cooling.

(a) 19th Century (3 MUTs)

(b) 1921 to 1960 (11 MUTs)

(c) 1961 to 1980 (30 MUTs)

(d) 1981 to 2000 (36 MUTS)



(e) 2001 to 2019 (100 MUTs)

Figure 2-1. Location of MUTs built at different time periods

Table 2-1. MUT projects in the world excluding Mainland China, Japan and Taiwan

COUNTRY	CITY	MUT LOCATIONS	YEAR	LENGTH (km)	DEPTH (m)	WIDTH(m)	HEIGHT(m)	SHAPE	MATERIAL	GAS	CLEAN WATER	REFUSE	DISTRICT COOLING	HEATING	SEWAGE	COMMUNICATION	ELECTRIC	REFERENCES
Belgium	Antwerp	Antwerp	1969					C			√				√	√	√	(Rogers & Hunt, 2006)
	Brussels	Brussels	1976	4		1.3	1.9	R	PC							√	√	(Rogers & Hunt, 2006)
Canada	Montreal	Montreal	2015	0.2	15	3	3		B							√	√	(Pomerleau, 2015)
Czech	Brno	Brno Phase I	2001	1.79							√			√	√	√	√	(INTERNATIONAL TUNNELLING et al., n.d.)
		Brno Phase II	2005	1.651							√			√	√	√	√	
	Jihlava	Jihlava	1984	1.7							√							
	Ostrava	Podebradova U.T.	1999	0.7		3.5	2.6	O			√			√	√	√		
	Ostrava	Centre Consumption U.T	2005	1.658	1.0	2.5					√			√	√	√		
	Prague	Celetna Street	1985	0.686				A		√								
		Rudolfinum	1985	1.08				A		√								
		Tyl Theatre	1985	0.563				A		√								
		New Town Hall	1985	0.603				A										
		RNLS U.T.	1985	0.72				A										
		Zizkov Bridge U.T.	1984	1.6		3.6												
		Prikopy U.T.	1997	1.054		2.5	3.3			√	√					√	√	
		Smichov U. T.	1998	2.58														
		Hlavkuv Bridge U.T.	1969	0.54														
		Vodickova U.T		1.263														
		Wenceslas Square U.T.		0.812														
		Center IA U.T.		2.684														
		Na Prikope St. Tunnel		1.971														
		Revolucni		0.905														
	Tabor	Zizkovo Square	1977															
Denmark	Copenhagen	Copenhagen	1980	1.6	35			C					√	√				(Rogers & Hunt, 2006)
Finland	Helsinki	Helsinki	1982	40	80	5	7	R	SC		√			√		√	√	
France	Angers	Angers	1970			1.3	1.9	OG	CSC		√			√	√	√	√	(Legrand et al., 2004; Rogers & Hunt, 2006)
	Besancon	Besancon	1966	12		1	1.8	OG	CSC		√			√	√	√	√	
	Dijon	Dijon	1977			2.2	3.4	R	CSC		√				√			
	Epinay-Sous	Epinay-Sous	1976	2		2	2	OG	CSC		√				√	√	√	

Table 2-1. MUT projects in the world excluding Mainland China, Japan and Taiwan (Continued)

COUNTRY	CITY	MUT LOCATIONS	YEAR	LENGTH (km)	DEPTH (m)	WIDTH(m)	HEIGHT(m)	SHAPE	MATERIAL	GAS	CLEAN WATER	REFUSE	DISTRICT	HEATING	SEWAGE	COMMUNICATION	ELECTRIC	REFERENCES
	Grenoble	Grenoble	1970	1.5	1.5	7.2	4	R	CSC		√			√	√	√	√	
	Lyon	Lyon	1984			2.1	2.9	R	PC		√			√	√	√	√	
	Marne La Vallee	Marne La Vallee	1972		0.5	2	2.4	R			√				√	√	√	
	Metz	Metz	1972		0.5	2.5	3.2	R	PC	√	√			√	√	√	√	(Rogers & Hunt, 2006)
	Normandy	Villers-sur-Mer	1971	3						√	√			√	√		√	
	Paris	Paris-Rive Gauche	1990	2.1		4.7	10.5	R	CSC	√	√			√	√	√	√	
		Paris	1851					O			√			√		√		(Wang et al., 2018)
		Paris La Defense	1992	12		3.6	2.5	OG	CSC		√		√	√	√	√	√	(Legrand et al., 2004; Rogers & Hunt, 2006)
		Saint Germain	1971	1.3		2.1	3	OG	CSC		√			√	√	√	√	
	Rennes	Rennes	1970	1.4										√				
	Rouen	Rouen	1967			1.9	2	R	PC		√				√	√	√	
	Saint Ettienne	Saint Ettienne	1972	0.4		1.5	1.9	R	PC	√	√				√	√	√	
	Toulouse	Toulouse	1972	0.7		2.2	2.5	R	CSC		√			√	√	√	√	
		Toulouse	1945	3.8		1.5	2				√				√	√	√	(Rogers & Hunt, 2006)
Germany	Hamburg	Hamburg	1893	0.45				R		√	√			√		√	√	(Wang et al., 2018)
	Lauchhiem	Lauchhiem	1995	0.3		2	2	C	Steel		√				√		√	(Rogers & Hunt, 2006)
	Potsdam	Fahrland	1994	0.3		2	2	C	PEHD		√				√		√	
	Speyer	Speyer	2004					O	VFRC	√	√			√			√	(Laistner & Laistner, 2012)
	Suhl	Suhl	1967					R		√	√			√		√	√	(Laistner & Laistner, 2012; Wang et al., 2018)
	Ulm	Ulm	1985					R			√			√		√	√	(Laistner & Laistner, 2012)
	Wachau	Wachau	1992	4		2	2	C	PEHD	√	√				√		√	(Laistner & Laistner, 2012)
	Bhopal	Bhopal	2001								√	√				√	√	(TATA Consulting Engieers Limited, 2017)
India	Gujarat	Gift City	2015	16	11	7.6	6.2	R			√	√	√		√	√	√	(BENTLEY SYSTEMS, 2013; Gujarat International Finance Tec-City., 2016)

Iran	Mashhad	Mashhad	2016	5	5			C	PC		√					√	√	(AKpipe, 2017; Imna, 2017; Mashhadenc, 2015; Mehrnews, 2010)
Israel	Haifa	Haifa	2006	1	5.5	3	3.75		PC		√				√	√	√	(Howling Pixel, 2019; Levin, 2012a, 2012b; Yefe Nof, n.d.)
Malaysia	Putrajaya	Putrajaya	2003	15	2	8	5	R	CSC	√	√		√		√	√	√	(Rogers & Hunt, 2006)

Table 2-1. MUT projects in the world excluding Mainland China, Japan and Taiwan (Continued)

COUNTRY	**CITY**	**MUT LOCATIONS**	**YEAR**	**LENGTH (km)**	**DEPTH (m)**	**WIDTH(m)**	**HEIGHT(m)**	**SHAPE**	**MATERIAL**	**GAS**	**CLEAN WATER**	**REFUSE**	**DISTRICT COOLING**	**HEATING**	**SEWAGE**	**COMMUNICATION**	**ELECTRIC**	**REFERENCES**
Netherland	Amsterdam	Amsterdam	2005	0.2						√	√	√	√	√	√	√	√	(F.M. Taselaar C.A.M. Hompe J.W. Van Liere, 2004; Hompetaselaar.nl, n.d.)
Norway	Oslo	Oslo	1990					R	PC		√		√		√	√	√	(Rogers & Hunt, 2006)
Qatar	Lusail	Lusail	2009	15					CSC			√	√			√	√	(Howling Pixel, 2019; Lusail City, 2015, n.d.)
Russia	Moscow	Moscow	1943	100		2	3	R	CSC		√		√		√	√	√	(Rogers & Hunt, 2006)
Singapore	New Downtown	Singapore	2004	20	2	12	4	R	CSC	√	√	√	√	√	√	√	√	(Rogers & Hunt, 2006)
Spain	Barcelona	Barcelona	1992	28	0	2	1	R	PC		√					√	√	(Canto-Perello, Curiel-Esparza, & Calvo, 2009; Rogers & Hunt, 2006)
	Madrid	Madrid	1940	100		2.1	4.5	OG	BM		√				√	√	√	(Rogers & Hunt, 2006)
	Pamplona	Pamplona	2008	7.8	6.5						√				√	√	√	(Ramírez Chasco et al., 2011)
Switzerland	Basel	Basel	1980					R	CSC		√				√	√	√	(Rogers & Hunt, 2006)
	Geneva	Geneva	1984	0.8	0.5			R	PC		√				√	√	√	(Rogers & Hunt, 2006)
	Lugano	Lugano	1963	10				C	PC							√	√	(Rogers & Hunt, 2006)
	Zurich	Zurich	2002					R		√	√				√	√	√	(Howling Pixel, 2019)
Ukraine	Kyiv	Kyiv	1950					R	PC		√		√		√	√	√	(Rogers & Hunt, 2006)
United Kingdom	Birmingham	Birmingham Univ.	2005	0.1	0	1.6	0.8	R	PC					√		√		(Rogers & Hunt, 2006)
	Liverpool	Mersey Tunnel	1972					C	PC	√						√	√	(Rogers & Hunt, 2006)
	London	London Holbum Viaduct	1861					OG	BM	√	√				√	√	√	(Canto-Perello et al., 2009; Rogers & Hunt, 2006)
		London Barbican	1957	4.5				R	CSC			√				√	√	(Rogers & Hunt, 2006)
		M6 Toll Road	2003					R	PC									(Rogers & Hunt, 2006)
United States	Alaska	Alaska Cape Lisburne	1951					OG	PC		√				√	√	√	(Rogers & Hunt, 2006)
		Fairbanks University	1938	1	1.8	0.9		OG	PC		√				√	√	√	(Rogers & Hunt, 2006)
	Chicago	Chicago	1992					OG	PC							√		(Rogers & Hunt, 2006)
	New York	New York	1952					C	PC		√				√	√	√	(Rogers & Hunt, 2006)
	Orlando	Disney	1982	1				R	PC		√				√	√	√	(Rogers & Hunt, 2006)
	Uttah	Provo	2015	0.033	9.1			C	PC									(Rogers & Hunt, 2006)

	Washington	Seattle University	1940					R	PC		√				√	√	√	(Rogers & Hunt, 2006)

Shape: C - Circular, OG - Ovoid with gutter, R - Rectangular, A - Arch Topped, O - Oval
Materials: CSC- Cast in-situ concrete PC- Pre-cast concrete BM- Brick and mortar SC- Sprayed concrete PEHD- High Density Polyethylene VFRC- Vinyl fiber reinforced concrete

Figure 2-2. Cross-section, shape and utilities hosted in MUTs in Europe

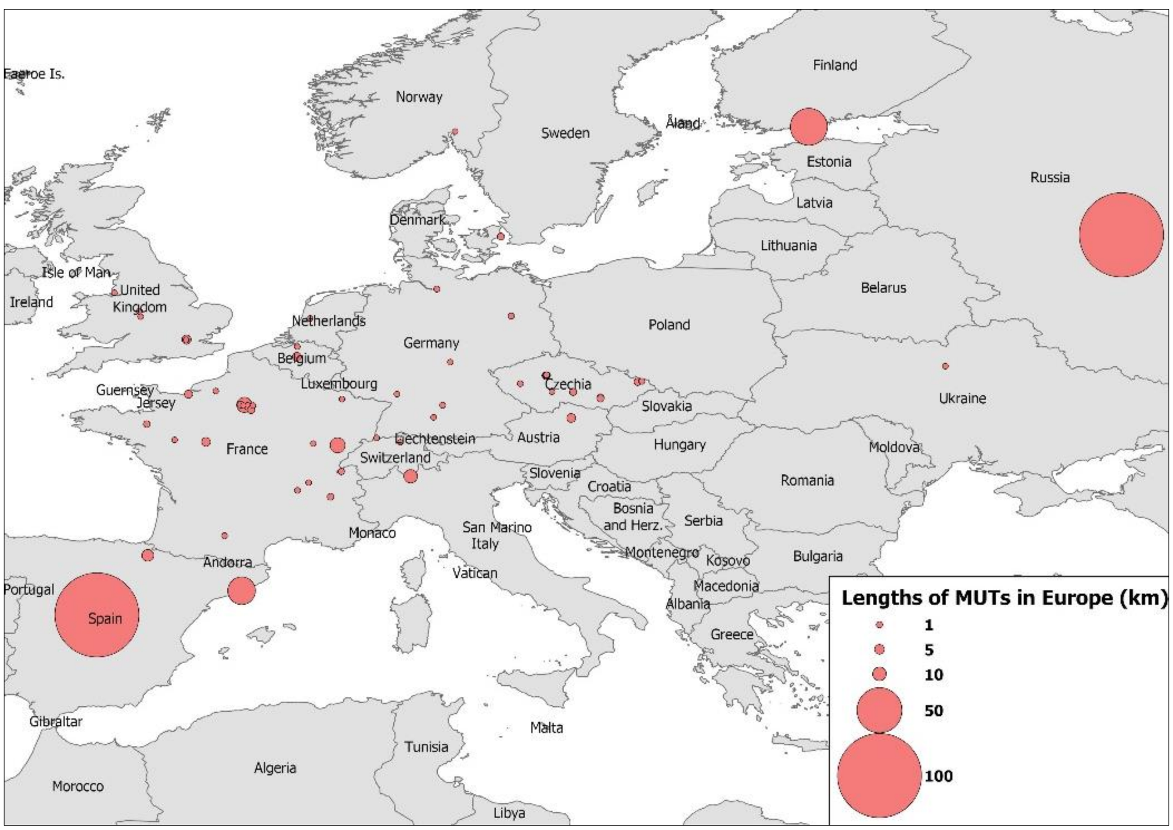


Figure 2-3. Lengths of MUTs in Europe

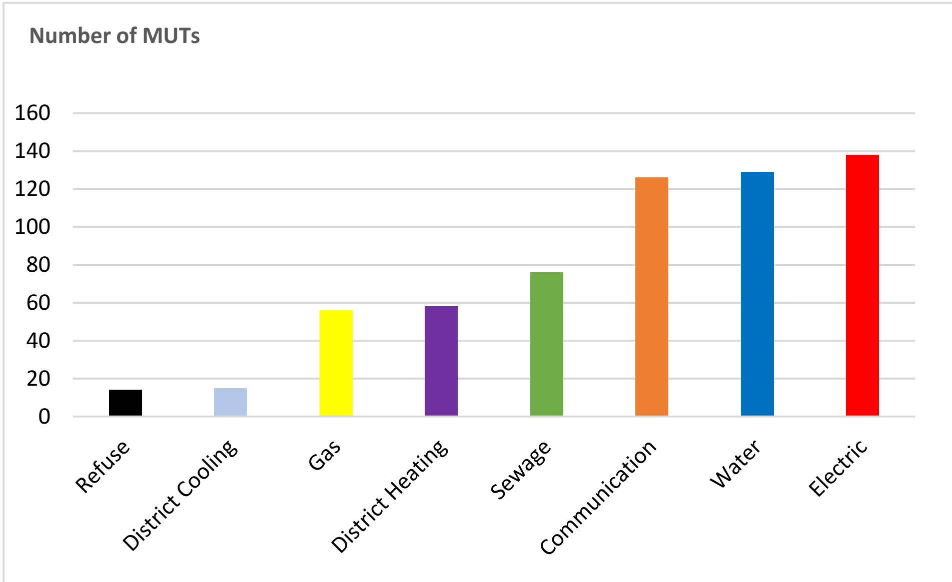


Figure 2-4. Utilities hosted in MUTs in Europe

2.4 MUT projects in Asia (excluding Mainland China)

2.4.1 MUT projects in Taiwan

The statistics of length and cost of main MUTs, branch MUTs, cable ducts and cables in Taiwan Province are shown in

Table 2-2 (CPAMI, n.d.). The main construction is in branch MUTs and cables. The main MUTs and cable ducts are mostly completed and only a few are under construction or in the design phase. Since the cost is based on the total length of different types of projects, it is not easy to estimate the unit cost for MUTs. Table 2-3 (CPAMI, n.d.) indicates the MUT projects in various cities and counties in Taiwan. The costs in

Table 2-2 and Table 2-3 are at the time the projects were constructed. Taipei as the provincial capital of Taiwan established Utilities Conduit Planning Section in February 1991. The Utility

Conduit Planning Section oversees MUT planning, design, budget control, MUT maintenance, management and policy-making (NCO, 2018; Zeng, 2015). According to the utility conduit policy, the planning of MUT should follow the qualifications: (1) development of new areas, (2) re-division areas, (3) metro system, (4) underground railway development, (5) other large projects (Zeng, 2015).

Table 2-2. Statistics of MUT length and cost in Taiwan (CPAMI, n.d.)

Project type	**Completed Length (km)**	**Under Construction (km)**	**In Design (km)**	**Total (km)**
Main MUT	73.590	3.146	0.000	76.736
Branch MUT	61.844	107.890	30.380	200.114
Cable Tunnel	58.921	25.803	26.974	111.698
Cables	569.284	215.574	146.783	931.641
Total Cost (C$M)	1241	336	245	1822

Taipei as the capital of Taiwan Province established Utilities Conduit Planning Section under the New Construction Office, Public Works Department, Taipei City Government in February 1991 (Zeng, 2015). The Utility Conduit Planning Section is in charge of MUT planning, design, budget control, MUT maintenance, MUT management and policy making (NCO, 2018). According to the utilities conduit policy, the planning of MUT should follow the qualifications: (1) development of new areas, (2) re-division areas, (3) MRT system, (4) underground railway development, (5) other large projects (Zeng, 2015).

Table 2-3. MUT length and cost in various cities and counties in Taiwan (CPAMI, n.d.)

City/County	Project Name	Length (km)				Phase			Cost (C$M)
		Main MUT	Branch MUT	Cable Tunnel	Cables	Completed	Construction	Design	
Keelung	Zhongshan Road MUT	1.796	0	0	1.796		√		27.39
Taipei	Shimin Road MUT	10.6	10.6	0	0	√			67.452
	Keelung River MUT	1.469	0	5.54	0	√			33.44
	South Port Trade Area MUT	0.91	0	1.38	0	√			20.46
	Zhoumei Expressway MUT	1.032	0	0.929	0	√			3.608
	Dadu Road MUT	6.472	0	0	0	√			66.44
	South Port Railway MUT	0	6.348	0	0	√			17.23
	MRT Xinyi Line MUT	5.562	0	0	0	√			294.8
	MRT Songshan Line MUT	4.343	0	0	8.686	√			136.4
	Beitoushilin Industrial Area MUT Phase 1	0	4.921	0	0.757	√			12.1
	Fuguo Road MUT Phase 1	1.18	1.23	0	0.087	√			15.89
	Fuguo Road MUT Phase 2	1.35	0.59	0	0.052		√		24.21
New Taipei	Danhai New Town MUT	2.641	0	0	0	√			26.84
	Banqiao New Railway Station MUT	0	4.2	0	0	√			8.756
	Linkou Specific Industrial Area #1 area MUT	0	13	0	0			√	25.84
Taoyuan	Aviation Town MUT	2.39	0	5.23	67.89	√			14.036
	Taoyuan Railway Station MUT	7.08	0	12.01	81.85	√			86.68
	Airport MRT A20 Station MUT	0	1.2	0	12.9			√	11.2
	Bade District Jieshou Road to Jiande Road MUT	0	3.4	0	0			√	13.31
	Taoyuan MRT green line MUT	0	12.78	0	13.5			√	80.88
Hsinchu	Expo MUT	0	0.266	0	0	√			0.343
Hsinchu	Hsinchu Railway Station MUT	2.69	0	5.38	0	√			34.76
Taichung	Zhenxing Road MUT	0	2.8	0	0	√			4.312
	Kuozi Area MUT	0	12.17	0	0	√			18.388
	Fengyuan District 2-1 Road MUT	9.548	13.81	0	0	√			6.6
	Taichung Railway Station MUT	1.753	0	2.35	0	√			10.098
	Liming District MUT	0	0.07	0	0	√			0.16
	Anhe District MUT	0	0.17	0	0	√			0.62
	No. 14 Re-division Area MUT	0	61.59	0	50.92		√		86.14
	Shuinan Trade Area MUT	0	32.3	0	5.2		√		82.69
	MRT Wenxinbeitun Line MUT	0	13.41	0	0		√		24.98
Hualien	Shoufeng Town Zhixue MUT	0	1.165	0	0	√			1.19
Yunlin	Yunlin Railway Station MUT	2.33	0	0	34.031	√			24.2
Chiayi	Chiayi Zhongxiao Road MUT Phase 3	1.65	3.08	0	0	√			10.56
	Chiayi Railway Station MUT	1.723	0	4.07	0	√			17.908
Tainan	Tainan Railway Station MUT	7.508	0	0	11.953	√			55.484
	Daqiao Area MUT	0	1.28	0	0	√			2.618
Kaohsiung	Minzu Road MUT	1.6	0	0	0	√			19.36
	Kaohsiung New Town MUT	0.843	0	1.386	0	√			4.4
Total		**76.47**	**200.38**	**38.28**	**289.62**				**1391.77**

2.4.2 MUT projects in Singapore

Singapore is the first country in Southeast Asia to implement MUT on a comprehensive scale. The location of the MUT project is in the downtown core by the Marina Bay. The complete system is 20 km and is divided into several phases (URA, 2006; Y. Zhou & Zhao, 2016) (Figure 2-5). Phase 1 was completed in May 2006, and the total length is 1.4 km with a cost of around CAD$66M (CAD$47M/km). The depth could reach 20 m in some parts (NUS, 2016). Phase 2 was completed around 2010, and the total length is 1.6 km with a cost of around CAD$111M (CAD$69M/km). Phase 3 was completed in 2016 (SmartBuildAsia, n.d.). As in Figure 2-6 (Lim, 2012), the MUT contains electricity, telecommunication, water and Newater networks which contain ultrapure reclaimed water (CLC, 2017). A district cooling system and a pneumatic waste collection system will be installed in the future.

An underground master plan that maps out the use of underground spaces as deep as around 100 m. This master plan includes the design of various urban infrastructure in different levels, and the depth of the MUT will be 15 to 50 m. It will be released in 2019 by the Government (Ng, 2018).

Figure 2-5. Layout of the Marina Bay MUT (Lim, 2012)

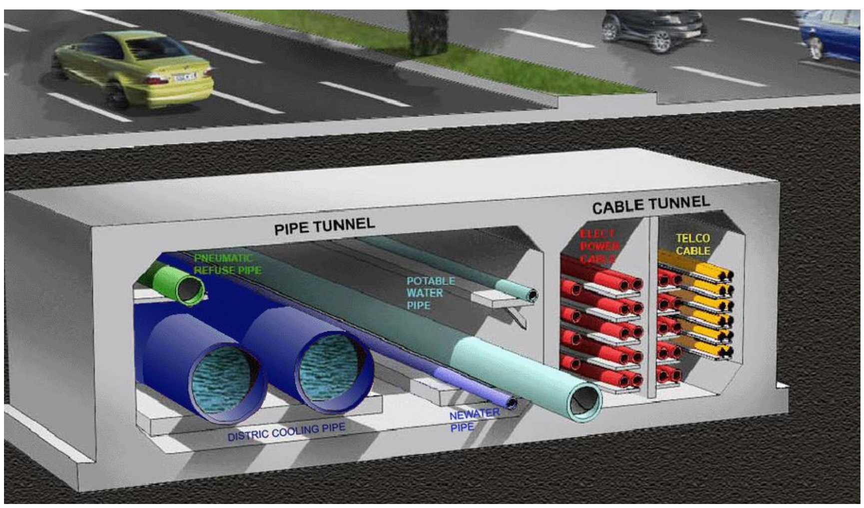


Figure 2-6. Cross-section of the Marina Bay MUT (Lim, 2012)

2.4.3 MUT projects in Japan

MUT construction in Japan started in 1923 in Tokyo, followed by Osaka and Nagoya after the Great Kantō earthquake. As one of city reconstruction projects, Tokyo set three MUT pilot projects. The first MUT project was 270 m long with a cross-section of 3 m × 2 m (width × height) including electricity, telecommunication, water and sewage in Kudanzaka. The second MUT project was built under the sidewalk with a cover of 0.5 m to 1.5 m including electricity compartment and telecommunication compartment, and this project was built to move the above-ground cables to underground. The third MUT project with a cross-section of 1.3 m × 1 m was built for a new construction method for gas pipes in Yaesu. Then Japan stopped MUT construction for nearly 30 years due to cost sharing issues and World War II. The second phase of MUT construction started in the 1960s in Tokyo (Shinjuku, Ginza, Tsukuba Scientific Town and Tama New Town), Osaka, and Nagoya to reduce road congestion. (Shinichi, 2013; Shu, 2003).

Information of some main MUTs is shown in Table 2-4 (Big Empire, n.d.; Hunt & Rogers, 2006; Park & Yun, 2018; Peng et al., 2003). The total planned length of MUT in Tokyo is 162 km, and only 118 km (73%) were completed and 6 km under construction until 2013 (Shinichi, 2013).

One of the new subcentral areas near the Tokyo Bay contains four districts. There are more than 10 utility types including water, sewage, telecommunication, gas, cooling, heating, and garbage system connecting to every building. To improve the operating efficiency, nine main pipes and cables except rainwater were moved to the MUT, which is 16 km with a total cost of USD$3.2B. The cross-section designs are shown in Figure 2-7 (Zhu, 2005).

Table 2-4. Main MUTs in Japan

City	MUT name	Length (km)	Construction year	Utilities housed							
				Telecom	Water	Electricity	Sewage	Gas	Cooling	Heating	Refuse
Hiroshima	Minami-ku	2.60	-1993	√	√	√	√	√	√		
Hyōgo Prefecture	Amagasaki	2.48	1980-1988	√		√		√			
Kawasaki	Kawasaki	2.72	1976-1983	√	√	√		√			
Kobe	Kobe	3.28	1987-	√		√	√	√			
Kyoto	Karasuma Line	0.52	1976-1979	√	√	√					
	Gojo Station	1.51	1979-1985	√		√					
Osaka	Fukushima-ku	2.37	1982-	√	√	√		√			
	Yodogawa-ku	3.71	1988-	√	√	√		√			
Tokyo	Aotoya	2.30	1971-1975	√		√		√			
	Azabu-Hibiya	4.30	-2010	√	√	√	√				
	Chiyoda	1.90	-1926		√	√	√	√			
	Kameido	2.04	1981-1989	√		√					
	Nerima	2.30	1973-1977	√	√	√		√			
	Takanawa	2.00	1965-1966	√		√					
Yokohama	Higashiterao	4.56	1979-1988	√	√	√					
	Minato Mirai	25.00	-2000	√	√	√	√	√	√	√	√
	Yoshino	2.60	1990-	√	√	√	√	√			

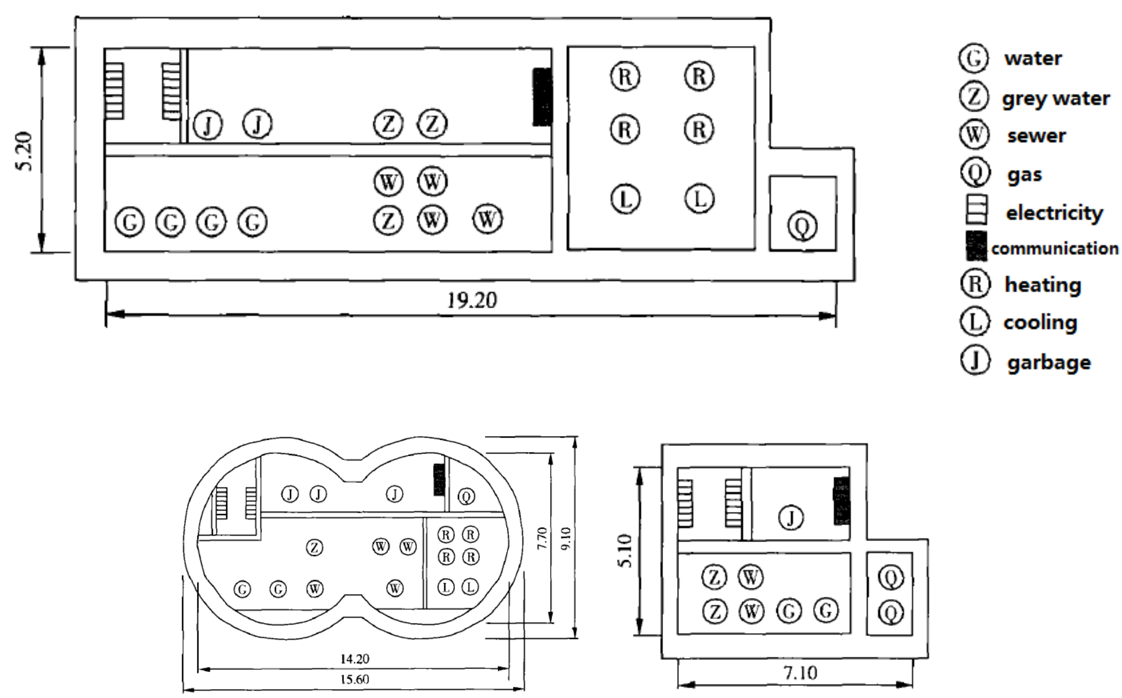


Figure 2-7. Cross-section of Tokyo Bay MUT (Zhu, 2005)

2.5 MUT projects in China

China urbanization rate in 2017 is 58.52% which is 1.17% more than that of 2016, and urban population is 813.47 million, which is 20.49 million more than that of 2016 (The State Council of China, 2018). During the past 20 years, the urbanization process was rapid; as a result, the infrastructure services should be improved to catch up with this process. To improve the municipal utility construction and maintenance, and to ensure utility safety, MUTs were introduced for utility companies in China (Jian Wang, 2018). The first MUT in China was built in Beijing in 1958 with a total length of 1.08 km containing water, electricity, telecommunication and heating. The first long MUT, which is seen as a signature project, was built under Shanghai Zhangyang Road with a total length of 11.50 km in 1994 (Ma et al., 2017). One of the longest completed MUTs in Hengqin Island, which is 33.4 km, contains electricity, water and telecommunication, and has extra room for future heating, cooling, grey water and garbage vacuum pipes (He, 2015).

Recently, China is making big progress in MUT construction as an essential urban infrastructure development. The State Council decided to start MUT construction nationwide in 2013 and identified 25 pilot cities in 2015 and 2016 (Ministry of Finance of China, 2015, 2016). In 2016, MUT construction length in China exceeded 2000 km including pilot cities and many other cities (MHURD, 2016). As a result, it is important to study MUT projects' planning and construction in China, and examine whether the gained experience is suitable to apply in other countries. This section reviews the new development of MUTs in China focusing on major Chinese cities including basic data on the length, cross-section, technical design, and cost analysis. It is hoped that this review will encourage further research about the usage of MUTs.

China has taken building MUTs as an important infrastructure development to improve the resilience of first-tier cities, as well as of new areas or less developed cities. Several policies and guidelines were announced to encourage MUT planning and construction. For future MUT development by MHURD, the construction rate under new roads in city new areas should be 30% by 2020, and the overall MUT construction rate in cities should be 2% by 2020 (MHURD, 2017). In 2016 and 2017, the Chinese government determined the construction planning of 2000 km each year including projects in pilot cities (The State Council of China, 2016, 2017). At the end of 2016, 147 cities including pilot cities had started the construction of 2005 km (MHURD, 2016). After 25 pilot cities determined during 2015 to 2016, there are no more pilot cities in China, and the MUT construction is slowing down mainly because of the high initial cost, less central government push, and more regulations are released, which MUT construction should follow.

Table 2-5 shows part of MUT projects of major cities in China. The MUT projects are listed according to the alphabetical order of cities. The grey cells refer to lack of information. 38 of the projects have been completed, and 43 projects are under construction. The shape "R" refers to rectangular and "C" for circular. Some projects have different segments with different numbers of compartment. For utilities housed in the MUT, most tunnels contain water pipes and electricity and telecommunication cables. Some tunnels contain gas pipes and heating ducts as well; but few contain sewage pipes. Cells with "*" in the "Utilities housed" refer to utilities to be installed in the future. Figure 2-8. MUT projects in China illustrates the status of the construction of MUTs in China (i.e. completed, under construction or no information). Figure 2-9. Lengths of MUTs in China shows the varying lengths of the MUTs built in China.

Figure 2-8. MUT projects in China

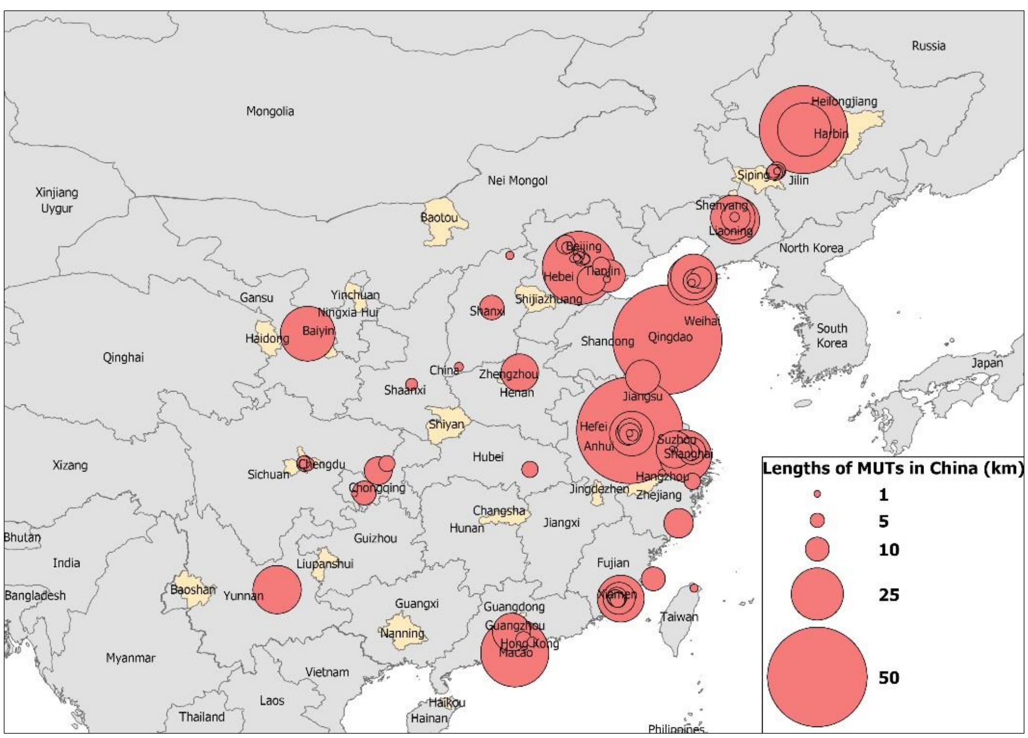


Figure 2-9. Lengths of MUTs in China

Table 2-5. MUT projects in China

City	Project name	Completion year	Phase		Length (km)	Shape	Number of compartments	Width (m)	Height (m)	Utilities housed											References
			Completed	Construction						Electricity	Telecommunication	Water	Grey water	Condensed water	Sewage	Heating	Cooling	Gas	Refuse collection	Rainwater/drainage	
Baiyin	7 projects			√	26.25	R	3	11.8	4.45	√	√	√			√	√		√			(Beijing General Municipal Engineering Design & Research Institute, n.d.-a; CHINAUTIA, 2016b)
Beijing	Beijing Expo 2019	2019		√	3.40					√	√	√	√			√		√			(C. Bao & Gao, 2017; Z. Cao, 2017a)
	Beijing Institute of Technology			√	0.96	R	2	7.3	4.4												(Hong Zhang, 2016)
	Beijing Tiananmen Square	1958	√		1.10	R	1	4.93	2.9	√	√	√				√					(Ma et al., 2017)
	Chaoyang District baiziwan guanghua new town	2015	√		4.20	R	2				√	√	√			√					(Fan, 2016)
	Future Science Town	2015	√		3.98	R	4	14.95	3.9	√	√	√	√			√					(Beijing General Municipal Engineering Design & Research Institute, n.d.-b; Yingming Liu, 2016; D. Zhou & Li, 2015)
	Laiguangyingbeilu			√	2.10					√			√					√			(Official website of Beijing Expo 2019, 2017)
	New airport highway	2019		√	36.00					√	√	√	√					√			(Z. Cao, 2017b)
	Shijingshan District			√	1.50					√	√	√				√					(Xin, 2018)
	Tongzhou canal		√		2.30	R	3	14.15	2.8	√	√	√	√			√			√		(Beijing General Municipal Engineering Design & Research Institute, n.d.-c; Beijing Traffic Management Bureau, 2014)
	Tongzhou District			√	3.80					√	√	√	√					√			(CHINAUTIA, 2018b)
	Wangfujing commercial area			√	1.80																(R. Xiao, 2004)
	Winter Olympics Yanqing area	2019		√	7.50					√	√	√	√								(Z. Cao, 2017b)
	Zhongguancun	2005	√		1.90	R	5	13.9	2.2	√	√	√	√			√		√			(Guan, 2009; Su, 2007; R. Xiao, 2004; Zhong et al., 2006)
Changchun	Dongsanhuanlu			√	1.20																(China Government Procurement Net, 2016)
	Haoyuedalu			√	4.41																
	Hedong Road			√	6.50					√	√	√									(China Government Procurement Net, 2016; Z. Yang, 2016)
	Linhe Road			√	5.50																(China Government Procurement Net, 2016; Zhongqing Construction Group Company Ltd., 2016)
	South new town			√	5.25																(China Government Procurement Net, 2016)
	Tengfeidalu	2017	√		4.80																(China Government Procurement Net, 2016; Z. Li, 2017)
Chengdu	Riyuedadao			√	5.70	R	4	13.00	3.00	√	√	√						√			(Huaxi City Daily, 2017)
	Chengluodadao			√	4.44	C	4	9.00	9.00	√	√	√						√			(Huaxi City Daily, 2017)
	Xinchuandadao	2017	√		4.30	R	2			√	√	√				√					(Huaxi City Daily, 2017)
Chongqing	Banan District			√	10.00					√	√	√				√		√		√	(Chongqing planning and Natural Resources Bureau, 2017)
	Binjiang new town	2017	√		0.66	R	3	7.3	3.5												(Cqnews, 2017)
	Dianjiang County	2017	√		12.13					√	√	√			√			√			(Sina News, 2017)

City	Project name	Completion year	Phase: Completed	Phase: Construction	Length (km)	Shape	Number of compartments	Width (m)	Height (m)	Utilities housed: Electricity	Telecommunication	Water	Grey water	Condensed water	Sewage	Heating	Cooling	Gas	Refuse collection	Rainwater/drainage	References
	Liangping District			√	5.87		2, 3			√	√	√	√					√			(Yue Shi, 2017; Sina News, 2017)
Dalian	Airport Economic Zone			√	23.70																
	East Port (Donggang)	2017	√		10.25					√	√	√	√			√					(Dalian Donggang Business Area Government, 2018)
	New airport commercial area			√	21.60		1, 2, 3, 4														(Shenyang International Engineering Consulting Group, n.d.)
	Hekou Bay	2015	√		1.32			5.50	3.00												(Dalian High-Tech Industrial Zone, 2013)
	Suoyu Bay	2016	√		4.70					√	√	√	√			√					(Dalian Municipal Design & Research Institute CO., LTD, n.d.; Y. Yan, 2015)
	Xiaoyao Bay	2017	√		8.78					√	√	√	√			√					(China Government Procurement Net, 2017)
Datong	Beidujie			√	1.79					√	√	√	√		√	√					(Y. Gao, 2017)
Fuzhou	Pingtantanxidadao			√	10.00			4.90	3.20	√	√	√									(W. Shi et al., 2015)
Guangzhou	Guangzhou Higher Education Mega Center	2004	√		17.40	R	2	7.0	2.8	√	√	√					√				(CHINAUTIA, 2017; X. Ding et al., 2010; Jiangbo Wang & Gou, 2011; J. Zhang, 2016)
Hangzhou	Hangzhou station square	1999	√		1.10	R	2	6.55	2.10	√	√	√			√	√					(Ye, 2001)
Harbin	First phase	2016	√		25.50					√	√	√				√		√			(CCTV, 2017; Harbin Municipal People's Government, 2016)
	Second phase			√	43.80																(Heilongjiang Daily, 2017)
Kunming	Kunluo Road			√	23.00			3.70	3.05	√	√	√									(W. Shi et al., 2015)
Lianyungang	Xuwei new district			√	15.51					√	√	√	√			√		√			(Y. Li, 2018)
Nanjing	Hexi new district	2017	√		8.70	R	2	6.45	3.45	√	√	√				√					(S. Chen, 2016; Duan & Ni, 2017; Nanjing Hexi New Town Government, 2017; Y. Zhang, 2016)
							2	5.90	3.90	√	√	√				√					
							1	2.40	3.10	√	√										
							1	2.40	3.10	√	√										
	Jiangbei new district phase 1	2016	√		10.00					√	√	√	√		√	√		√	√	√	(Duan & Ni, 2017; Yi Shi & Zhang, 2016)
	Jiangbei new district phase 2			√	53.41					√	√	√	√		√	√		√	√	√	(Duan & Ni, 2017; X. Lu & Li, 2017; Qiu, 2018; Yi Shi & Zhang, 2016)
	Jiangning District		√		3.50																(A. Zhou & Jiang, 2017)
	Jiangxinzhou Ecological Science and Technology Island		√		1.00	R	1	3.90	2.90	√	√	√	√								(S. Chen, 2016)
	Pukou new town	2015	√		10.20	R	2	6.00	2.90	√	√	√									(Fan, 2016)
							1	2.80	2.90	√	√										(Fan, 2016; J. Zhou, 2015)
							1	2.40	2.90	√	√	√									(Fan, 2016)
	South new town			√	20.91																(Duan & Ni, 2017; Qiu, 2018)
Ningbo	East new town			√	6.00					√	√	√				√					(W. Shi et al., 2015)
Qingdao	Gaoxinqu Huaguan Road	2015	√		55.00	R	2	5.85	3.10	√	√	√	√			√					(Q. Chen, 2017; Geng, 2015; D. Yu et al., 2013)
Sanya	Haiyudongxian			√	7.67	R	1	5.45	5	√	√	√	√								(TMEDI, n.d.; Yanxiang Wang et al., 2016)
Shanghai	Anting New Town	2004	√		5.80	R	2	2.4	2.4	√	√	√						√			(Honghui Zhang, 2006)

City	Project name	Completion year	Phase: Completed	Phase: Construction	Length (km)	Shape	Number of compartments	Width (m)	Height (m)	Utilities housed: Electricity	Telecommunication	Water	Grey water	Condensed water	Sewage	Heating	Cooling	Gas	Refuse collection	Rainwater/drainage	References
	Shanghai Expo 2010	2010	√		6.40	R	1	4.5	3.75	√	√	√	*			√			*		(Lv, 2011; Q. Qian, 2017; K. Zhang, 2014)
							2	7.35	3.6												(Q. Qian, 2017)
	Shanghai Zhangyang Road	1994	√		11.50	R	2	5.9	2.6	√	√	√						√			(W. Liu, 2015; Jiangbo Wang & Gou, 2011; Wei & Meng, 1997)
	Songjiang new town			√	24.70					√	√	√			√			√		√	(Liberation Daily, 2018; Shanghai Municipal Government, 2016)
Shenyang	Hunnan new town	2012	√		22.30	R	1	2.60	2.40	√	√										(CHINAUTIA, 2016a; Ning & Xin, 2017; W. Shi et al., 2015; Yunbo Wang, 2017; Huilei Zhang et al., 2015)
	South canal			√	12.83	C	3	5.40	5.40	√	√	√	√			√		√			(LiaoShen Evening News, 2016; R. Xiao & Long, 2017)
	Tiexi new town			√	21.00	R	3	10.50	3.80	√	√	√				√		√		√	(Y. Han, 2015; Ning & Xin, 2017)
							5	15.30	3.80												
							2	5.90	3.80												
							2	6.70	3.80												
Shenzhen	Guangqiao Road	2013	√		5.50	R	2	9.00	3.60	√	√	√	*								(Zhuoru Chen, 2011)
	Shenzhen Dameisha-Yantianyou	2003	√		2.68	R	1	2.40	2.85		√	√			√			√			(H. Huang & Chen, 2002; W. Shi et al., 2015)
Suzhou	Chengbei Road	2017	√		11.50	R	4	9.1	5.5	√	√	√	√					√		√	(ARTS Group Engineering Consulting Co., Ltd, 2017; Yu Wang et al., 2016)
	Industrial park			√	17.00					√	√	√				√					(W. Shi et al., 2015)
	Sangtian Island	2016	√		7.79					√	√	√				√			√		(Suzhou Industrial Park Administrative Committee, 2016; Suzhou Municipal Government, 2017)
	Yueliang Bay	2011	√		0.92			3.4	3	√	√	√									(W. Shi et al., 2015)
Taiyuan	Jinyuandong District			√	10.41																(Y. Ding, 2016)
Tianjin	Baodi District			√	6.80	R	2			√	√	√				√					(Baodi District Government, 2016)
	Jinghai District			√	12.50					√	√	√									(Tonight News Research, 2017)
	Sino-Singapore Eco-City			√	14.50					√	√	√				√		√		√	(W. Li, 2017; Shanghai Urban Construction Design & Research Institute, n.d.)
	Yujiapu	2016	√		1.10					√	√	√				√					(China Guanjing Net, 2016)
Wenzhou	Oujiangkou new town phase 1	2019		√	13.00																(B. Yang & Wang, 2017)
Wuhan	Wangjiadun		√		6.00					√	√	√									(W. Shi et al., 2015)
Xiamen	Jimei Road		√		5.90	R	2	4.80	2.80	√	√	√	√								(CHINAUTIA, 2018a; G. Zhang, 2016)
	Jinzhong Road			√	5.54			3.00	3.40	√	√	√									(W. Shi et al., 2015)
	Lake Reservoir	2011	√		5.20	R	2	6.45	3.40	√	√	√	√								(Z. Gao, 2010; Z. Yan & Wang, 2017)
	Meishan Road			√	7.91	R	1	3.60	3.60	√	√	√	√								(Ziqiang Chen, 2014; G. Wang, 2019)
							2	5.80	3.40												
	Xiangan new airport			√	22.20	R	1,2,3			√	√	√	√		√			√		√	(CHINAUTIA, 2018a, 2018c; X. Wang, 2017; Weng, 2016)
	Xiangan South New Town	2018	√		14.33					√	√	√	√								(CHINAUTIA, 2018c; X. Wang, 2017)
Xi'an	Kunming Road	2017	√		3.74	R	5	12.00	10.90	√	√	√	√					√		√	(Y. Xiao, 2017)

City	Project name	Completion year	Phase		Length (km)	Shape	Number of compartments	Width (m)	Height (m)	Utilities housed											References
			Completed	Construction						Electricity	Telecommunication	Water	Grey water	Condensed water	Sewage	Heating	Cooling	Gas	Refuse collection	Rainwater/drainage	
Yuncheng	Zhongyinbeilu			√	2.23	R	3														(Qi, 2017; Yuncheng Planning Survey Bureau, 2017)
Zhengzhou	Zhengdong new district			√	17.28					√	√	√	√		√	√		√			(Yang Wang, 2018)
Zhuhai	Hengqin Island	2013	√		33.40	R	1	3.80	2.90	√											(L. Han, 2017; Yong Liu, 2018; Z. Liu, 2017; Pan, 2017; Q. Qian, 2017; W. Shi et al., 2015; Zhao, 2016) 117
							1	5.50	2.90		√	√	√	√							
							2	5.75	3.30	√	√	√	√	√							
							3	8.30	3.20	√	√	√	√	√							

Notes: “R”: Rectangular, “C”: Circular, “*” in “Utilities housed”: utilities to be installed in the future.

2.6 Regulations and standards of MUTs

Table 2-6 lists regulations and standards of MUTs in the world including Japan, China, and Singapore. The Japanese government issued a special act on MUTs in 1963 which is the first in Asia. This act mainly focused on the purpose of MUTs, construction and management, occupancy issues and cost sharing (Sugie, 2016). The main aspects are: (1) MUT planning based on the priority and importance of roads determined by the central and local governments. This planning should be released to the public. (2) Construction planning including MUT location, structure, utility selection, etc. (3) Occupancy issues: utility companies apply for utilizing MUT and the applications are vetted. (4) Technical standards of MUT construction and utility installations. (5) Cost sharing of MUT construction and operation (Shinichi, 2013; Shu, 2003). Design guidelines of MUT including design of cross-section, ventilation and disaster prevention facilities were issued in 1986 (Sugie, 2016).

Taiwan provincial government issued Enforcement Rules of Common Duct Act and Regulations on Cost Allotment of Common Duct Construction and Management in 2001, and published Design Standard of Common Ducts in 2003 (CPAMI, 2001a, 2001b, 2003). The Enforcement Rules of Common Duct Act mainly focuses on planning, construction, and management of MUTs and mandating the use of MUTs as well as penalties and appeals. Regulations on Cost Allotment of Common Duct Construction and Management define cost-sharing concepts among MUT owners and utility companies.

Chinese central government issued some guidelines of MUT projects before 2015 and issued Technical Code for Urban Utility Tunnel Engineering in 2015 (MHURD, 2015a). Guidelines for the Preparation of Urban Underground MUT Project Planning and Technical Specification for

Urban MUT Engineering was issued in 2015 (Song, 2016). Index of Investment Estimation of Urban Utility Tunnel Projects was issued in 2018 (MHURD, 2018). Technical Standard for Operation, Maintenance and Safety Management of Urban Utility Tunnel was issued in 2019. This standard includes mandating the use of MUT, requirements of inspections and management as well as penalties and appeals (Sohu, 2018). Technical Guidelines for Urban Utility Tunnel Construction Planning was issued in June 2019. This guideline consists of feasibility analysis, location selection, utility type selection, cross-section design, etc. (MHURD, 2019).

The Common Services Tunnels Bill was passed on March 2018 in Singapore. The Bill lays down the provisions including mandating the use of MUT, requirements of ancillary structures and penalties and appeals that will apply to MUT in Marina Bay and tunnels in the future ("Lawrence Wong on Common Services Tunnels Bill," 2018; Seow, 2018).

Table 2-6. Regulations and standards of MUTs

Country	Regulations and standards	Year
Japan	Special act on MUT	1963
	Design guidelines of MUT	1986
Taiwan, China	Enforcement Rules of Common Duct Act	2001
	Regulations on Cost Allotment of Common Duct Construction and Management	2001
	Design Standard of Common Ducts	2003
China (Mainland)	Technical Code for Urban Utility Tunnel Engineering	2015
	Guidelines for the Preparation of Urban Underground MUT Project Planning and Technical Specification for Urban MUT Engineering	2015
	Technical Standard for Supervision and Alarm System Engineering of Urban Utility Tunnel	2017
	Index of Investment Estimation of Urban Utility Tunnel Projects	2018
	Technical Standard for Operation, Maintenance and Safety Management of Urban Utility Tunnel	2019
	Technical Guidelines for Urban Utility Tunnel Construction Planning	2019
Singapore	Common Services Tunnels Bill	2018

2.7 Smart MUT system

MUTs should be used for a long period (e.g. 100 years). Therefore, the tunnel and the utilities inside should be monitored to improve maintenance and enhance the safety and security of the MUTs. With a clear awareness of MUT benefits, there is a high potential of MUT implementation that can contribute to the development of smarter, more sustainable and resilient cities. MUTs can be equipped with sensors for better and safer maintenance and management, consequently serving the functions of smart infrastructure systems of the future.

2.7.1 Risks of MUTs

MUTs have several safety and security issues (e.g. fire, water leaks, gas leaks and explosions, sabotage, etc.). MUTs can be easily accessed by workers for inspection and maintenance, therefore, reducing the maintenance costs. However, the multitude of users is a challenge in the management of MUTs (Afaneh & Shahrour, 2017; International Telecommunication Union, 2015). The nature of the utilities placed in MUTs makes them a target for a number of threats as shown in Figure 2-10.

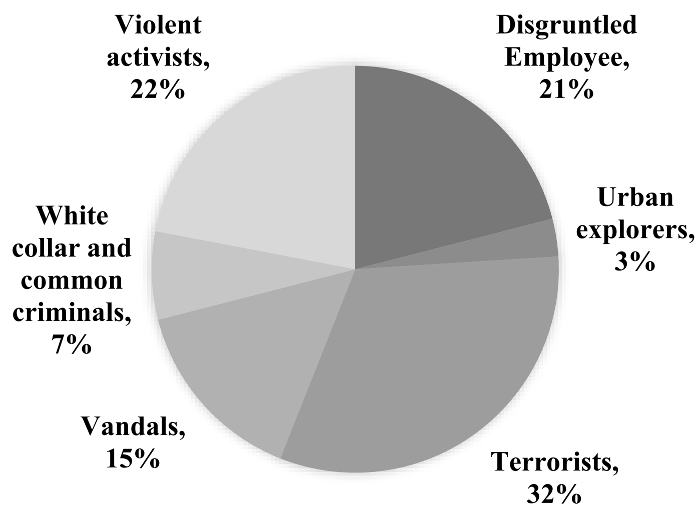


Figure 2-10: Possible Threats to MUTs (Julian Canto-Perello & Curiel-Esparza, 2013)

MUT risks are divided into two groups of natural and manmade risks. MUTs are susceptible to natural risks and hazards such as earthquakes, flooding, etc. Natural risks could also result from compatibility and safety issues. Placing some utilities close to each other could pose a high risk because of their incompatibility (Cano-Hurtado & Canto-Perello, 1999b; Hunt & Rogers, 2005). For example, housing of gas pipes and electricity cables together poses a potential fire risk (Julian Canto-Perello et al., 2009b; Julian Canto-Perello & Curiel-Esparza, 2001b; Legrand et al., 2004). Therefore, if a utility fails, the other utilities are in danger of damage (Hunt et al., 2014b).

Providing the security of MUTs from manmade attacks is another issue. To improve the security of MUTs, various solutions are suggested, such as limiting access doors, limiting access for people, and using sensors and surveillance systems (Julian Canto-Perello & Curiel-Esparza, 2013).

MUTs as a transport infrastructure are interdependent on several systems such as power supply, emergency services, etc. Their failure affects more than the safety but also has significant impacts on the economy and society at large. The costs of implementing monitoring systems are high. However, the costs of rebuilding or repairing the infrastructure and its equipment, as well as the economic and social costs, are much higher. As a result, sensing and monitoring systems are of vital importance to avoid infrastructure failures and help to design a more resilient structure (Q. Li et al., 2018; Mair & Yatteau, 2016).

To meet the challenges, a smart MUT system should be developed integrating: (1) security and monitoring systems including accurate locating; (2) alarm system including emergency response; and (3) operation and management system based on Geographic Information Systems (GIS), Building Information Modelling (BIM), IoT and other technologies (Shahrour 2017, Zheng, Wang, et al. 2016, Zheng, Luo and Wang 2017). Smart MUTs are adaptive structures equipped with sensors, actuators, and controllers with the use of data analysis and management systems.

2.7.2 Sensor Monitoring

Sensors ensure that smart MUTs operate at an optimal level. The sensors used to achieve this are either wired or wireless sensors. The decision on what sensor to use is determined by the sensory data to be measured, the distance of coverage, the number of sensors needed, accuracy and response time, etc. Both types of sensors have their pros and cons. In terms of reliability, wired sensors are relatively more reliable because the sensors are directly linked to the DAS receiving the sensory data, therefore no data is broadcasted, which can be intercepted or hacked. Wired sensors operate at a faster speed when compared to the wireless sensors, this makes wired sensors suitable for real-time sensing. However, considering the number of different systems/ subsystems and utilities hosted in MUTs, wired sensors require additional space and this could pose a challenge when maintaining the sensors. Wireless sensors offer more flexibility than wired sensors as they can be configured to meet specific requirements of MUTs. Wireless sensors are also relatively cheaper than the wired sensors and can cover wide monitoring areas. Notwithstanding, wireless sensors have a number of disadvantages such as the signal range is limited by obstructions, which results in inconsistency because of signal interference and this makes wireless sensors unreliable for real-time monitoring of critical systems. Loss of packets during data transfer and latency could also affect the speed of the data stream (Environmon, 2017; Flammini et al., 2009).

Different types of sensors serving different purposes can be embedded in MUTs, which transforms the MUT into a smart infrastructure. MUT monitoring can be classified into four types as shown in Table 2-7: (1) tunnel SHM: deformation, displacement, etc., (2) environmental monitoring: temperature, humidity, lighting, acoustics, air quality, air flow, water level, etc., (3) security monitoring: intrusion detection, surveillance cameras, fire detection, smoke extractors, and (4) utility monitoring: drinking water, sewage, electricity, heating, gas, etc. (Kang, Lin, & Zhang, 2018.; Shahrour 2017).

2.7.2.1 Tunnel SHM

Optical fiber sensors can be used in MUTs for monitoring structure deformation and displacement as shown in Figure 2-11. Optical sensors are placed in longitudinal and traverse directions as shown in Figure 2-12. The vertical and horizontal displacement due to adjacent excavations can be detected by the sensors (Nakano et al., 2011). The hydrostatic levelling system is a technique that is used widely in vertical settlement measurement (Shardakov et al., 2016; Yin, 2013). The vertical settlement of tunnels due to surrounding excavations can be detected by the hydrostatic levelling system (Yin, 2013). The hydrostatic levelling system used in a MUT is as shown in Figure 2-13.

2.7.2.2 Environmental Monitoring

Environmental monitoring includes sensors to detect temperature, humidity, oxygen, smoke, gas, fire, lighting, water infiltration, etc. Additionally, flood detection sensors may be used in MUTs to avoid hazards resulting from tunnel flooding, and to maintain wet and dry partitions as this will ensure the continuity of utility services (International Telecommunication Union, 2015; Shahrour et al., 2018). For example, a DHT11 temperature and humidity sensor and a PT550 analog ambient light sensor which detects the ambient light illuminance can be used in MUTs. The controller periodically fetches the sensor data and sends the data to the server which stores and processes the monitoring data (Figure 2-14). These sensors together create a “wireless sensor network” which was combined with BIM and provided a comprehensive view of MUTs (Kang, Lin, & Zhang, 2018). The DHT11 temperature and humidity sensor is an ultralow-cost sensor with 3 to 5V power, and good for 20-90% humidity with ±5% accuracy and 0-50˚C with ±2% accuracy. The body size is 15.5 mm × 12 mm × 5.5 mm which is very small. In addition, the low power consumption and accuracy on humidity calibration make it convenient to connect in a system (Adafruit, 2017). The ambient light sensor detects the light density and reflects the analog voltage signal back to the controller. The PT550 sensor is more sensitive to light than normal light sensors and the measurement range is from 1 to 6000 lx (Geemi, 2016; K. Kang et al., 2018).

2.7.2.3 Security Monitoring

The security issues include maintenance staff access control and prevention of intrusion, vandalism, sabotage, and terrorist attacks, which can be achieved utilizing visible and covert sensors. Surveillance cameras or other devices should be used for intruder detection as shown in Figure 2-15. Sign-in and sign-out procedures, access cards, or facial recognition systems can be used in MUT access control. In addition to entrances and exits, ventilation openings, manholes, escaping exits and entrances to lateral buildings should be monitored and controlled to avoid manmade risks (Julian Canto-Perello & Curiel-Esparza, 2013). Additionally, geo-localization systems can be used to track each person in the MUT as well as to track illegal intrusions (Shahrour et al., 2018).

2.7.2.4 Utility Monitoring

For utilities housed in MUTs, regular condition monitoring and hazard prevention monitoring should be applied. Water level, velocity, pressure and turbidity sensors monitor the regular conditions of water pipes and sewage pipes. Abnormal events can be detected according to the flow and water consumption (Hunaidi et al., n.d.; Stoianov et al., 2008) Leak detection and water quality detection are two other important monitoring aspects of water pipes monitoring. Acoustic vibration sensors are used for leak detection and locating leakages in water pipes (Jeffrey Yang et al., 2009). Multi-parameter water quality sensors such as Censar and Hach can be used to detect and acquire various water quality parameters. Conventional water quality sensors test contaminants including pesticide, herbicides, alkaloids, Escherichia coli, etc. (Finnish Energy, 2013; Shahrour et al., 2018). For sewage pipe inspection, laser profilometry sensors and ultrasonic-based sensors can be used. In addition, sewage gas leaks are serious problems causing corrosion, high operational costs and health risks. A drifting sensor can be used to detect sewage gas for preventive maintenance and repair (S.-C. Huang et al., 2007; M.-S. Kim & Lee, 2009). Gas leaks are serious to the MUT environment and can cause explosions especially when gas pipes and electricity cables are in the same tunnel compartments without barriers. Fiber optic in-line distributed sensors and acoustic wave sensors can be used for gas leakage detection (Finnish Energy, 2013; Yin, 2013). Temperature sensors can be used to detect the temperature of cables and heating pipes (Shardakov et al., 2016; Huilei Zhang et al., 2015).

Figure 2-16 shows one type of temperature sensors used on the cable tray to measure temperature (Senkox, n.d.).

2.7.3 MUT Control

2.7.3.1 Actuators

Actuators receive a control signal (electric current, pressure) and convert the signal into mechanical motion. Several actuators are used to accomplish different tasks in smart MUTs. Internet of Things (IoT) valve actuators use electric, pneumatic or hydraulic power sources to control valves. IoT damper actuators suppress the spreading of fires and smokes by controlling the airflow in HVAC systems. Distributed control monitors several independent actuator controllers from a single point to control actuators for access control and sprinklers (Cardenas et al., 2008). Access to restricted areas of MUTs can be controlled with switches and actuators, the switches send the control signal in the form of electric current to the actuators, which in turn physically change the state of an access point (open or close) based on if access is granted or denied by a security protocol. Sprinklers are also controlled by sensor/actuator pair(s). Smoke detectors detect and transmit signals to a control unit that sends a command to the switch, which in turn, sends an electric current to the actuator that triggers the sprinklers ON or OFF.

Table 2-7. MUT monitoring

Monitoring type		**Detection or Measurement**	**Example sensors**	**References**
Tunnel SHM		Deformation, displacement, etc.	Optical fiber sensors, hydrostatic levelling sensors	(Nakano et al., 2011)
Environmental monitoring		Temperature, humidity, lighting, acoustics, air quality, air flow, water level, etc.	Temperature and humidity sensors, ambient light sensors	(K. Kang et al., 2018)
Security monitoring		Intrusion, vandalism, sabotage, terrorist attacks, etc.	Surveillance cameras, Access cards	(Julian Canto-Perello & Curiel-Esparza, 2013)
Utility monitoring	Water pipes	Velocity, pressure, turbidity, water quality, pH, temperature, chlorine, conductivity, leakage, etc.	Acoustic vibration sensors, conventional water quality sensors	(Abbas et al., 2017; Hunaidi et al., n.d.; Jeffrey Yang et al., 2009; Shahrour, 2015; Shahrour et al., 2018; Stoianov et al., 2008)
	Sewage pipes	Water level, water flow, pressure, turbidity, water quality, leakage, etc.	Laser profilometry sensors and ultrasonic-based sensors	(Abbas et al., 2017; Duran et al., 2002; J. Kim et al., 2009)
	Gas pipes	Pressure, flow, leakage, etc.	Acoustic wave sensors	(S.-C. Huang et al., 2007; M.-S. Kim & Lee, 2009)
	Electricity cables	Temperature, current, voltage, tension, frequency, etc.	Temperature sensors	(Finnish Energy, 2013; Shahrour et al., 2018)
	Heating	Temperature, flow, pressure, etc.	Temperature sensors	(Finnish Energy, 2013; Shahrour et al., 2018)

Figure 2-11: Optical fiber sensor in a MUT (Nakano et al., 2011)

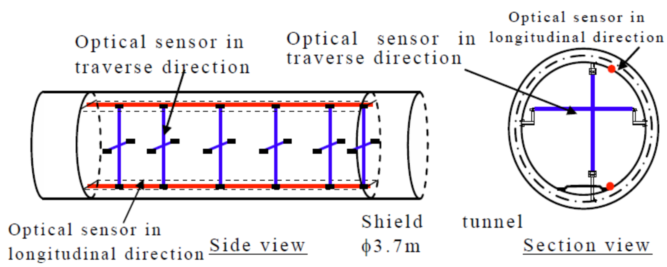


Figure 2-12: Installation of optical fiber sensors in side view and section view (Nakano et al., 2011)

Figure 2-13: Hydrostatic levelling system used in a MUT

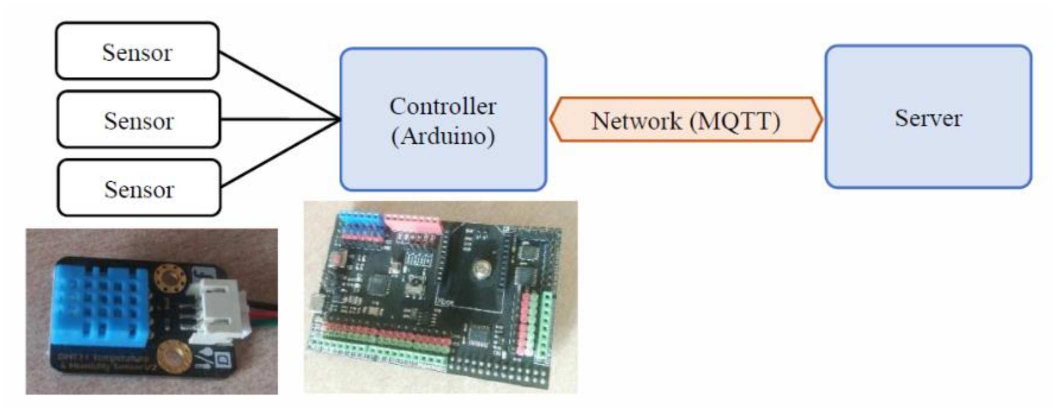


Figure 2-14: Monitoring devices and connection to the server (K. Kang et al., 2018)

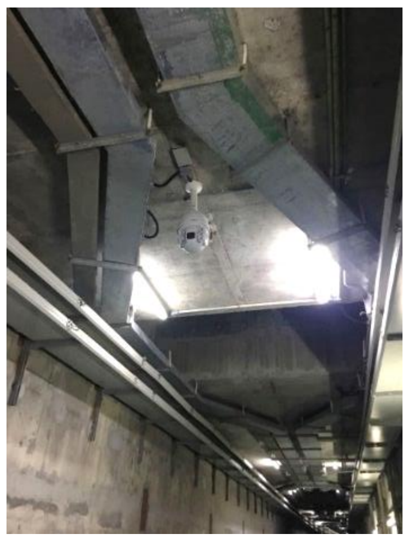


Figure 2-15: Surveillance camera in a MUT

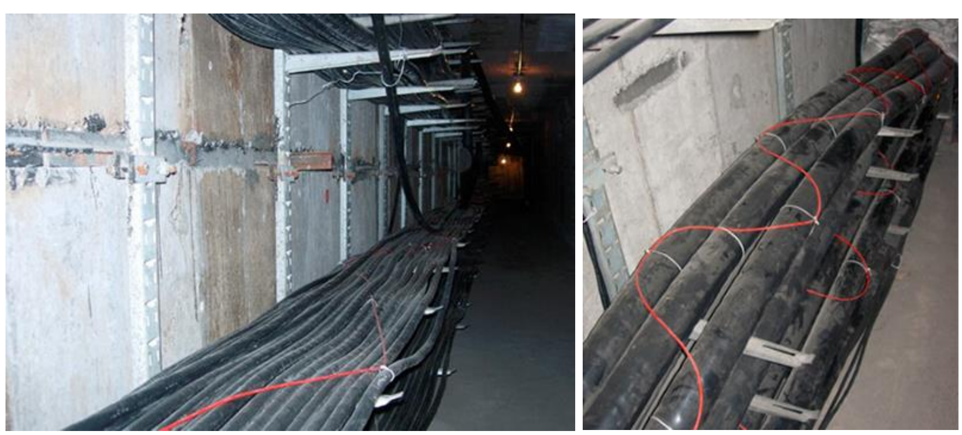


Figure 2-16: Temperature sensors for cables (Senkox, n.d.)

2.7.3.2 Inspection Robots

Inspection and maintenance of the existing MUTs are important for operation and management teams. Most of the tunnel inspections are still performed by human inspectors, but poor air quality and potential hazards can put inspectors in dangerous situations. Due to costs and mobility issues, inspection robots are used in infrastructure inspections instead of human inspectors; and can collect various types of data and access areas that are hard to reach. Tunnel inspection methods include visual, strength-based, sonic and ultrasonic, magnetic, electrical, thermography, radar, radiography, and endoscopy methods (Lattanzi & Miller, 2017; Montero et al., 2015). To collect various types of data, several types of sensors should be installed on the robots. A laser inspection system can be used to detect inner defects (Montero et al., 2015). Robots carrying cameras can work all the time. When in emergencies, robots can extinguish fires more efficiently than humans as shown in (Guancha Syndicate, 2017). Another type of inspection robot is equipped with high-definition cameras and thermal imaging lenses. With thermal imaging lenses, the robots can detect the temperature of cables and equipment and locate fires. In addition, the robots can be equipped with sensors for detecting gas, smoke, humidity, etc. to monitor MUTs at all times (Tetra, n.d.).

Figure 2-17. Inspection robots in the MUT (Guancha Syndicate, 2017)

2.7.4 DATA MANAGEMENT AND ANALYSIS

The majority of BIM adoption in civil infrastructure is for highways and bridges. Although it is transferable to tunnels and utilities, few studies are in the utility infrastructure sector especially MUTs (Alaghbandrad & Hammad, 2018; Bradley et al., 2016; K. Kang et al., 2018; Lee et al., 2018). In MUT lifecycle management, information losses are one of the main problems for optimizing efficiency and reducing costs (Shahrour 2017). Moreover, field workers can strike the underground pipes or break pipes only based on 2D maps. BIM is also a useful way for information exchange and intelligence (K. Kang et al., 2018; Poirier, 2016). 3D visualization will provide a useful way to avoid the problems which waste time and costs (R. Liu & Issa, 2012). BIM integrates all types of information in the entire life cycle of a structure and provides a meaningful way for data sharing (Eastman et al., 2008). BIM has four characteristics which are visualization, interoperability, simulation and optimization. It can also integrate physical parameters, location parameters and functional parameters of pipes, cables and equipment to store in one model, and achieve the integration of design, construction and management of MUTs to satisfy the visual monitoring requirements in 3D environment for MUT managers (Q. Li et al., 2018). The model of MUT can include the tunnel and housed utilities and connection of main tunnels to branch tunnels. It provides a wealth of information for all project stakeholders including utility companies, municipality, contractors, etc. It is also important that the construction process simulation and cost estimation can be provided via BIM (Alaghbandrad & Hammad, 2018). In addition, BIM can provide effective management platforms and tools for complex MUT maintenance and operation (K. Kang et al., 2018).

The large dataset of elements includes structural components of the tunnel and information of facilities such as pipes and cables. The utility elements have several attributes such as diameter, pressure, installation date, status, user, etc. In addition, the monitoring system, firefighting system, lighting system, drainage system, ventilation system, etc., should be added to the BIM model with manufacturer and security information. To sum up, the contents of the MUT operation and maintenance management system should consist of the following information: (a) structure information: tunnel BIM model including structure, dimensions, space, locations of facilities, entrances and exits and surrounding environment, (b) location information: start points, connection points and endpoints of pipelines and cables, (c) product information: dimensions, materials, manufacturer, installation date, etc., of pipes, cables and their equipment, (d) function information: classification of pipes and cables and security parameters, functions of monitoring facilities, and (e) management information: users and managers of utilities, maintenance records, security scheme, etc. (K. Kang et al., 2018; Q. Li et al., 2018).

A comprehensive MUT BIM model includes a utility tunnel structural model with utilities, equipment, sensors, and devices (Lee et al., 2018). Some MUT projects combine BIM, GIS and IoT technologies, and these technologies can solve the problems in the construction and management phases as well as improve the monitoring system (K. Kang et al., 2018). As shown in Figure 2-18, data collected from monitoring sensors through the sensor network and the message queue server transfers the monitoring data to the real-time monitoring system and monitoring data storage. The real-time monitoring system shows the current and historical data of the monitoring. In addition, the BIM data can be imported into storage and used by the real-time monitoring system for regular management and emergency management (K. Kang et al., 2018). Another emergency response system is based on UTDM model, which is an indoor geometric network model. Data collected from BIM is converted into the database of the operation and maintenance platform. After the combination of real-time emergency information input, an optical path plan is generated (G. Yu et al., 2019).

Attributes of BIM elements consist of Element ID Category ID, Category Name such as lighting equipment, electric wire, etc., Type ID, Element Name, etc. Element ID which is unique provides links to BIM and GIS information in the models. Sensors and devices also add monitoring data attributes to BIM models (Lee et al., 2018). As shown in Figure 2-19, the monitoring data will be collected by sensors and sent to the control system. The system will automatically search for rules related to elements according to Element ID in the database and compare whether the sensing data achieve the requirements of the rules. In this case, the related elements will be recognized as normal in the operating and management system and the data will be stored in the database as historical data. If the required conditions are not fulfilled, the system will search in the BIM database to extract related information and locate the related elements including parameters, location and surrounding environment information of utilities, and then warn the managers. The MUT manager will have element visualization with related information for decision making. In some scenarios, the MUT system will automatically respond to emergency situations. For example, pumps or ventilation systems will automatically start working when there is pipe leaking or when oxygen concentration is decreasing (Lee et al., 2018; Q. Li et al., 2018; Zhu, 2005).

A temperature and humidity sensor and an analog ambient light sensor were used in a meeting room (K. Kang et al., 2018), the colored area in the BIM model and in the floor plan (Figure 2-20) is the study area with sensors. The average of temperature, humidity and light and data according to time can be easily displayed in the system with the BIM model as shown in Figure 2-20. This framework can be also applied to MUTs. In addition, more sensor categories should be added such as gas and water level in MUT environment (K. Kang et al., 2018). Another smart MUT project integrated BIM, 3D GIS and sensors together to the management and operation system. GIS can provide geological information, which is essential to the management and operation of MUTs and underground spaces (Lee et al., 2018).

The comprehensive MUT BIM management system should have the following functions: (1) information inquiry of utilities and related equipment, (2) smart control of utility pipes and cables, (3) security alarm system, (4) monitoring system, (5) maintenance system, (6) emergency response simulation, (7) management of devices, and (8) administration management (Q. Li et al., 2018).

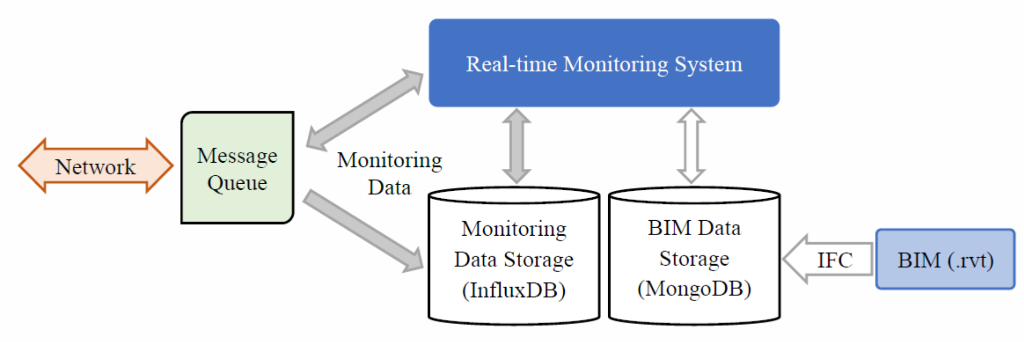


Figure 2-18: Server architecture design (K. Kang et al., 2018)

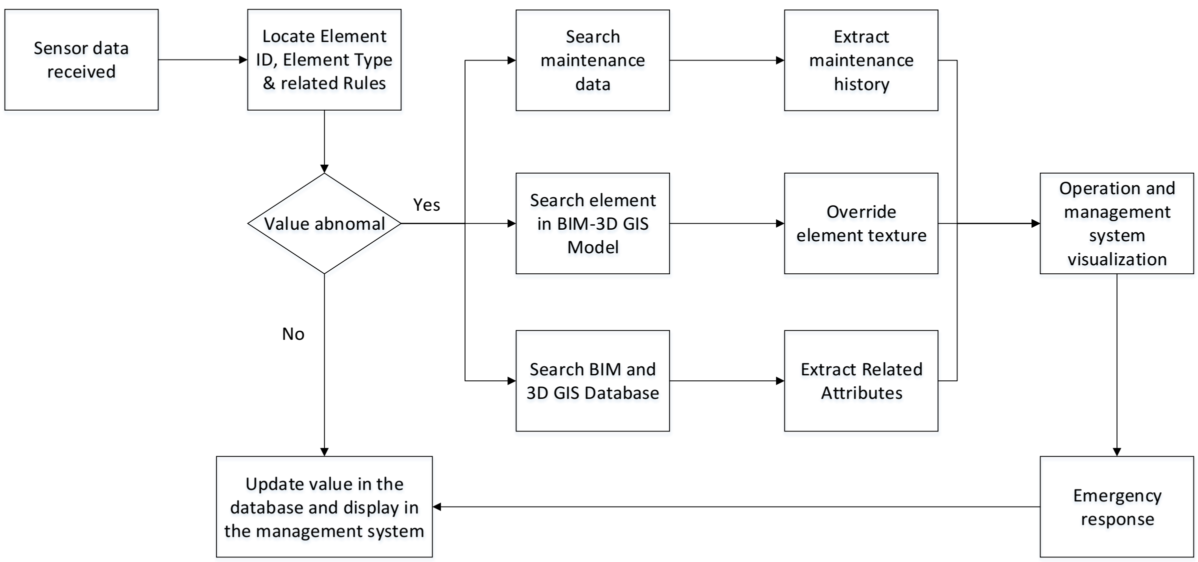


Figure 2-19: Process of integrating monitoring data (Lee et al., 2018)

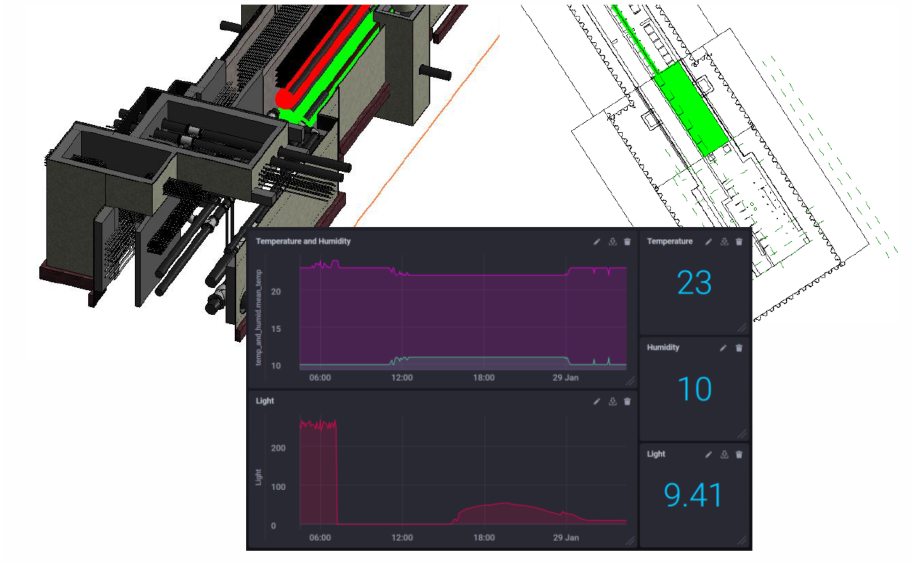


Figure 2-20: Temperature, humidity and light data in the BIM model (K. Kang et al., 2018)

2.8 Multi-criteria decision making for MUT planning

2.8.1 MUT Planning

MUT planning is a key factor of urban underground space (UUS) planning which is an important part of urban planning. Safety and security as well as sustainable development issues increase the complexity of MUT planning (Julian Canto-Perello et al., 2016).

MUT planning includes the following aspects (Peng et al., 2018):

1) Analyze the need and feasibility of MUT construction based on economics, population, land use, underground development, utilities, climate, geology, hydrology, etc.
2) Determine the aim, construction scale and areas.
3) MUT location selection and network design of various types of MUTs.
4) Utility type selection based on the feasibility of utility installation in MUTs.
5) Determine MUT compartment, cross-section design based on utility types, MUT scale, construction method and safety issues.

6) Determine the underground depth and location of the MUT with other underground facilities for better underground space usage design.
7) Design of the construction of MUTs with metro, underground passages, etc.
8) Design of ventilation, firefighting, electricity, lighting, drainage, supporting facilities, entrances, exits, etc.
9) Long-term MUT construction planning.
10) Cost estimation.

This thesis will mainly focus on location selection and utility type selection.

2.8.1.1 Location selection

Planning is an important phase for MUT projects. Several projects indicate MUTs can be built with other projects like traffic tunnels, commercial areas and sponge cities projects (Su, 2007). Route planning for MUT is complicated due to several factors which should be included in the planning phase, such as population, existing utilities, metro lines, road and utility reconstruction, excavation planning, etc. According to Jiang and Wang (2016), old city MUTs should consider the scale of existing cables and pipes including priority and quantity. The priority of utilities in the MUT should first consider main cables and pipes and utilities with high density.

According to DHURD. Liaoning (2016) and MHURD (2015), route planning factors are as follow: (1) main users (power plants, water plants), (2) main road intersections, intersections of roads and railways or rivers, (3) road attributes (road level, road width, roads which affect city landscape), (4) existing utility pipelines and cables, (5) metro lines, (6) road, metro and utility reconstruction and excavation planning, (7) land use and intensity (commercial, residence, industrial, vegetation etc.), (8) underground space utilization (underground complex, underground roads), (9) central area & important plaza, (10) population, (11) geological and hydrological conditions (slopes, precipitation etc.). All these factors are of vital importance since they are related to the city's conditions especially for old cities.

According to Zhang (2016) and Gao (2010), the planning of Xiamen MUT projects is based on the following factors: (1) the selection of locations in high density areas; (2) the planning of relocation of high voltage cables which need excavation; (3) the selection of locations with future metros or other underground planning.

Pilot city qualifications consist of: (a) high construction density areas with a population more than 200,000, (b) heavy transportation, (c) high demand of underground space development and utilization, such as for subways or cables, (d) MUT length more than 10 km, (e) utility types more than three, (f) suitable geological and hydrological conditions, (g) financial conditions and whether public-private partnership (PPP) investment model is reasonable, and (h) new areas at first and then old important areas (MHURD, 2015a, 2015c).

The overall MUT location selection is based on three aspects (Peng et al., 2018):

1) High density areas such as commercial areas, high density underground areas. This aspect can be represented by population density, land use, locations near public facilities and high-rise buildings, etc.
2) Areas with high traffic volume and high utility density.
3) Areas with construction or repairs of roads, utilities, metro, underground roads/passages, underground commercial areas, etc. This aspect can be represented by number of expected excavations of repair works, underground development projects, etc.

2.8.1.2 Utility type selection

For utility type selection, the priority is electricity, followed by pressure pipes (water, gas and heating) and gravity flow pipes (sewage and drainage). In addition, since telecommunication cables do not require much space, MUT should also consider the cables first (Ye et al., 2017).

According to Ye et al. (2017), utility type selection process is to determine which types of utilities should be placed in the tunnel and it is based on the utility needs. Water pipe selection is according to pipe diameter and number of pipes. For most cases, the chosen water pipe diameter is larger than DN 1200 (1200 mm). Electricity cable selection mainly refers to 110 kV and 220 kV cables since 500 kV cables are usually built outside the city center, and most of the projects are in the city central areas. China MUTs usually include water, electricity, telecommunication and grey water as common municipal cables and pipes.

However, for gravity pipes such as sewage and drainage, the slope should follow the slope of the terrain (Chen, 2014; He, 2016). As indicated in Table 2-8 and Table 2-9, the requirements for minimum slopes permitted for various sewage sizes are different. In general, the requirements are as in Table 2-8. However, sanitary sewages have higher requirements as in Table 2-9. For gas pipes, there should be a separate section with firefighting, emergency infrastructures and evacuation passages for safety reasons (Chen, 2014; He, 2016). They require high construction cost, which may lower the suitability of MUT. As a result, gas pipe selection is not only based on needs and technology, but also on cost (Ye et al., 2017).

Table 2-8. Minimum slopes permitted for various sewage sizes in general (City of Edmonton, 2015)

Sewer Size	Minimum Slope
200 mm	0.40%
250 mm	0.28%
300 mm	0.22%
375 mm	0.15%
450 mm	0.12%
525 mm	0.10%
600 mm	0.10%

Table 2-9. Minimum slopes permitted for sanitary sewage sizes (City of Edmonton, 2015)

Sewer Size	Minimum Slope
200 mm	0.40 %
250 mm	0.31 %
300 mm	0.25 %
375 mm	0.18 %
450 mm	0.15 %
525 mm	0.13 %
600 mm and larger	0.10 %

2.8.2 Multi-criteria decision making

Multi-criteria decision making (MCDM) is one of the best-known branches of decision making (Triantaphyllou, 2000). MCDM can be divided as multi-objective decision making (MODM) and multi-attributes decision making (MADM). Objective can be referred to alternatives, and attributes can be referred to decision criteria. Decision criteria indicate the dimensions for which alternatives can be evaluated. Criteria can be arranged as a hierarchy structure. Sub-criteria may have conflicts with other sub-criteria (Triantaphyllou, 2000). In this thesis, criteria are of the same level. Sub-criteria are calculated by specific formulas and no need to evaluate sub-criteria.

MCDM has criteria and alternatives as a hierarchy structure and usually needs to define weights for each criterion to have a ranking of all criteria for alternative evaluations. The methods of MCDM include the weighted sum model (WSM), the weighted product model (WPM), the analytic hierarchy process (AHP), the analytic network process (ANP), Delphi, ELECTRE, TOPSIS, multi-attribute utility theory (MAUT), multi-attribute value theory (MAVT), etc. Among them, AHP method is the most popular MCDM method in civil engineering (Jato-Espino et al., 2014; Triantaphyllou, 2000; Zavadskas et al., 2015).

2.9 Summary and conclusions

An obvious decrease in MUT construction in European countries can be observed in recent years (Hunt & Rogers, 2006; Laistner & Laistner, 2012). On the other hand, MUTs have a rapid development in Asian countries, especially in China; and some of the recent development of MUT projects in China were reviewed in this chapter. In China, several MUT projects have unique technological design which provide good case studies for other countries.

On the other hand, the US National Research Council report (National Research Council, 2013) mentioned the benefits and obstacles of MUT development in the US. The main obstacles include unavoidable investment abandonment of in-service utilities, operational liabilities concerns, safety issues in a shared utility environment (e.g., gas and electricity), administrative concerns about access of non-related people to MUT, and high initial costs. It was mentioned in this report that "The viability, value, and benefits of utilidors may be effectively communicated with (1) development of workable scenarios for secure multi-utility facilities; (2) development of workable scenarios for effective transitioning from current configurations; (3) lifecycle cost-benefit analyses comparing separate and combined utility corridors; and (4) demonstration projects. In the United States, utilidors have been built typically as part of major old and new developments or underground transportation improvements (e.g., Disney World in Orlando, Florida, with its extensive underground service “city” and the Chicago freight tunnel network). If the United States is to improve the sustainability of its urban utility services and preserve underground space for more cost-effective sustainability opportunities for future services, then this impasse needs renewed attention” (National Research Council, 2013).

With a clear awareness of MUT benefits, there is a high potential of MUT development in other countries that can contribute to the development of smarter, more sustainable and resilient cities. MUT can be equipped with sensors and firefighting systems for better and safer maintenance and management, and they can serve the functions of smart infrastructure systems of the future. This chapter also summarized the requirements of smart MUTs and related issues such as safety and security sensors, MUT control, and data management and analysis. The implementation of MUTs could reduce the need for excavations for utility maintenance and repair, which will inevitably reduce social costs and improve the quality of service by providing an environment for all-year-round maintenance. Utility owners benefit from the use of MUTs as utilities hosted in MUTs have a longer life span. MUTs are susceptible to risks such as natural risks and manmade risks. The use of sensors in smart MUTs reduces the need for human intervention in terms of monitoring, inspection and control. MUT control is achieved with the use of actuators and robots to improve the quality of service and reduce overall cost. Data collected from smart devices enable effective decision making and collaboration between utility owners and city planners. Smart MUTs are a vital component of smart cities as they improve sustainability and resilience.

MUT planning is a key aspect for underground sustainable infrastructure planning. Location selection is the most important aspect in the first phase of MUT planning to make the projects useful and cost effective. MUT location selection is based on three aspects including high density areas, areas with high traffic volume and high utility density, and areas with underground projects.

MCDM process is one of the best well known method for decision making. Among various methods for MCDM process, AHP is widely used in civil engineering projects to determine the weights of different criteria.

CHAPTER 3 COST ANALYSIS OF MUT PROJECTS AND A FRAMEWORK FOR SMART MUT SYSTEM

3.1 Introduction

This chapter provides a cost analysis based on the information of MUT projects in China. In addition, a framework for smart MUT system with the use of sensors and control devices is proposed in this chapter.

3.2 Cost Analysis of MUTs in China

Figure 3-1 shows examples of the tunnel lengths of completed MUT projects in China. The longest tunnel is in Qingdao which is 55 km, and it was completed in 2015. The years in project names on the x-axis are project completion years. Figure 3-2 indicates the tunnel length of example Chinese MUT projects under construction. The longest MUT is Nanjing Jiangbei New Area which is 53.41 km in one of the pilot cities, Nanjing.

The costs of MUT projects (Figure 3-3 and Figure 3-4) have been calculated according to the time value of money. The basic time value of money formula (J. Chen, 2018) is:

$$FV = PV \times (1 + i)^t \tag{3-1}$$

Where

FV = future value of money,
PV = present value of money,
i = interest rate,
t = number of years
Equation 3-1 is used to calculate the current construction cost. In this chapter, in order to calculate the time value of money in China, the interest rate of one-year (1.75%) (Bank of China, 2015) is

used. In addition, the unit costs are not calculated if the completion year is not known. The exchange rate of Chinese Yuan to Canadian Dollar used in this research is 1 Chinese Yuan equals to 0.20 Canadian Dollar. For the cost information, the costs may also include ancillary infrastructure construction cost (e.g. the three-level Beijing Zhongguancun project) and utility installation costs.

In Figure 3-3 and Figure 3-4, the highest MUT costs are in large cities, such as Beijing, Shanghai and Shenyang. Beijing and Shanghai are the two largest cities in China, and the MUTs with highest unit costs are mostly in the areas with high population density or in commercial areas. Shenyang City South Canal MUT project is in the old city area, and the construction has to go below two metro lines and under the expressway tunnel, which increases the construction difficulty and cost (Tao, 2017). More factors affecting MUT costs, such as the dimensions of the tunnel cross-section, number of utilities, depth, and construction method, are to be examined in the future.

Rental costs of MUTs in Suzhou City: year 1 - 75% by the government, 25% by utility companies, year 2 - 45% by the government, year 3 - 40% by the government (oral confirmation from an expert in Suzhou MUT company).

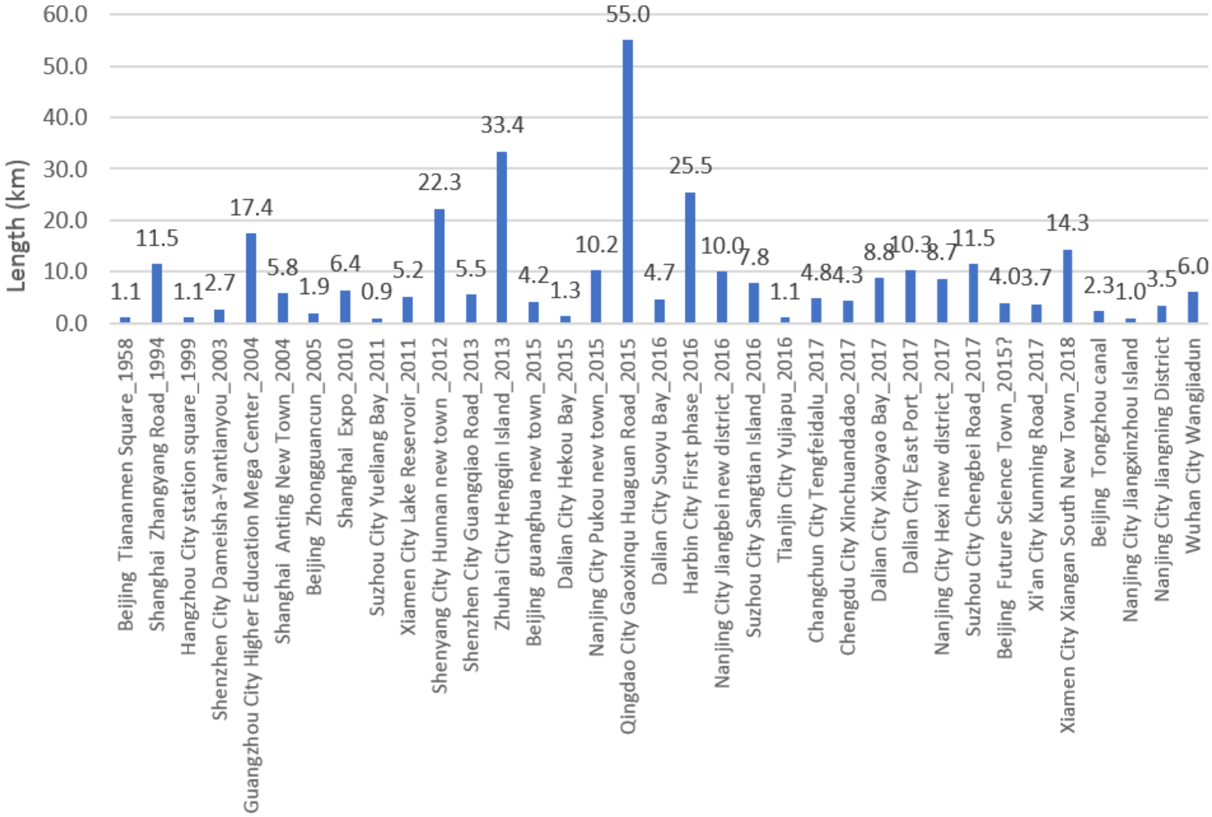


Figure 3-1. Length of completed MUT projects in China

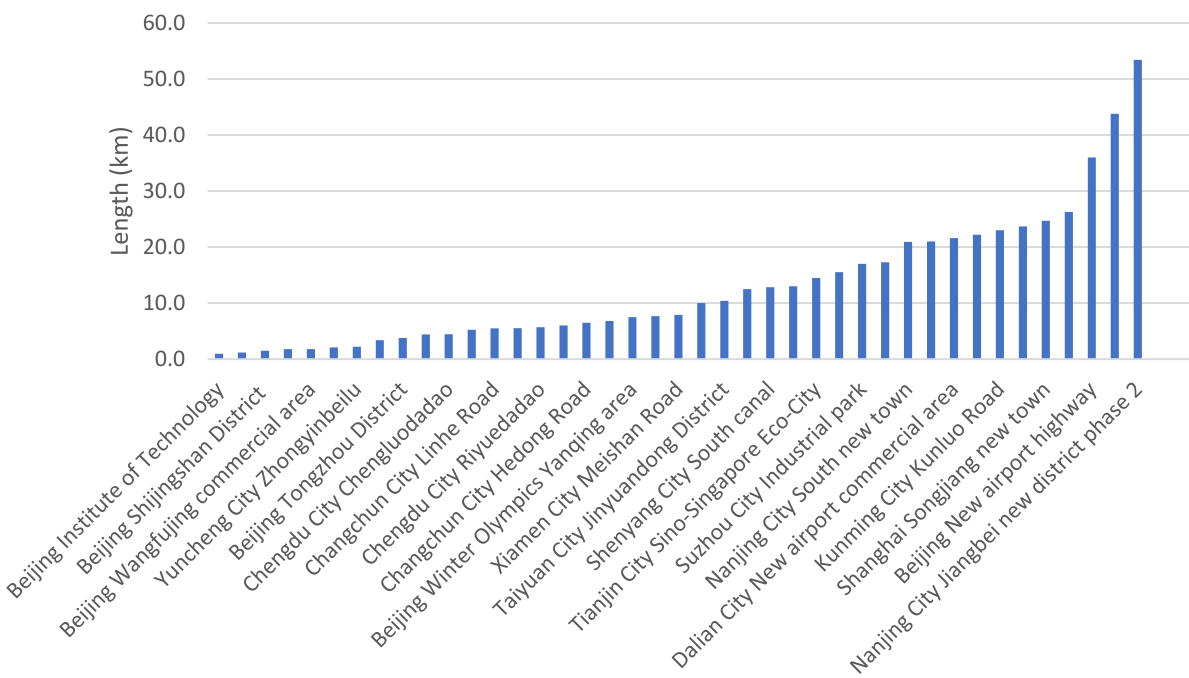


Figure 3-2. Length of MUT projects under construction in China

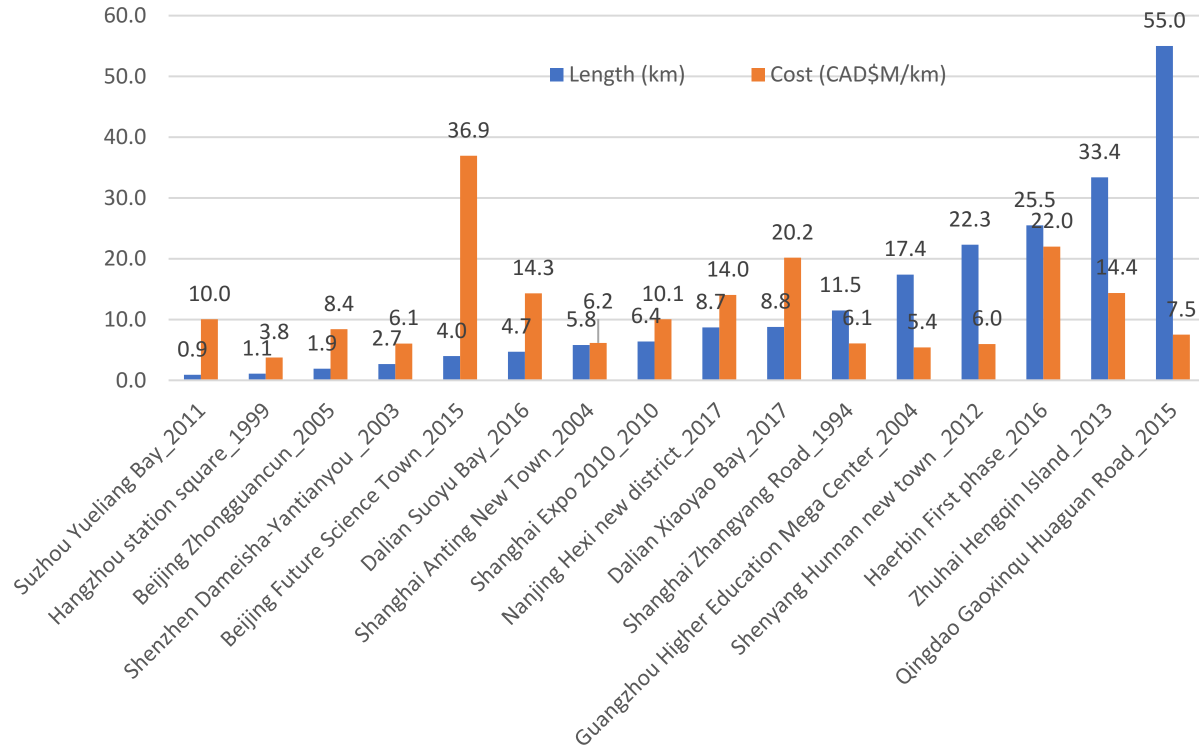


Figure 3-3. Cost of completed MUT projects in China

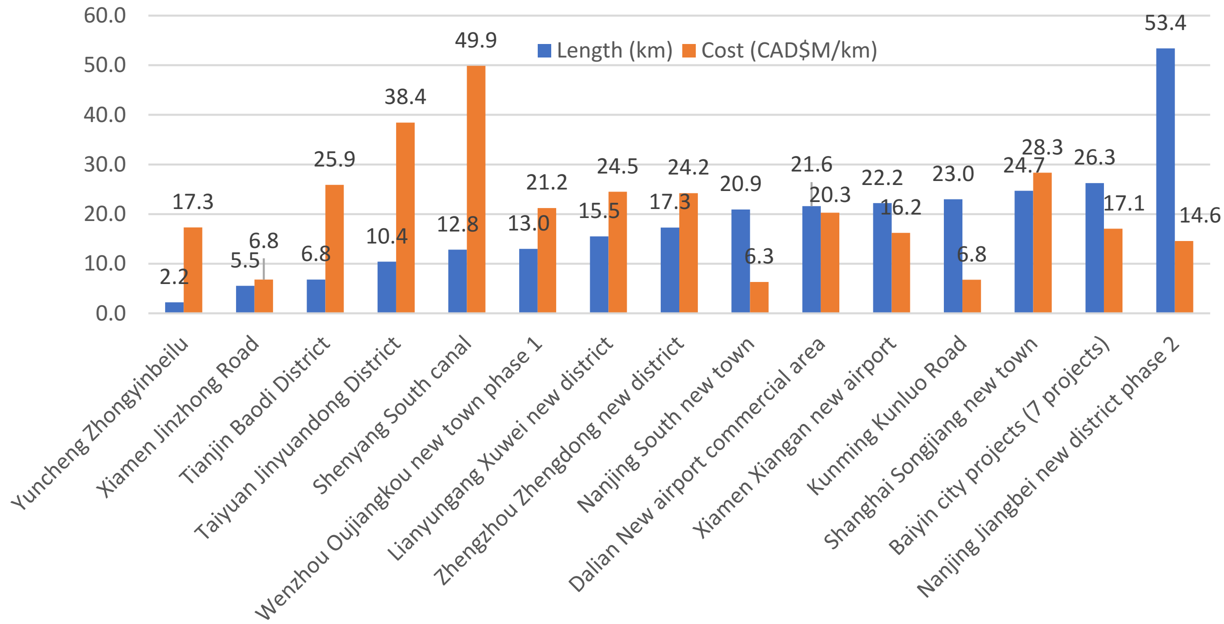


Figure 3-4. Costs of MUT projects under construction in China

3.3 Smart MUT system

Based on the review in Section 2.7 it is proposed that a smart MUT system should consist of modelling, sensing, control, analysis and management as shown in Figure 3-5. Modelling includes MUT Information Modelling (MUTIM), GIS and CityGML. MUTIM provides models of the tunnel, utilities, auxiliary services, light, HVAC and power. GIS and CityGML data are used for 3D geo-visualization. The comprehensive MUT model will support MUT users and operators for the design, construction, operation, geo-localization, maintenance, and management. Sensing includes sensors used for tunnel SHM, environmental, security, and utility monitoring. Control includes the control of ventilation, sprinklers, access (e.g., fire doors), valves, and switches based on actuators and robots. These are automatically controlled when in an emergency such as fires. All data gathered from sensors are analyzed with modelling and control information for system big data analysis using machine learning (e.g., deep learning), statistical analysis, etc. All information is sent to a management platform for MUT operation, inspection, health & safety monitoring, security monitoring, and emergency management. Smart MUTs provide a controlled and safe management for utility companies and MUT owners while supporting the development of a more effective, sustainable and resilient city.

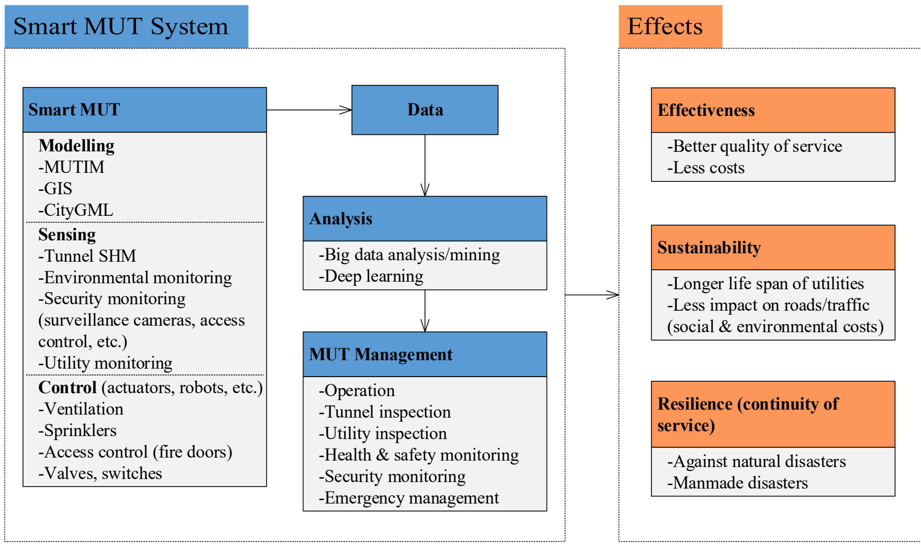


Figure 3-5: Smart MUT system

3.4 Summary and conclusions

From the cost analysis of MUT projects in China, the highest costs are mostly in short (below 10 km) and mid-length (around 15 km) MUT projects. Most high-cost MUT projects are in major cities such as Beijing, Shanghai and Shenyang which have more population density and more commercial areas. The construction difficulties also increase the MUT costs. More factors affecting MUT costs, such as the dimensions of the tunnel cross-section, number of utilities, depth, and construction method, are to be examined in the future. In addition, a framework for smart MUT system with the use of sensors and control devices is proposed in this chapter. Smart MUTs are a vital component of smart cities as they improve sustainability and resilience.

CHAPTER 4 MULTI-CRITERIA DECISION MAKING FOR MUT LOCATION SELECTION

4.1 Introduction

Location selection for MUTs is an important phase for MUT planning and it is complicated because it depends on several criteria, such as traffic volume and the density of the utilities. This research provides a general method for MUT location selection at different urban scales (e.g. street, district, borough) using Geographic Information System (GIS) spatial analysis. Multi-criteria decision making (MCDM) is used in this research to select potential MUT locations. The weights of the criteria are calculated using the Analytic Hierarchy Process (AHP) method. The AHP questionnaire is sent to experts in different industries (e.g. City of Montreal and Videotron) to collect the weights of the criteria.

4.2 Multi-criteria decision making

4.2.1 MCDM model

MUT location selection uses the MCDM model. As shown in Figure 4-1, the MUT location selection criteria are firstly determined based on Section 2.8.1 After data collection, the GIS data are preprocessed based on each road segment using operations such as joining tables, overlaying data layers and combining small segment. All data layers are normalized. Weights of the criteria derived from AHP method are used to calculate the comprehensive evaluation scores of the road segments. The comprehensive evaluation scores are ranked to select the potential road segments for MUT construction.

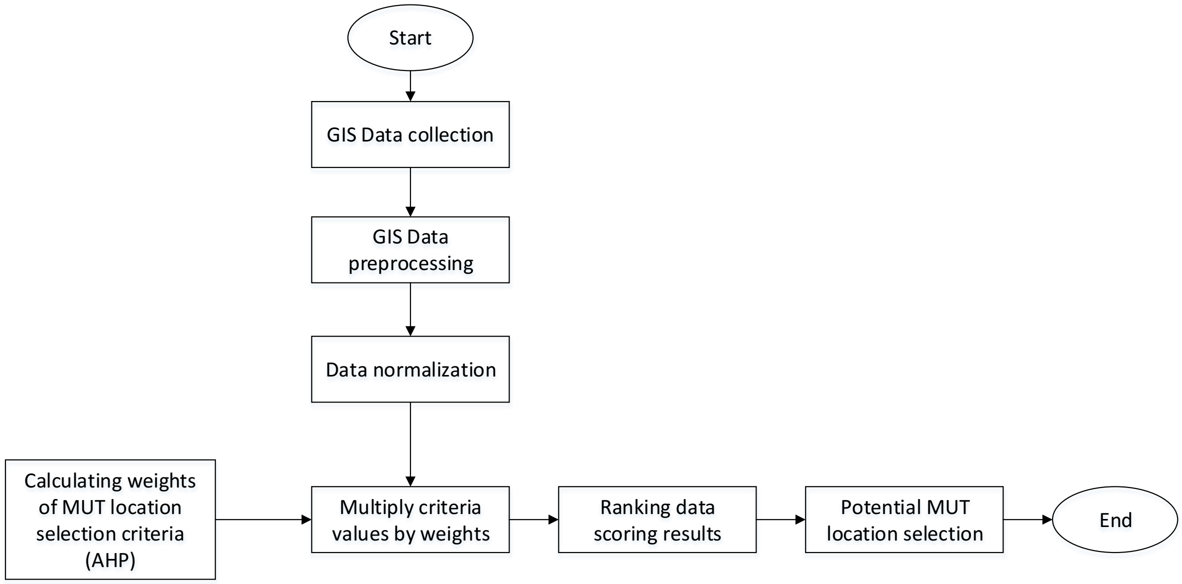


Figure 4-1. MCDM model

4.2.2 Criteria for MUT location selection

Based on the factors mentioned in Section 2.8.1 , the combined criteria for MUT location selection are listed in Table 4-1.

Table 4-1. Twelve criteria for MUT location selection

No	Criteria
1	Annual average daily traffic (AADT)
2	Road class
3	Utility density
4	Number of expected excavations for utility repair activities
5	Underground development projects
6	Population density
7	Land use
8	Near to public facilities
9	Near to high-rise buildings
10	Soil type
11	Slope of utilities

12	Flood plain

The first three criteria are related to high traffic volume and utility density. Criteria 4 and 5 are related to construction and repair works. Criteria 6 to 9 are related to high density areas. Criteria 10 and 12 are related to MUT construction difficulty. Criterion 11 is related to selecting utility types in MUTs.

1) Annual average daily traffic (AADT): MUTs would reduce the need for excavation for underground asset maintenance, and consequently, they will reduce the impact on traffic delays. Therefore, MUTs should be built under roads with high AADT.
2) Road class: Similar to AADT, MUTs should be built under higher class roads such as national roads, provincial roads, highways, etc.
3) Utility density: MUTs would reduce the frequency of excavation of repair and replacement activities for underground utilities. Therefore, MUTs should be built under roads with high utility density. Utility density includes:
   (1) Total number of utility pipes and cables, and
   (2) Level of utilities: selecting main utilities according to diameters of pipes, voltage of electricity cables, pressure of gas pipes, etc.
4) Number of expected excavations for utility repair activities: MUTs would reduce the need of excavations of utility repair activities. Therefore, roads with large number of excavations of utility repair activities have high priority to build MUTs. This criterion can benefit from two types of GIS data: (1) Historical number of excavations, and (2) Intervention plan of utilities and roads.
5) Underground development projects: MUTs can be constructed at the same time with underground development projects. Therefore, MUTs should be built under roads with new construction of underground passageways, metro line, malls, etc.

6) Population density: MUTs should provide services to areas with high population density to be cost effective.

7) Land use (commercial, residential, industrial, etc.): Areas with different land uses have different needs of MUTs, and they also reflect the number of potential users that do not show in the population density.

8) Near to public facilities (hospitals, universities and colleges, etc.): Public facilities have more users. MUTs built near to public facilities will be cost effective.

9) Near to high-rise buildings: Similar to criterion 8, MUTs should be built near to high-rise buildings because this will need to build lateral connections of MUT.

10) Soil type: Soil type affects MUT construction method and materials, and consequently, it may increase the costs. Therefore, MUTs should be built in the area with appropriate soil type.

11) Slope of utilities: MUTs should be cost effective. Including gravity-based pipes (i.e. sewage) inside the MUTs may increase the costs a lot, and consequently, slope affects utility type selection in MUTs. Therefore, slope of utilities is a factor for MUT location selection.

12) Flood plain: MUT construction in flood plain areas may highly increase the construction difficulties and costs. This is a basic condition for MUT location selection. Therefore, this will not be added to the questionnaire.

After considering the 12 criteria, the last four criteria have been reclassified. Flood plain areas should be considered before the MCDM process to decrease the costs and risks. Soil type affects the construction costs which should be considered after the MCDM process. Slope of utilities affects the selection of utilities (gravity-based pipes e.g. sewage) inside the MUTs which should also be considered after the MCDM process. Public facilities have buildings either with large scale or more floors which can be combined with high-rise buildings. As a result, there are main eight criteria to be considered in the MCDM process as shown in Table 4-2.

Table 4-2. Main eight criteria

No	Criteria
1	Annual average daily traffic (AADT)
2	Road class
3	Utility density
4	Number of expected excavations for utility repair activities
5	Underground development projects
6	Population density
7	Land use
8	Near to public facilities/ high-rise buildings

4.2.3 Spatial data

The study area used in this thesis is shown in Figure 4-2 within nine boroughs in Montreal including Ville Marie, Mercier–Hochelaga-Maisonneuve, Le Plateau–Mont-Royal, Rosemont–La Petite-Patrie, Outremont, Côte-des-Neiges–Notre-Dame-de-Grâce, Le Sud-Ouest, LaSalle and Verdun. The availability of GIS data is shown in Table 4-3. The information of each layer is shown in Table 4-4. Layers from the City of Montreal geomatique department include Hydro Quebec, gas, water and sewage networks. GIS data layers from Montreal open source data (highlighted in green) include roads lines, land use, and public facilities (health facilities, colleges and universities). The data types and useful attributes of each layer are shown in the table.

Figure 4-2. Study area

Table 4-3. Availability of GIS data

No	Criteria	Layers	Availability
1	Annual average daily traffic (AADT)		×
2	Road class	Roads	√
3	Utility density	Water, Sewage, Hydro Quebec, Gas	√
4	Number of expected excavations for utility repair activities	Roads intervention plan	√
5	Underground development projects	Project 2020-2030	√
6	Population density	Population density	√
7	Land use	Land use	√
8	Near to public facilities/high-rise buildings	Health facilities, colleges, universities	√
		High-rise buildings	×

Table 4-4. Information of GIS data

#	Type	Layer	Data Type	Useful Attributes	Layer Name in ArcGIS
1	Roads	Roads	Lines	Length, class, direction	Roads
2	Water	Water pipes	Lines	Diameter, material, length	AQU_SEGMENT_P_J_VM
3	Sewage	Sewages pipes	Lines	Diameter, material, length, installation date, DATEINSTALLPREC_REF, segment form, status, segment type, network type, RADIERAMONT, RADIERAVAL	ECO_SEGMENT_P_J_VM
4	Hydro Quebec	Electricity cables	Lines	Voltage, type (above ground/underground), length, description (main/branch/…)	HQ_ligne
5	Gas	Gas pipes	Lines	Diameter, material, length, pressure, installation date	Conduite
6	Intervention plan	Roads intervention plan	Lines		PIM_TRONCON_UNIFIE_L_J
7	Future city projects	Project 2020-2030	Lines		Projet 2020
8	Population	Population density	Polygons		borough_population
9	Land use	Land use	Polygons	Class, area	AffectationPU
10	Public facilities	Health facilities	Points	Type, agglomeration/metropolitain	EqSante
11		Colleges	Points		EqCollegial
12		Universities	Points		EqUniversitaire

4.2.4 Data normalization and scoring

4.2.4.1 Data with numeric values

Data with numeric values are normalized using Equation 4-1.

$$x' = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{4-1}$$

4.2.4.1.1 Annual average daily traffic

The AADT is the total volume of vehicle traffic of a road for a year divided by 365 days. Data normalization will be calculated directly using Equation 4-1.

4.2.4.1.2 Utility density

Utility density is calculated using Equation 4-2 and normalized using Equation 4-1. In Section 4.2.2 calculation of utility density includes two parts which are total number of utilities and level of utilities. As a result, the utility density uses total utility length based on utility levels per unit road segment length. The total utility length is calculated based on four types of utilities which are water, sewage, electricity and gas. Utility levels are based on diameter of pipes or types of cables. Level score is a score assigned to each utility level based on importance of utility levels.

$$UD = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} L_{ij} LS_{ij}}{l_r} \tag{4-2}$$

UD = Utility density of one road segment;
i=Number of utility types in the road segment;
j= Number of utility levels in one utility type;
L_{ij}=Length of different utility shapes;
LS_{ij}=Level score (based on diameter of pipes etc.);
l_r=Length of the road segment.

The level score of water, sewage and gas pipes are assigned according to the normalization of pipe diameter. The level score of electricity cables are assigned values from 0-1 based on experience. For example, in this research, the level scores for electricity cables are shown in Table 4-5.

Table 4-5. Level scores of electricity cables

Description	Count	Level Score
<Null>	65	0
Biphasé	18	0.6
Branchement	192088	0.1
Éclairage	444	0.5
Monophasé	13741	0.4
Neutre	1939	0.9
Non renseigné	532	0
Secondaire principal	133246	0.9
Triphasé	130042	0.7

4.2.4.1.3 Number of expected excavations for utility repair activities

Utility pipes and cables breakage rate should be used in this criterion to predict the total number of expected excavations for different types of utility repair activities. The pipe breakage rate is calculated using Equation 4-3 and normalized using Equation 4-1.

However, only the water pipe breakage rate is used to predict the number of expected excavations for utility repair activities because of the lack of GIS data.

$$\mathrm{NE} = \sum_{i=1}^{n}\sum_{j=1}^{m} BR_{ij} LS_{ij} \tag{4-3}$$

NE =Number of expected excavations for utility repair activities for one road segment;
i=Utility type in the road segment (1 to n);
j=Utility segment for each utility type i (1 to m);
BR=Breakage rate
LS=Level score (based on diameter of pipes etc.);

4.2.4.1.4 Population density

Population density is calculated using Equation 4-4 and 4-5 and normalized using Equation 4-1.

$$\text{Population density (PD)} = \frac{Population}{Area} \tag{4-4}$$

$$PD_T = \frac{\sum_{i=1}^{n} Length_i \times PD_i}{\sum_{i=1}^{n} Length_i} \tag{4-5}$$

The average population density is calculated by summation of PD_i multiply by the intersected length of road segments $Length_i$ and divided by the summation of $Length_i$.

4.2.4.1.5 Near to public facilities/high-rise buildings

This criterion is used to evaluate the number of public facilities and/or high-rise buildings MUTs can provide service for. If there are more public facilities or high-rise buildings which means more users, construction of MUTs will be cost effective.

This criterion is calculated based on the number of public facilities (points of health facilities, colleges and universities) and high-rise buildings (points) within a distance of the road segments and normalized using Equation 4-1.

The MUT planning is focusing on long-term MUT network planning, which include main MUTs and branch MUTs. The branch MUTs are used to provide service to nearby users. The MUT under one road segment between two intersections can provide services to the nearest blocks on both sides as shown in Figure 4-3. As a result, the buffer size of the road segments that have MUTs to public facilities and/or high-rise buildings is the average distance between two parallel roads which is average length of road segments. The average length of road segments in the study area is 128 m. This length will be used as the buffer size to calculate the number of public facilities and high-rise buildings near the road segments.

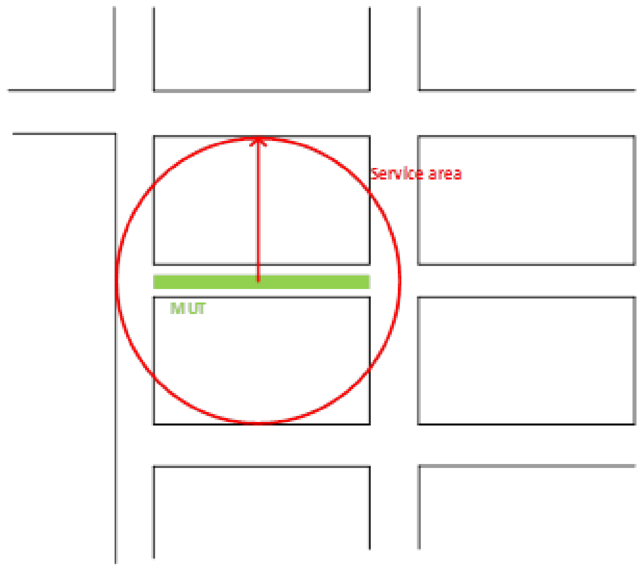


Figure 4-3. MUT service area

4.2.4.2 Data with categories

4.2.4.2.1 Road class

Scores of each road class are defined in

Table 4-6 based on importance level. The scores are assigned values from 0-1 based on experience. If there are more than one road class, the score of the road class can be calculated using summation of $Length_i$ multiplied by $Score_i$ and divided by the total length as Equation 4-6.

Table 4-6. Scores of road classes

Class	Class name	Scores
0	Rues locales (local roads)	0.5
1	Certaines voies piétonnières (pedestrians)	0.2
2	Places d'affaire (business places)	0.6
3	Quai (wharf)	0.1
4	Privée (private)	0
5	Collectrices (collectors)	0.8
6	Artères secondaires (secondary arteries)	0.8
7	Artères principales (main arteries)	1.0
8	Autoroutes (highways)	1.0
9	Rue projetée (projected street)	0.3

$$RC = \frac{\sum_{i=1}^{n} Length_i \times Score_i}{\sum_{i=1}^{n} Length_i} \tag{4-6}$$

4.2.4.2.2 Underground development projects

Scores of underground development projects are defined in Table 4-7. Roads with underground development projects are assigned to 1, and roads without underground development projects are assigned to 0.

Table 4-7. Scores of underground development projects

Underground development projects	Scores
Yes	1
No	0

4.2.4.2.3 Land use

Scores of each land use are defined in Table 4-8 based on importance level. The scores are in the range 0-1. Land use is calculated by summation of land use type score ($Score_i$) multiplied by intersected length with selected road segments ($Length_i$) divided by the summation of intersected lengths used as Equation 4-7.

Table 4-8. Scores of land use

Land use	Scores
Activites Diversifiees (Diversified activities)	1.0
Agricole (Agricultural)	0
Conservation (Preservation)	0.1
Emplois (Employment)	1.0
Infrastructure (Infrastructure)	0.7
Institution (Institution)	0.9
Mixe (Mix)	0.8
Parc (Park)	0.1
Religieux (Religious)	0.2
Residential (Residential)	0.6

$$LU = \frac{\sum_{i=1}^{n} Length_i \times Score_i}{\sum_{i=1}^{n} Length_i} \tag{4-7}$$

4.2.5 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) method is a measurement of the weights of different criteria. In this study, only one round of questionnaire can be sent to the experts who are extremely busy, so Delphi method is not suitable. This method can be carried out by a pairwise comparison matrix. The relative weights of criteria and alternative comparison can be calculated for MCDM. The AHP method is introduced by Saaty (1987). The steps include: (1) Creating a hierarchical model which consists of the goal, criteria, sub-criteria and alternatives, (2) A pairwise comparison for main criteria and sub-criteria, (3) Deriving the scale of weights and checking the consistency, (4) Ranking the options (R. W. Saaty, 1987; T. L. Saaty, 2008).

A pairwise comparison questionnaire was created to collect experts' opinions to define the weight of each criterion. The values of importance are defined in Table 4-9. The consistency index (CI) is calculated using Equation 4-8. The Random Index (RI) is 1.41 when number is criteria is 8. The Consistency Ratio (CR) is calculated using Equation 4-9 (T. L. Saaty, 1982).

Table 4-9. Value of importance definition in the AHP questionnaire (T. L. Saaty, 1982)

Value of importance	Definition	Explanation
1/9	extremely less important	One criterion is extremely less important than the other
1/7	very strongly less important	One criterion is very strongly less important than the other
1/5	moderately less important	One criterion is moderately less important than the other
1/3	slightly less important	One criterion is slightly less important than the other
1	equal	Two criteria are equal
3	slightly more important	One criterion is slightly more important than the other
5	moderately more important	One criterion is moderately more important than the other

7	very strongly more important	One criterion is very strongly more important than the other
9	extremely more important	One criterion is extremely less important than the other

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4\text{-}8)$$

$$CR = \frac{CI}{RI} \quad (4\text{-}9)$$

The AHP questionnaire and calculation is using an online software called AHP-OS (Goepel, 2018). AHP results from the questionnaire are shown in Table 4-10. This table shows the weights of the eight criteria from each expert. The last column is the consistency ratio of each expert between different criteria. The last two rows are average of criteria weights and consistency of weights between different experts. The three most important criteria from each expert are highlighted using different colors. From the AHP results, three most important criteria are utility density (24.46%), underground projects (18.63%) and number of excavations (16.24%). From the highlighted criteria for each expert, cable companies focus on utility density more than the City of Montreal. The City of Montreal focuses more on the underground projects; however, the results are more even on different criteria. The acceptable consistency ratio is depending on matrix size. Some researches used results with consistency ratio above 10%, and a few researches tolerated results with consistency ratio below 20% (Ho et al., 2005; T. L. Saaty, 1982; Wedley, 1993). As there are eight criteria which makes the AHP process complicated. The average weights are calculated based on results with consistency ratio below 20%.

The interviews with the City of Montreal, Hydro Quebec, Bell and Videotron provided understanding from different sectors' point of view for implementing MUTs in Montreal. The City of Montreal is responsible for water and sewage pipes which are much older than cables maintained by Hydro Quebec and private telecom companies. There are no high expectations for increasing needs of pipes in the future. The main issues are water and sewage pipe leakage. The cable companies including Hydro Quebec, Bell and Videotron use cable ducts underground. Among them, Bell has their own ducts, while Hydro Quebec and Videotron rent ducts from Commission des services électriques de Montréal (CSEM) at a low cost. The cable companies are satisfied with current situation of the use of the CSEM cable ducts which is unique in Canada. In addition, the work of burying cables from above-ground to underground is requested by the City of Montreal, and until now there are still up to 50% of cables above ground (mostly in suburban areas). Telecom companies push cables to the ducts and use access points for maintenance. As a result, there is limited or no need for excavations for repairs and maintenance. The cable repair or replacement works are often taken places when the City of Montreal has excavation works (e.g. road). Moreover, the cable companies are more focusing on connections to end users. The telecom companies have needs of data increase and 5G.

The comprehensive evaluation score can be calculated using Equation 4-10.

$$S = \sum_{i=1}^{n} w_i x_i \tag{4-10}$$

S: comprehensive evaluation score;

w_i: weight of evaluation criterion *i* ($0 \leqslant w_i \leqslant 1$, $\sum_1^n w_i = 1$);

x_i: value of evaluation criterion *i* ($0 \leqslant x_i \leqslant 1$);

n: number of criteria.

4.3 Summary and conclusions

This chapter provided a general method for MUT location selection based on GIS spatial analysis. Multi-criteria decision making (MCDM) is used in this research to select potential MUT locations. There are 12 criteria considered at first, and then the criteria were reduced to eight which are used in the MCDM process using AHP. The other criteria are to be considered before or after the MCDM process or combined with the eight remaining criteria. The weights of the criteria are calculated using the AHP method. Based on the AHP questionnaire results, among the eight criteria used in the questionnaire, the most important criteria for MUT location selection are utility density, expected number of excavations for utility repair activities and future underground development projects. The cases studies based on this method are explained in Chapter 5

Table 4-10. AHP results

Company	Expert	AADT (%)	Road class (%)	Utility density (%)	Number of excavations (%)	Underground projects (%)	Population density (%)	Land use (%)	Near to public facilities/high-rise buildings (%)	Consistency (%)
Hydro Quebec	A	10.33	2.39	35.73	15.41	7.67	20.34	4.46	3.66	15.96
	B	8.34	5.94	26.97	7.28	22.11	4.78	4.26	20.33	7.37
	C	4.12	2.50	26.91	8.52	36.18	12.23	6.23	3.31	18.12
Bell	D	5.52	5.52	40.27	16.06	10.51	5.52	2.42	14.19	8.66
	E	3.19	22.08	21.21	24.23	11.12	7.82	7.03	3.31	3.96
	F	30.04	16.14	6.50	6.50	10.99	6.01	18.89	4.93	8.00
	G	4.14	3.42	25.95	24.61	12.36	15.16	4.52	9.83	7.87
City of Montreal	H	10.67	2.11	9.02	22.59	35.52	7.51	9.95	2.63	9.91
	I	13.90	3.40	24.60	17.90	13.10	7.50	5.40	14.00	25.00
	J	14.53	21.76	10.17	14.38	32.25	3.71	1.47	1.73	11.39
	K	8.89	4.46	8.42	11.64	9.79	29.65	14.83	12.32	8.17
	L	5.45	10.32	19.49	8.65	21.43	4.00	25.63	5.04	4.26
Videotron	M	3.52	5.28	21.21	34.29	10.54	2.37	15.61	7.18	6.62
	N	12.63	6.38	35.68	7.73	2.55	26.32	4.23	4.47	8.88
	O	2.19	3.18	18.14	4.25	46.45	6.77	10.52	8.49	9.58
	P	2.98	3.30	32.37	21.50	24.22	3.39	3.39	8.85	3.99

CERIU	Q	16.60	7.40	14.80	16.60	30.60	1.70	7.50	4.70	46.00
	R	12.40	1.90	3.80	26.70	5.90	19.50	16.50	13.30	37.00
Average weights (%)		8.01	7.05	24.46	16.24	18.63	9.76	8.40	7.45	
Consistency (%)		6.86	6.41	10.89	8.31	12.55	8.46	6.67	5.15	

CHAPTER 5 CASES STUDIES

5.1 Introduction

This chapter provides 10 cases studies based on the general method developed in Chapter 4 In this chapter, 10 locations (as shown in Figure 5-1, Figure 5-2 and Figure 5-3) are selected to test the method which are in Ville Marie borough and three boroughs surrounding it. The selection of locations is mainly based on the topology of utility density since utility density is one of the most important criteria and the data gathered for this criterion is the most accurate. The lengths of the road segments are all around 200 m. The labels shown in Figure 5-2 and Figure 5-3 are the attribute "Segment ID" in Table 5-1. The total scores of each road segment are calculated using Equation 4-7. The score of each criterion is calculated as explained in Chapter 4 And the weights are the geometric mean from the AHP questionnaire results in Table 4-10.

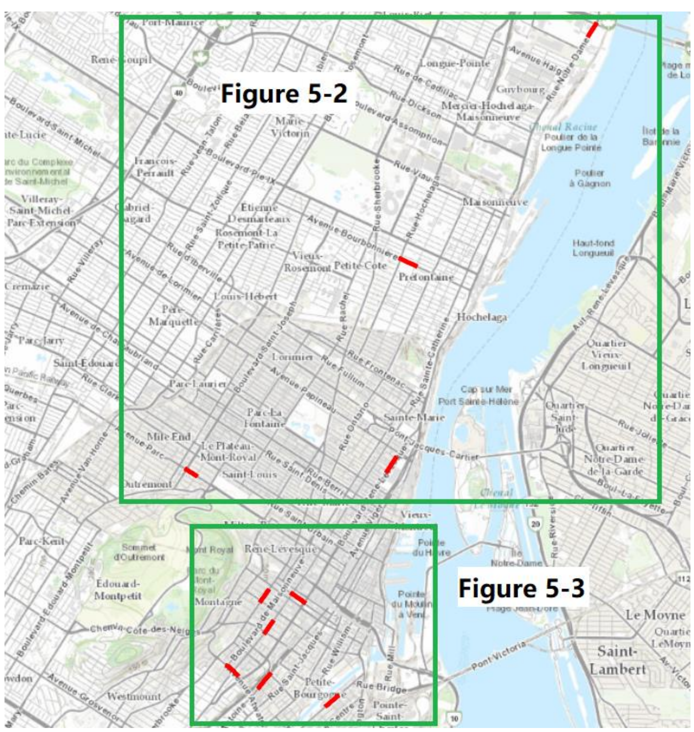


Figure 5-1. Road segments selected in the cases studies

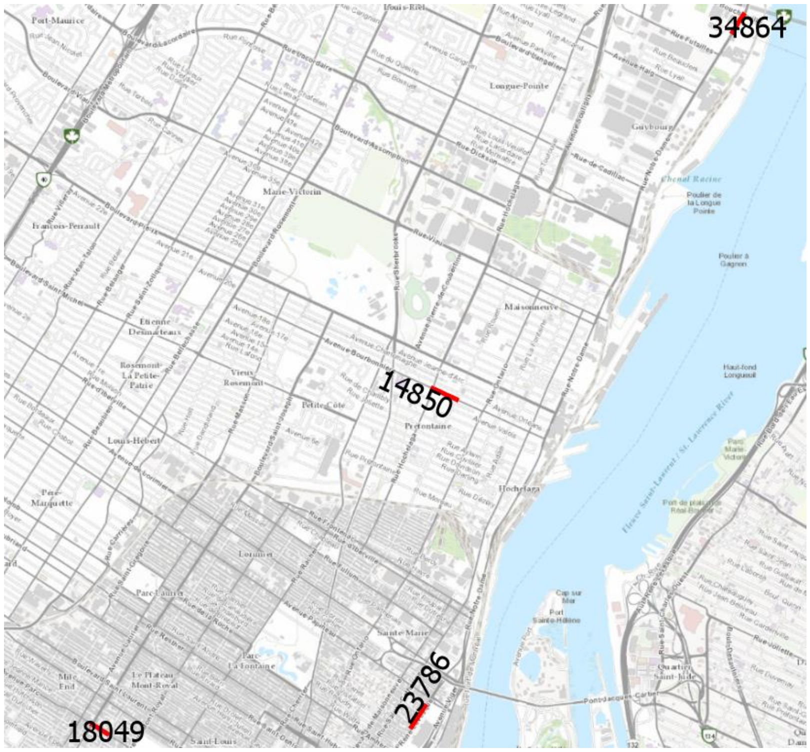


Figure 5-2. Four locations of the 10 locations

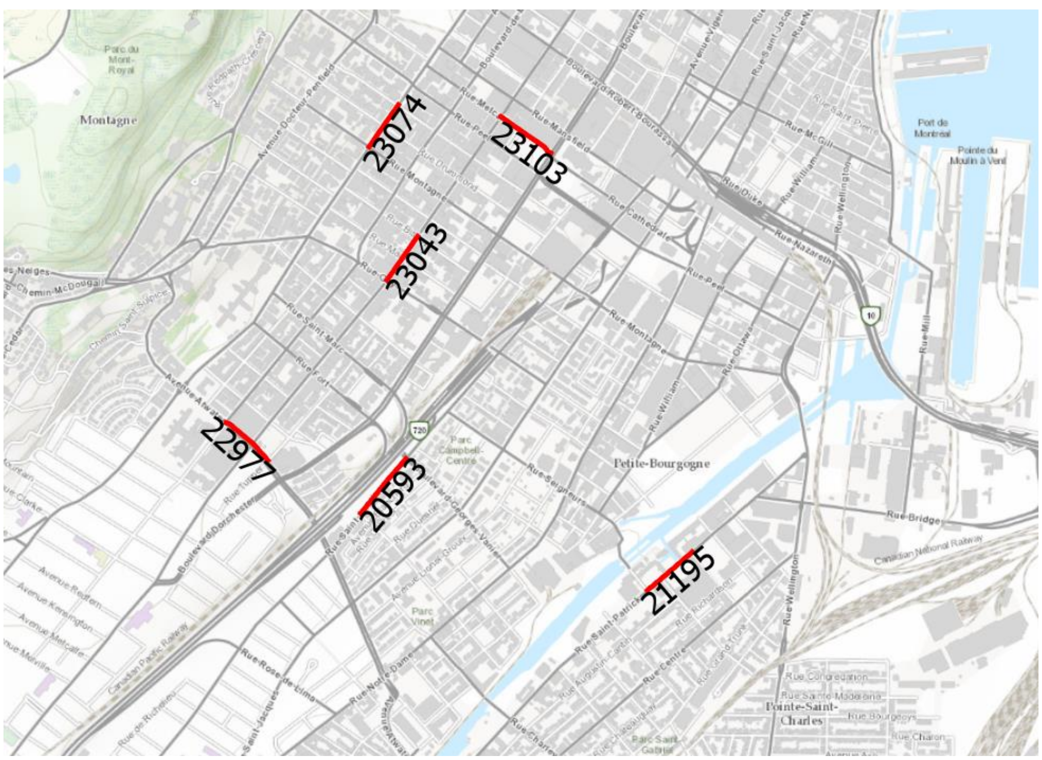


Figure 5-3. The other six locations of the 10 locations

Table 5-1. Information of 10 selected locations

Segment ID	Borough	Location	Length (m)
23043	Ville-Marie	Sainte-Catherine (Bishop to Guy)	205.48
23074	Ville-Marie	Sherbrooke (Stanley to Montagne)	196.49
23786	Ville-Marie	Rene-Levesque (Panet to De Champlain)	254.76
22977	Ville-Marie	Atwater (Tupper to De Maisonneuve)	217.90
23103	Ville-Marie	Metcalfe (Rene-Levesque to Sainte-Catherine)	239.32
20593	Le Sud-Ouest	Saint-Antoine (Georges-Vanier to Vinet)	272.85
21195	Le Sud-Ouest	Saint_Patrick (Privee to Seigneurs)	226.67
34864	Mercier–Hochelaga-Maisonneuve	Notre-Dame (Hector-Barsalou to De Boucherville)	208.89
14850	Mercier–Hochelaga-Maisonneuve	Bourbonnière (Rouen to Hochelaga)	267.83
18049	Le Plateau-Mont-Royal	Parc (Villeneuve to Saint-Joseph)	176.37

5.2 Data analysis

5.2.1 Annual average daily traffic

Because of the AADT data is unavailable, the scores of the selected road segments are assigned to 0.

5.2.2 Utility density

The utility density is calculated using Equation 4-2. At first, all utilities related to selected road segments are selected similar to the example shown in Figure 5-4. The level scores are assigned to each utility segment as indicated in Section 4.2.4.1.2 . The total score of each utility segment are calculated using level score multiply by length. The summation shown in the chart properties (blue highlighted) is the total length of selected utility type of selected road segment. Apply this to all utility types and to all selected road segments and normalize to have the total scores of this criterion of the selected road segments in the cases studies.

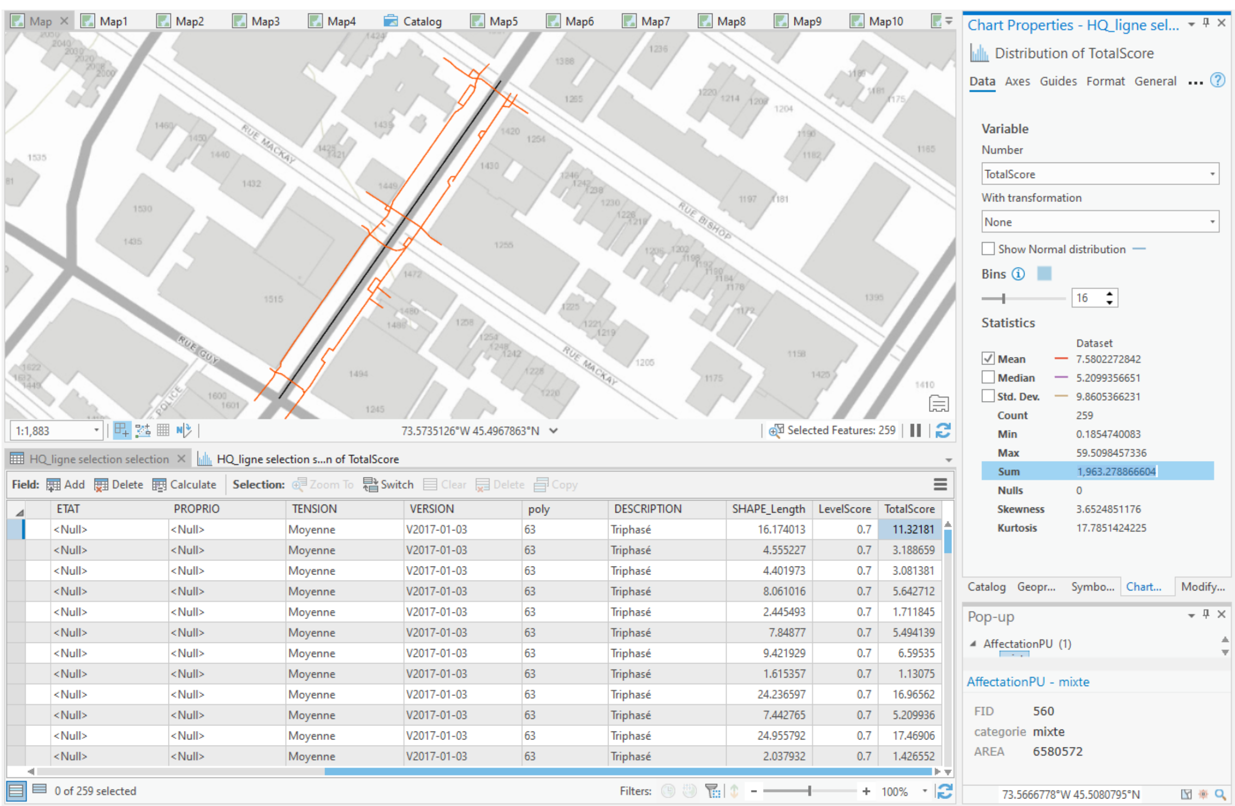


Figure 5-4. Utility density of electricity cables of road segment 23043

5.2.3 Number of expected excavations for utility repair activities

In the road intervention plan layer (PIM_TRONCON_UNIFIE_L_J), the water pipe breakage rate is indicated in the "Taux de bris max. (Nb/km/an)" column. This refers to the number of water breakage per km per year. Because of the lack of breakage rate data of other utilities, only water pipe breakage rate is used in the cases studies to predict the number of expected excavations for utility repair activities as shown in Table 5-2.

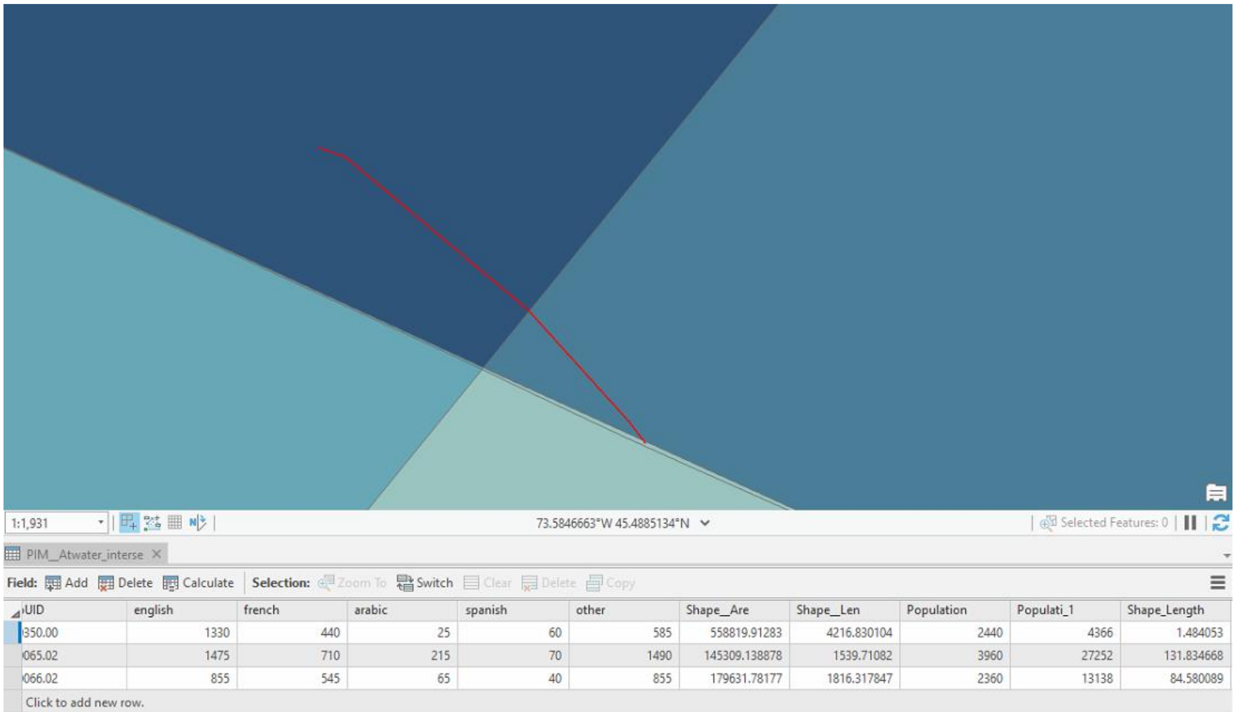
5.2.4 Population density

As shown in Figure 5-5, except road segments with ID 22977 and 21195, the other road segments are inside one population polygon or in between two population polygons. The calculation for road segments in between two polygons is the average of two population densities. For road segments 22977 and 21195, the population density polygons and the road segment are intersected and divide the road segments into two segments or more. The "Intersect" tool is used on road layer and population density layer to have the intersected lengths as shown in Figure 5-6. The population density is calculated using Equation 4-4 based on the last two columns in Figure 5-6. The average population densities are shown in Table 5-2.

5.2.5 Near to public facilities/high-rise buildings

The available layers for this criterion are health facilities, colleges and universities. Buffers of each road segment with a size of 128 m (Figure 5-7) are created to calculate the number of public facilities. Because of the lack of high-rise buildings data, only the number of public facilities is used in the case studies. The numbers are indicated in Table 5-2.

Figure 5-5. Population density



UID	english	french	arabic	spanish	other	Shape_Are	Shape_Len	Population	Populati_1	Shape_Length
350.00	1330	440	25	60	585	558819.91283	4216.830104	2440	4366	1.484053
065.02	1475	710	215	70	1490	145309.138878	1539.71082	3960	27252	131.834668
066.02	855	545	65	40	855	179631.78177	1816.317847	2360	13138	84.580089

Figure 5-6. Population density of road 22977

Figure 5-7. Buffer of road 23043 to calculate number of public facilities

5.2.6 Road class

In the roads layer, the values in the CLASSE attribute are used to calculate the score of this criterion using Equation 4-5. The values are shown in Table 5-2.

5.2.7 Underground development projects

Project 2020 layer is used with roads layers to indicate whether there are underground development projects intersected with road segments. If there are, the values are assigned to 1; if not, the values are assigned to 0. The values are shown in Table 5-2.

5.2.8 Land use

In this criterion, only road segment 23043 (Sainte-Catherine) intersects with two different land use polygons as shown in Figure 5-8, the other road segments are inside one land use polygon. The score of land use for road segment 23043 is calculated using Equation 4-6. The values of this criterion are shown in Table 5-2.

The scores of each criterion of the 10 selected locations are shown in Table 5-2. The scores after normalization and total scores after applying weights are shown in Table 5-3. Among the 10 selected locations, the total score of Sainte-Catherine is the highest. Part of the case study results are shown in Figure 5-9. The line thickness is based on the total score of each road segment.

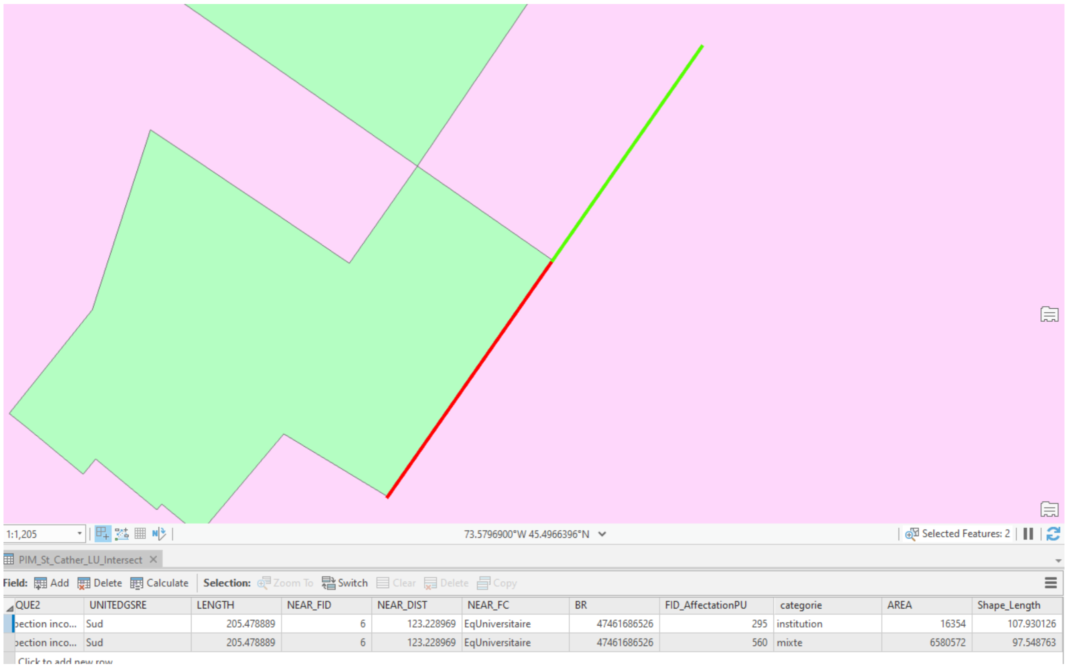


Figure 5-8. Land use intersection with road segment 23043

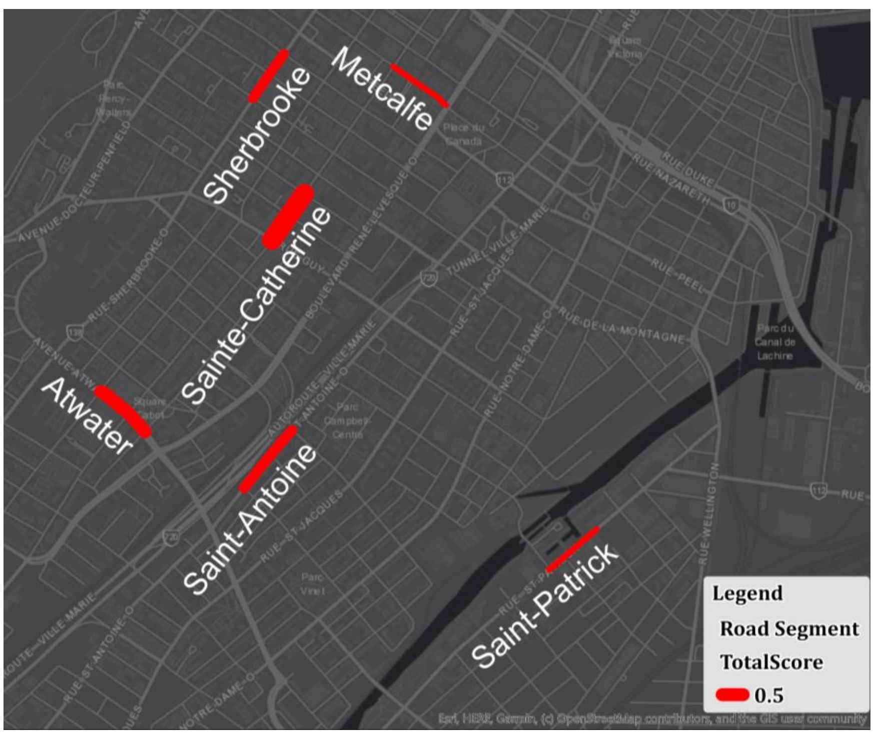


Figure 5-9. Case study results (part)

Table 5-2. Scores of 10 selected locations (before normalization)

	Sainte-Catherine	Sherbrooke	Rene-Levesque	Atwater	Metcalfe	Saint-Antoine	Saint_Patrick	Notre-Dame	Bourbonnière	Parc
Segment ID	23043	23074	23786	22977	23103	20593	21195	34864	14850	18049
Length (m)	205.48	196.49	254.76	217.90	239.32	272.85	226.67	208.89	267.83	176.37
AADT	0	0	0	0	0	0	0	0	0	0
Road class	5	6	7	6	5	6	6	7	5	7
Utility density	10.50	13.85	5.93	13.27	4.78	7.99	4.50	8.67	2.62	6.95
Number of excavations	4.75	0	0	0	0	2.53	0	0	0	0
Underground development project	1	0	0	0	0	0	0	0	0	0
Population density (person/km^2)	5712.50	9140.50	6235.50	21617.61	3217.00	13843.00	5953.00	848.00	9046.00	16271.59
Land use	0.83	0.80	0.60	0.80	0.80	0.60	0.80	1.00	0.60	0.80
Near to public facilities/high-rise buildings	1	0	0	1	0	0	0	0	0	0

Table 5-3. Total scores of 10 selected locations (after normalization)

	Weights (%)	Sainte-Catherine	Sherbrooke	Rene-Levesque	Atwater	Metcalfe	Saint-Antoine	Saint_Patrick	Notre-Dame	Bourbonnière	Parc
ID_TRC_PI		23043	23074	23786	22977	23103	20593	21195	34864	14850	18049
Length (m)		205.48	196.49	254.76	217.90	239.32	272.85	226.67	208.89	267.83	176.37
AADT	8.01	0	0	0	0	0	0	0	0	0	0
Road class	7.05	0.80	0.80	1.00	0.80	0.80	0.80	0.80	1.00	0.80	1.00
Utility density	24.46	0.76	1.00	0.43	0.96	0.35	0.58	0.32	0.63	0.19	0.50
Number of Excavations	16.24	1.00	0	0	0	0	0.53	0	0	0	0
Underground development project	18.63	1	0	0	0	0	0	0	0	0	0
Population density	9.76	0.26	0.42	0.29	1.00	0.15	0.64	0.28	0.04	0.42	0.75
Land use	8.40	0.83	0.80	0.60	0.80	0.80	0.60	0.80	1.00	0.60	0.80
Near to public facilities/hig h-rise buildings	7.45	1.00	0	0	1.00	0	0	0	0	0	0
Total score		**0.76**	**0.41**	**0.25**	**0.53**	**0.22**	**0.40**	**0.23**	**0.31**	**0.19**	**0.33**

5.3 Conclusion

From the cases studies, the differences of the most important criteria determined the results. Sainte-Catherine road segment has an above average utility density, the highest excavation number and is the only one that has underground development projects. As a result, this road segment has a total score of 0.76 which is 0.23 higher than the second highest road segment. Therefore, it is selected as the most suitable location for MUT placement among the ten locations. The results of the cases studies indicate that the proposed method of MCDM spatial analysis of MUT location selection is feasible based on various types of GIS data. In addition, the weights of the criteria should be determined by different experts in different areas to achieve unbiased results. Due to the lack of data, AADT data and high-rise buildings are not considered in the cases studies, and should be added in the future. The number of excavations should be based on more parameters.

CHAPTER 6 CONCLUSIONS AND FUTURE WORK

6.1 Summary and conclusions

An obvious decrease in MUT construction in European countries can be observed in recent years (Hunt & Rogers, 2006; Laistner & Laistner, 2012). On the other hand, MUTs have a rapid development in Asian countries, especially in China; and some of the recent development of MUT projects in China were reviewed in Chapter 2 . In China, several MUT projects have unique technological design which provide good case studies for other countries.

On the other hand, the US National Research Council report (National Research Council, 2013) mentioned the benefits and obstacles of MUT development in the US. The main obstacles include unavoidable investment abandonment of in-service utilities, operational liabilities concerns, safety issues in a shared utility environment (e.g., gas and electricity), administrative concerns about access of non-related people to MUT, and high initial costs. It was mentioned in this report that "The viability, value, and benefits of utilidors may be effectively communicated with (1) development of workable scenarios for secure multi-utility facilities; (2) development of workable scenarios for effective transitioning from current configurations; (3) lifecycle cost-benefit analyses comparing separate and combined utility corridors; and (4) demonstration projects. In the United States, utilidors have been built typically as part of major old and new developments or underground transportation improvements (e.g., Disney World in Orlando, Florida, with its extensive underground service "city" and the Chicago freight tunnel network). If the United States is to improve the sustainability of its urban utility services and preserve underground space for more cost-effective sustainability opportunities for future services, then this impasse needs renewed attention" (National Research Council, 2013).

With a clear awareness of MUT benefits, there is a high potential of MUT development in other countries that can contribute to the development of smarter, more sustainable and resilient cities. MUT can be equipped with sensors and firefighting systems for better and safer maintenance and management, and they can serve the functions of smart infrastructure systems of the future. This chapter also summarized the requirements of smart MUTs and related issues such as safety and security sensors, MUT control, and data management and analysis. The implementation of MUTs could reduce the need for excavations for utility maintenance and repair, which will inevitably reduce social costs and improve the quality of service by providing an environment for all-year-round maintenance. Utility owners benefit from the use of MUTs as utilities hosted in MUTs have a longer life span. MUTs are susceptible to risks such as natural risks and manmade risks. Under this circumstance, a framework for smart MUT system with the use of sensors and control devices is proposed in this chapter. The use of sensors in smart MUTs reduces the need for human intervention in terms of monitoring, inspection and control. MUT control is achieved with the use of actuators and robots to improve the quality of service and reduce overall cost. Data collected from smart devices enable effective decision making and collaboration between utility owners and city planners. Smart MUTs are a vital component of smart cities as they improve sustainability and resilience.

MUT planning is a key aspect for underground sustainable infrastructure planning. Location selection is the most important aspect in the first phase of MUT planning to make the projects useful and cost effective. MUT location selection is based on three aspects including high density areas, areas with high traffic volume and high utility density, and areas with underground projects. MCDM process is one of the best well known method for decision making. Among various methods for MCDM process, AHP is widely used in civil engineering projects to determine the weights of different criteria.

From the cost analysis of MUT projects in China, the highest costs are appeared mostly in short (below 10 km) and mid-length (around 15 km) MUT projects. Most high-cost MUT projects are in major cities such as Beijing, Shanghai and Shenyang which have more population density and more commercial areas. The construction difficulties also increase the MUT costs. More factors affecting MUT costs, such as the dimensions of the tunnel cross-section, number of utilities, depth, and construction method, are to be examined in the future. A framework for smart MUT system with the use of sensors and control devices is proposed in this research. Smart MUTs are a vital component of smart cities as they improve sustainability and resilience.

This research provides a general method for MUT location selection based on GIS spatial analysis. Multi-criteria decision making (MCDM) is used in this research to select potential MUT locations. There are 12 criteria considered at first, and then the criteria were reduced to eight which focusing during the MCDM process using AHP. The other criteria are to be considered before or after the MCDM process or combined with the eight remaining criteria. The weights of the criteria are calculated using the Analytic Hierarchy Process (AHP) method. Based on the AHP questionnaire results, among the eight criteria used in the questionnaire, the most important criteria for MUT location selection are utility density, expected number of excavations for utility repair activities and future underground development projects. Cases studies based on this method are explained in Chapter 5

From the cases studies, the differences of the most important criteria determined the final results. Sainte-Catherine road segment has an above average utility density, the highest excavation number and is the only one that has underground development projects. As a result, this road segment has a total score of 0.77 which is 0.26 higher than the second highest road segment. Therefore, it is selected as the most suitable location for MUT placement among the ten locations. The results of the cases studies indicate that the proposed method of MCDM spatial analysis of MUT location selection is feasible based on various types of GIS data. In addition, the weights of the criteria should be determined by different experts in different areas to achieve unbiased results. Due to the lack of data, AADT data and high-rise buildings are not considered in the cases studies, and should be added in the future. The number of excavations is based on only water pipe breakage rate to predict which may be inaccurate.

6.2 Future work

In Chapter 3, the cost analysis can be done by using more parameters such as cross section area, depth, construction method, materials based on more information of the MUT projects. The weights of the criteria should be determined by more experts in different areas to avoid bias when applying the MCDM spatial analysis to larger scales. This research used AHP to determine the weights of the criteria. However, some criteria may have interdependency issues such as road class and AADT, so in future studies Analytic Network Process (ANP) method can be used to avoid interdependency issues in AHP method (Jato-Espino et al., 2014). There are other MCDM methods which are depending on data instead of experts' opinion can be used in this kind of research. In addition, AADT data and high-rise buildings should be considered. The level scores used in utility density can be defined combining different attributes such as pipe diameters and types. Number of excavations should be defined combining the breakage rates of all types of utilities. There are also other methods to predict the number of excavations combining more attributes that can be used in the future study. When applying this method in larger area or in other places, other criteria may also be considered such as ground water level. In addition, more research on smart MUTs for safety issues and cost-benefit analysis including cost sharing model can be conducted in the future.

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APPENDICES

Appendix I. Examples of MUT Projects in China

7.1.1 MUT project in Hengqin, Zhuhai

This MUT is in Hengqin Island, Zhuhai City, which is near Macau and Hong Kong. Because of the central location of Hengqin Island in the south development area, the central government considers Hengqin as an important commercial development area. The MUT length is 33.4 km and was completed in 2013. It is one of the longest completed MUTs with a cost of about CA$400M (CA$12M/km) (Yong Liu, 2018). Hengqin Island has a large area of rivers and fish ponds with sludge as deep as 30 m. As a result, this project is one of the most complicated MUT projects in China (J. He, 2015). The MUT contains electricity, telecommunication, water, grey water, cooling, and garbage vacuum system. As shown in Figure 0-1, this project includes electricity tunnel and MUT tunnels with one to three compartments due to various needs. The cross-section area has several dimensions as shown in Figure 0-2 (Yong Liu, 2018).

As shown in Figure 0-2, the MUT with one compartment (a) contains telecommunication, water, grey water, cooling, and several sensors. The MUT with two compartments (b) contains electricity in the left compartment, and telecommunication, cooling, water and grey water in the right compartment. The MUT with three compartments (c) also contains electricity in the left compartment, water, and telecommunication in the middle compartment, and grey water and cooling in the right compartment. The MUT was built under the green belt with 2 m cover. There are also other utilities under the sidewalks and green belt such as heating, gas, sewage and storm water pipes, which are not included in the MUT. For the intersections, a two-level structure was built, with MUT at the top and electricity tunnel at the bottom (Yong Liu, 2018).

The layout of underground utilities is shown in Figure 0-3. MUT was built under the green belt with a two-meter cover. There are also other utilities under the sidewalks and green belts such as heating, gas, sewage and rainwater pipes, which are not included in the MUT, and some cooling and water pipes. For the intersections, a two-level structure with MUT at the top and electricity tunnel at the bottom was applied as in Figure 0-4 (Yong Liu, 2018).

In the design phase, clash detection was done in Navisworks which discovered 176 clashes in Huandao North Road before construction to avoid construction difficulty and decrease construction time. Tunnel optimization was also done in Navisworks which reviewed the structure design and operation space of pipes and stairs (Xie, 2015). In this phase, pipe adjustment in different views and pipe intersections can be done using BIM (Figure 0-5) (Y. Cao & He, 2016). During construction, building models using using Navisworks and 4D BIM with design drawings and surveying information provide an overall understanding of the construction planning monotoring (Figure 0-6) (Y. Cao & He, 2016).

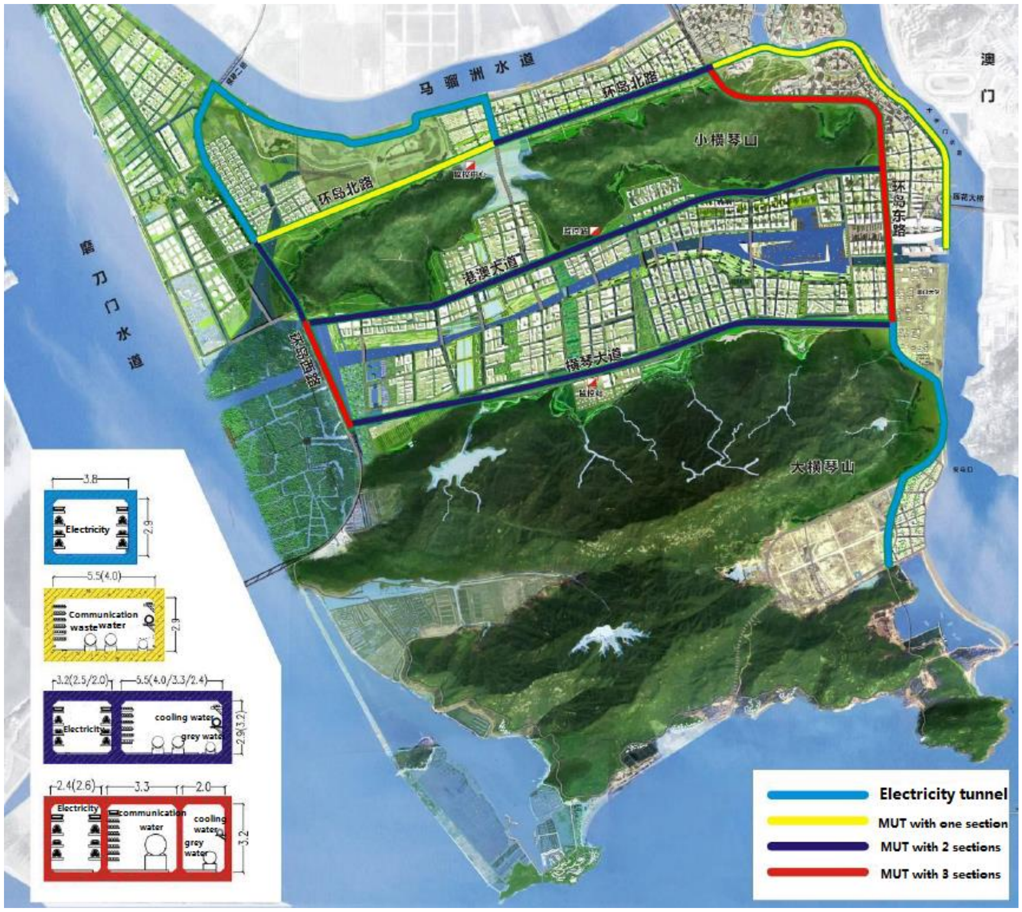
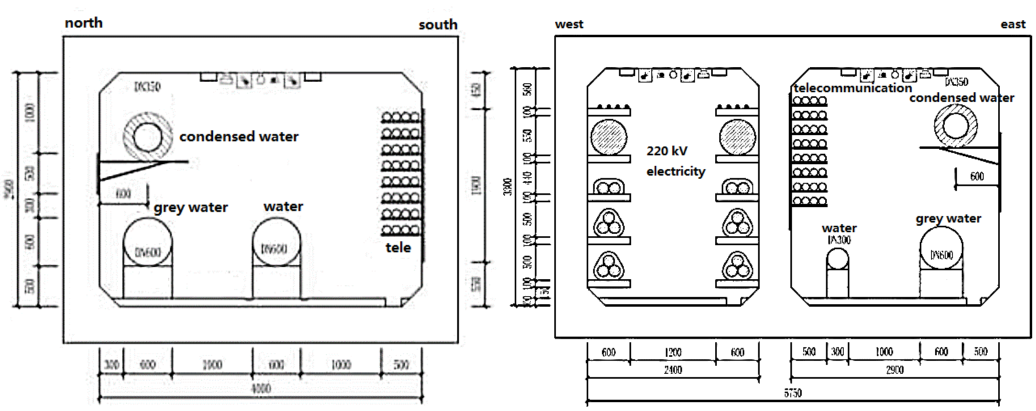


Figure 0-1. The layout of Hengqin New Area MUT project (Yong Liu, 2018)



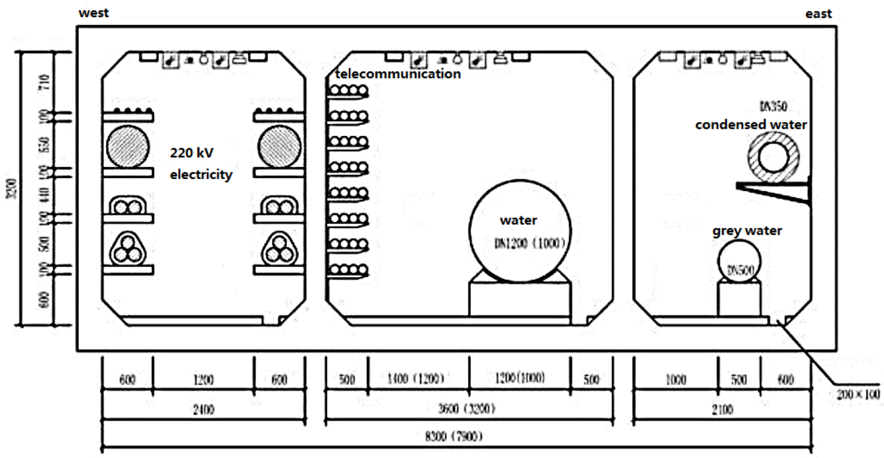


Figure 0-2. Cross-sections of MUTs with one, two and three compartments (W. Lu, 2018)

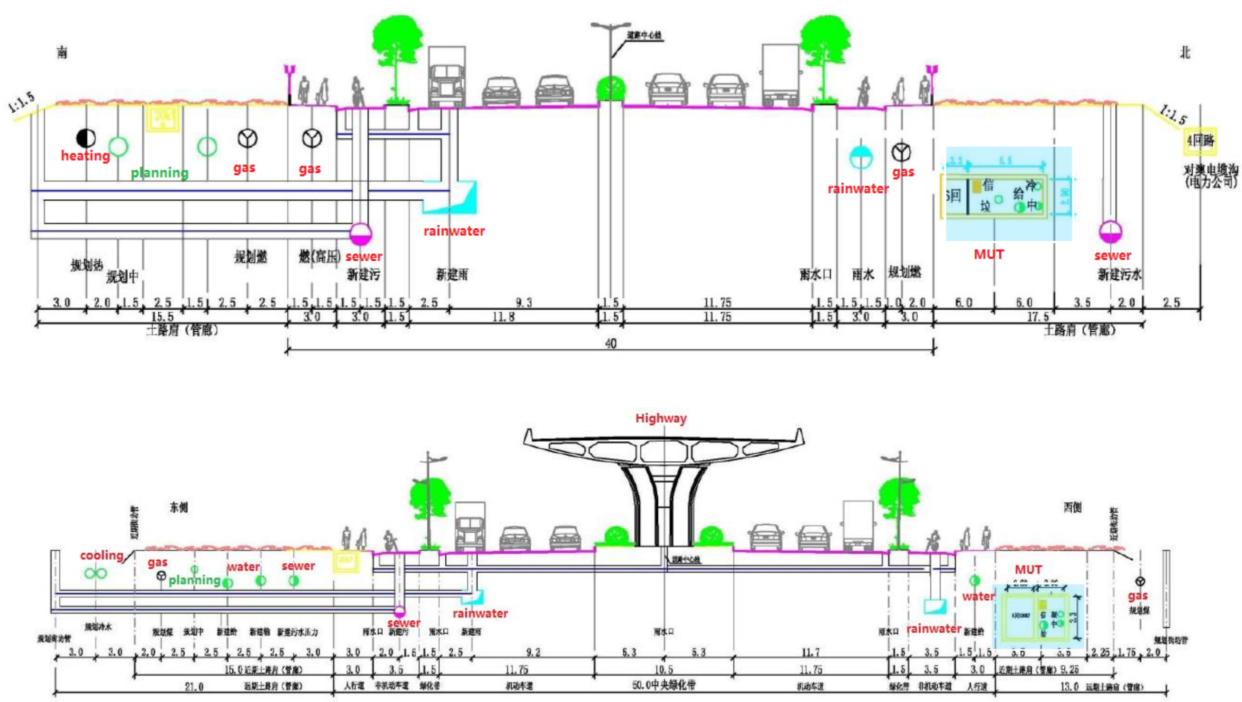


Figure 0-3. The layout of underground utilities (Yong Liu, 2018)

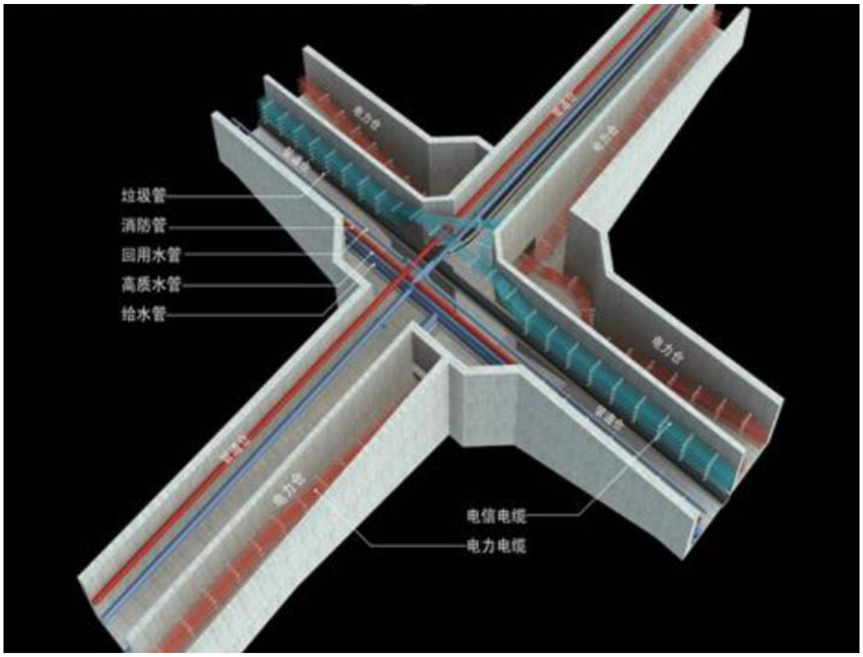


Figure 0-4. Two-level structure intersection (Liu, 2018)

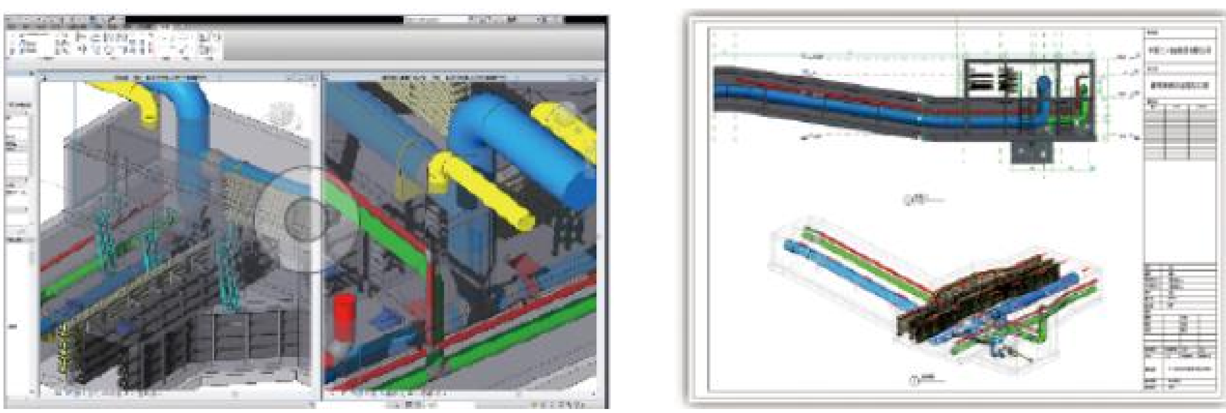


Figure 0-5. Pipe adjustment (left) and pipe integration (right) (Cao & He, 2016)

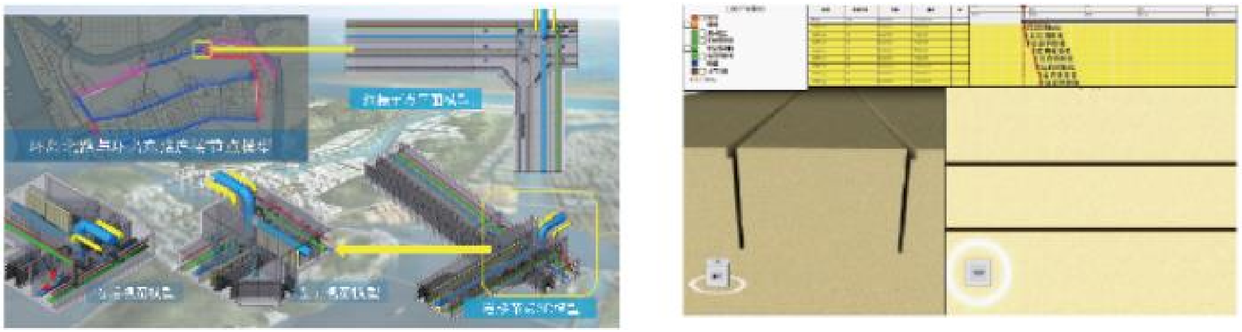


Figure 0-6. Visualization of key technologies (left) and 4D BIM (right) (Cao & He, 2016)

7.1.2 MUT projects in Xiamen

Xiamen City is considered as an important natural harbor located along the southeast coast of China. Xiamen is near Hong Kong, Guangzhou, and Shenzhen, and faces Taiwan across the sea. Since Xiamen government decided to build MUT in 2007, Xiamen is the first city in China to legislate for MUT in the form of local regulations, and the completed MUT length is more than 20 km (D. Qian et al., 2018). As a MUT pilot city, Xiamen has several MUT projects completed in recent years or under construction. There are 17 MUT projects as shown in Figure 0-7, three of which are completed, two of which are under construction and the others are in planning (Yanyan Wang, 2016).

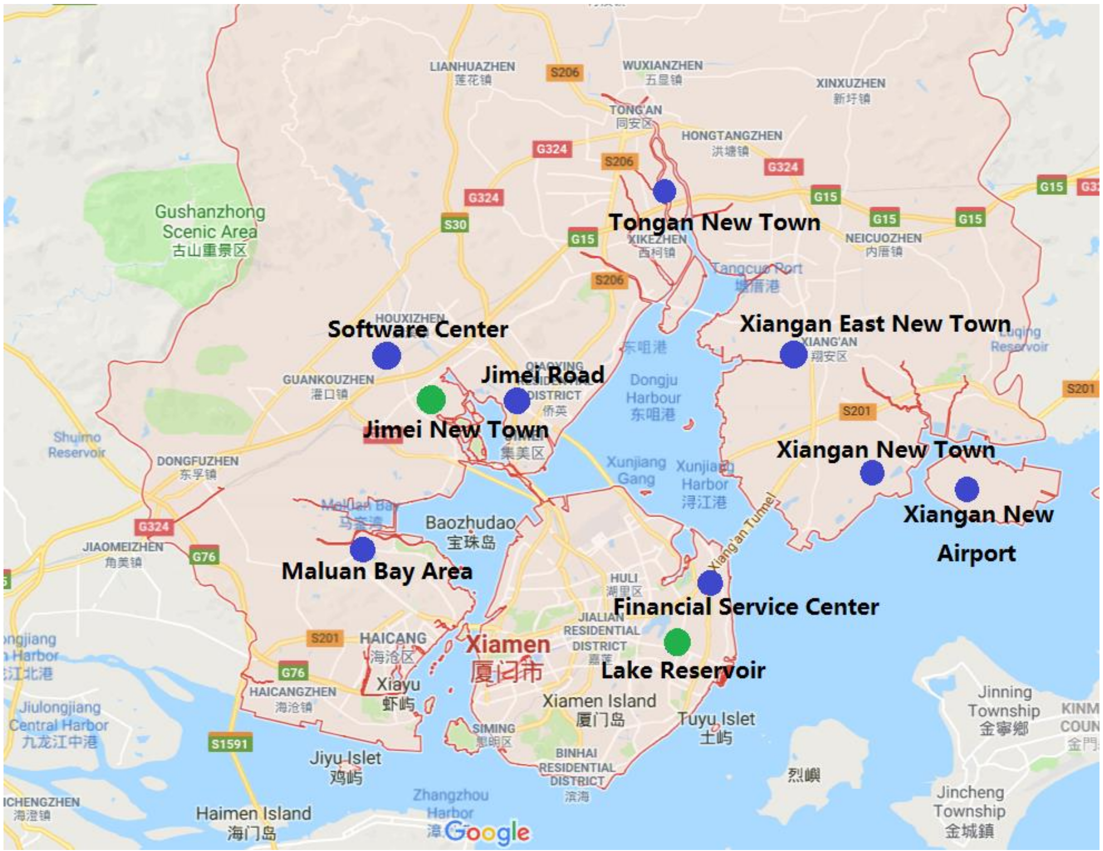


Figure 0-7. Xiamen MUT map

7.1.2.1 Meishan Road MUT

Meishan Road MUT is located on the east coast of the central area of Xiamen, which is a new city area for beach tourism development similar to Miami. The total length of Meishan Road MUT is 7.91 km. The MUT crosses through the central area of Technology Park, and in the east are the hotel's area and the coast. The underground space usage was almost full due to existing utility pipes and cables. In addition, the major road east to Meishan Road was planned as a road for tourism and then expanded to add Bus Rapid Transit (BRT) lane. Hence, existing utility pipes and cables cannot bear the development intensity of the municipal construction of the technology innovation park. Moreover, Meishan Road is the only main road in the nearby area, and high-voltage electricity cables were all above ground, which led to the occupancy of land resources. As a result, Meishan Road MUT is the solution to this new area development construction needs (Ziqiang Chen, 2014).

For utility selection, electricity, telecommunication, and water are common in MUT, but rainwater, sewage and gas should be considered carefully. Slope direction consistency is beneficial to contain gravity pipes. But in Meishan Road, some gravity pipes should have a slope not aligned with the ground slope, which will increase the depth and cost. In addition, due to tides, seawater can be poured into MUT through rainwater pipes. Moreover, gas pipes should be built in a separate compartment, but the cost is very high. Therefore, this MUT project did not consider gravity and gas pipes. The final planning for Meishan Road MUT includes electricity, telecommunication including traffic signals cables, water, and grey water pipes (Ziqiang Chen, 2014).

7.1.2.2 Jimei New Town MUT

Jimei New Town is in the central area of Xiamen City. The planning of Jimei New Town is a comprehensive new town with business, commercial, cultural, tourism, and residential development. Jimei Road is in the east-central area of Jimei New Town, and there were several high voltage cables above the ground. To improve the land utilization rate, the government decided to move the cables underground which can save 25 ha of land use. After the construction company combined all sources of information and consultations, they decided to build MUT to solve the issue. In addition, the planning of MUT is based on the following factors: (1) select the locations in high density areas; (2) based on the relocation of above-ground high voltage electricity cables to underground; (3) select locations with future metro or other underground planning (G. Zhang, 2016).

7.1.2.3 Xiangan New Town MUT

This Xiangan New Town MUT is in a high technology industrial park. Industrial park construction phase 1 area had already started construction. In order not to postpone the construction progress as well as to avoid the effects of frequent excavation on residents, the MUT was planned in the residential area. The MUT was planned with the length of 4 km. Cable tunnels were planned with a length of 15.9 km (H. He, 2016).

7.1.2.4 Lake Reservoir MUT

The Lake Reservoir MUT, which is the first MUT in Xiamen, is in the east of Xiamen Island with a length of 5.2 km and a cost of RMB 0.179B. Based on the existing utilities underground and relocation planning of above-ground high voltage electricity cables to underground, the MUT was planned to be built under the sidewalk and green belt with electricity, telecommunication, traffic signals cables and water, grey water pipes inside. The rainwater pipes were under the central line of the road, and sewage and gas pipes were under the other side's sidewalk and green belt. This design reduced the cross-section of MUT to lower the cost, and utility cables and pipes were safer (Z. Gao, 2010).

The commonly used cross-section is rectangular as shown in Figure 0-8, with the left compartment contains telecommunication, water, grey water, and low voltage electricity cables, and the right compartment contains high voltage electricity cables. This project also used a circular prefabricated section design as indicated in Figure 0-9. The circular MUT includes telecommunication, water, grey water, and low voltage electricity cables. Moreover, the MUT had a two-meter cover to achieve the requirements of most cables and pipes intersections; but at crossing with the river or metro, the depth of MUT is increased, and the construction method is shielding or pipe jacking for circular cross-section (Z. Gao, 2010).

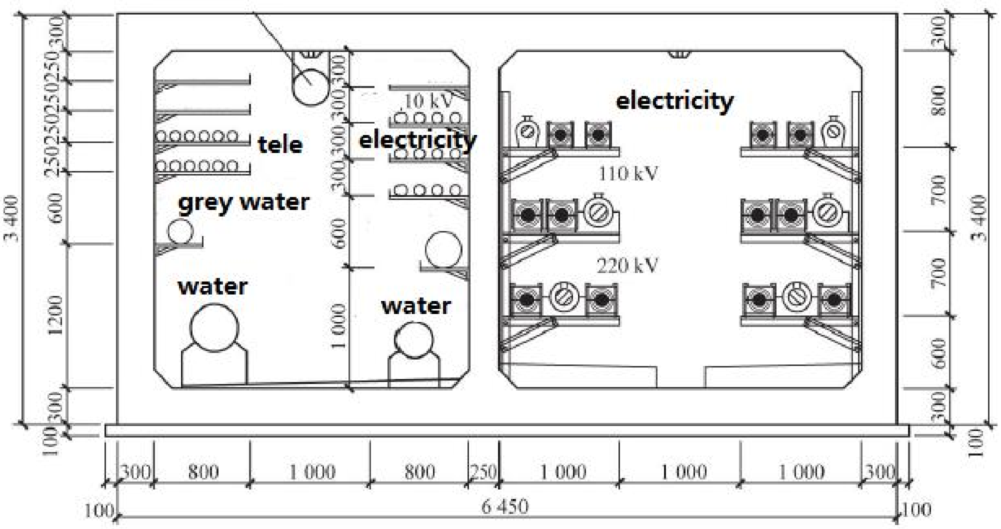


Figure 0-8. Cross-section of MUT with two compartments (Z. Gao, 2010)

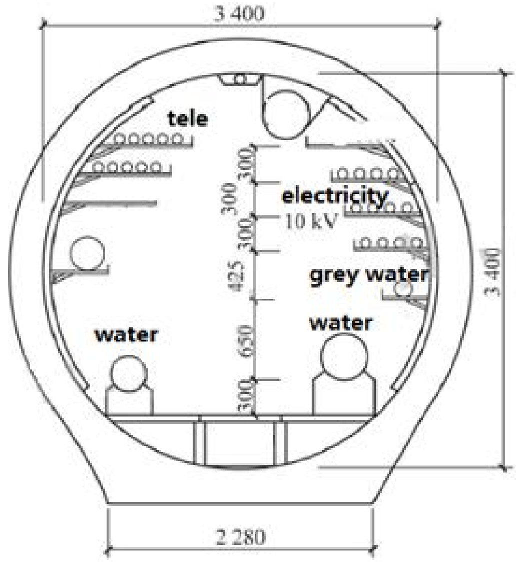


Figure 0-9. Cross-section of MUT with one compartment (Z. Gao, 2010)

7.1.2.5 New Airport MUT

The total length of the New Airport MUT is 22.2 km with a cost of RMB1.8Bwhich is around CAD$16.2 M/km. This project used the PPP model to fund the project. This MUT project included 10 roads with electricity and telecommunication cables, and water and grey water pipes. Only some roads also include gas, rainwater and sewage pipes since only roads with enough slope can contain gravity pipes such as rainwater and sewage (Weng, 2016).

7.1.3 MUT Projects in Beijing

Beijing is the capital of China and has the second largest population after Shanghai. Beijing has the needs for old city reform, transportation infrastructure construction and development of underground spaces. In addition, the powerful economic status and technology advances are advantages for MUT development in Beijing (Song, 2016).

As shown in Figure 0-10, yellow labels indicate the projects that have been completed, the green label shows the projects under construction and red labels show the projects in the design phase in 2016. The central area in Beijing is the blue polygon with a star at its center, and the right green polygon refers to the subsidiary administrative center in Beijing. There are six completed MUT projects in the central area. There is one completed project and one project under construction in the subsidiary administrative center. Since the city is expanding, several projects are taking place between the central area and the sub-central area and in the north. The total length of the projects shown in the figure is about 36.01 km, in which the length of MUT in the design phase is 3.2 km and the MUT under construction is 5.6 km (Song, 2016).

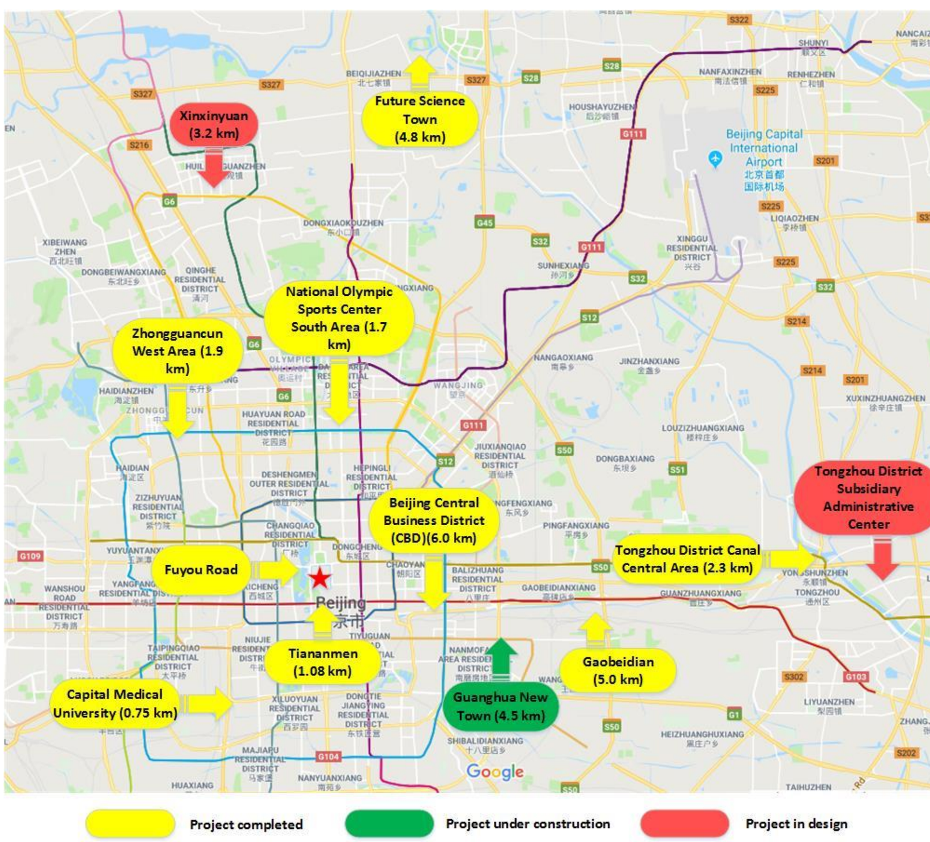


Figure 0-10. MUT projects in Beijing (adapted from Song, 2016)

Zhongguancun is in the central area of the northwest educational and commercial area in Beijing. The land is extremely limited due to the high population density. In addition, this area has 40 routes of buses and several metro stations including one transfer station. To ease the traffic pressure and the limited above-ground space, underground development is of vital importance. As a result, the Beijing government decided to develop a comprehensive underground structure including underground traffic tunnel, parking, MUT and underground commercial areas (Su, 2007).

As shown in Figure 0-11, the storm water and wastewater pipes are buried under the sidewalk, and the comprehensive underground structure is built under the traffic lanes. The first layer of the underground structure is a traffic tunnel, the second layer is metro passages, parking, and commercial areas, and the third layer is the MUT with five compartments which have gas, telecommunication, water and grey water, electricity and heating utilities. The length of the MUT is 1.9 km and it is designed as a closed ring (Figure 0-12) to effectively connect the functions of nearby areas (Su, 2007). The cross-section area of the MUT is 12.7 m×2.2 m (R. Xiao, 2004). The design of the MUT section was based on the discussion among the property developer, utility companies and design organizations according to the management system, and the design has extra space for future utility planning. To connect the main cables and pipes in the MUT to the nearby areas, the branches were built above the MUT (Su, 2007).

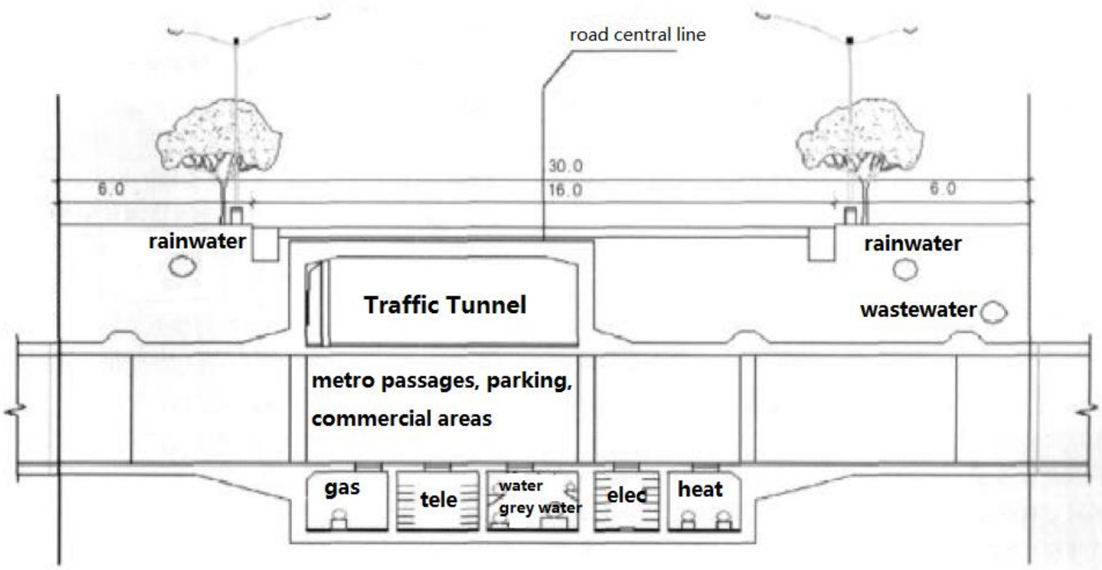


Figure 0-11. Cross-section of underground layout including Zhongguancun MUT (Su, 2007)

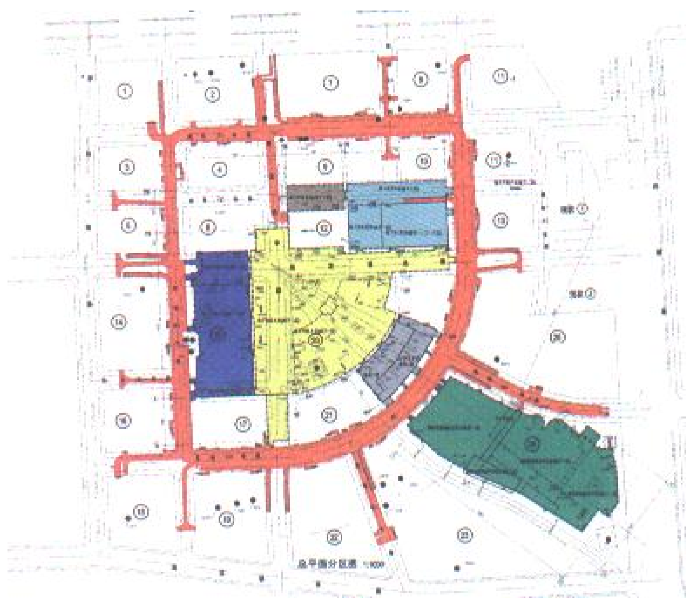


Figure 0-12. Zhongguancun MUT layout (R. Xiao, 2004)

7.1.4 MUT projects in Suzhou

Suzhou as one of the first 10 MUT pilot cities in China started to plan, design and construct the first MUT in Jiangsu Province which is Yueliang Bay MUT. The MUT operation management system is advanced in China. In investment, construction, operation and maintenance aspects, Suzhou is more complicated than Xiamen since project investment and construction are responsible by different companies and investment and construction methods are not the same. MUT in urban areas constructed based on PPP model (D. Qian et al., 2018).

Suzhou would start five MUT projects construction and the total length would be 31.2 km with a cost of around CA$0.8B.

7.1.5 MUT project in Hangzhou (a comprehensive infrastructure enhancement project)

The total length of this project is 7.86 kilometers and the cost is RMB1.9B which is around CA$0.38B. The project includes the construction of a utility tunnel, elevated highway, bridges, rainwater collector and auxiliary structures as shown in Figure 0-13. The utility tunnel is divided into four compartments, which are the gas compartment, rainwater compartment, water and telecommunication compartment, and electricity compartment from left to right as shown in Figure 0-14. The project met several challenges such as numerous existing pipelines and road intersections. During construction, the crossings of the MUT with a sewage pipeline and a river were complicated since the MUT must be built between the existing sewage pipelines and river, and the nearest distance was only 0.5 m from the MUT to the sewage pipe (S. Bao, 2017).

This project is complex due to the construction of different infrastructures and the presence of existing pipelines. Comprehensive construction of various infrastructures often appears in recent Chinese projects since a number of these projects are in less developed cities or new areas in old cities. The development planning should consider several kinds of infrastructures for sustainability and long-term development.

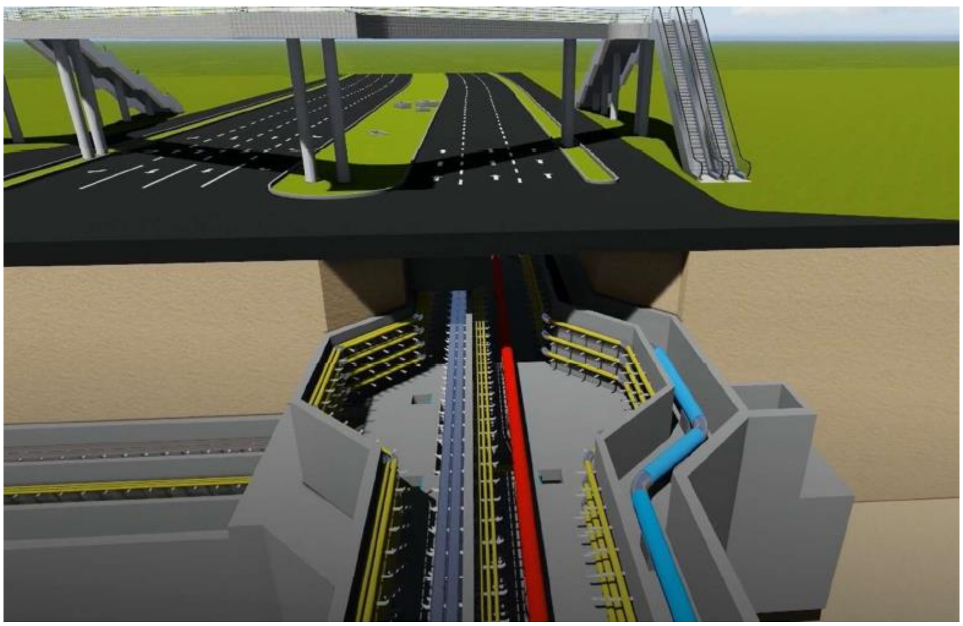


Figure 0-13. A comprehensive infrastructure enhancement project in Hangzhou, China (S. Bao, 2017)

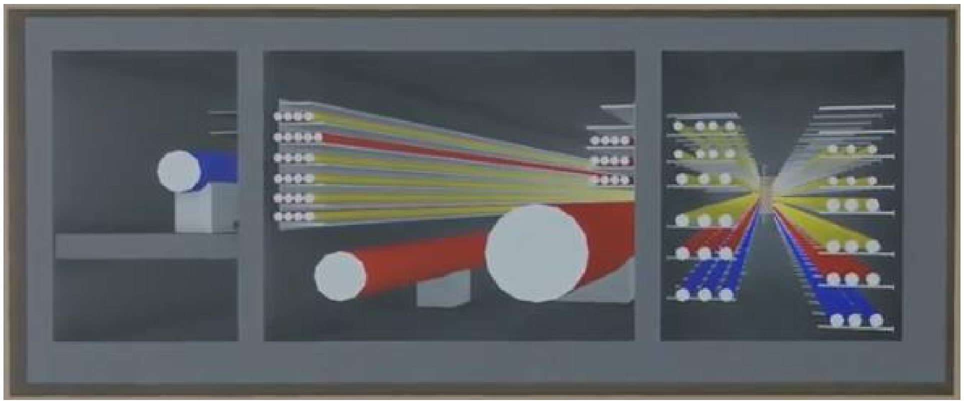


Figure 0-14. MUT cross-section (S. Bao, 2017)

7.1.6 MUT project in Shenzhen ("City of the future" project)

This MUT project is located at the Airport New Town in Shenzhen. The total length will be nearly 35 km with a total investment of more than CAD$740M. The MUT contains water, electricity, telecommunication, sewage, and gas, and leaves space for grey water, drinking water and vacuum garbage pipes (Sohu, 2017). To avoid hazards, the MUT is separated into four compartments: electricity compartment, gas compartment, telecommunication and water compartment, and an empty compartment for future use as shown in Figure 0-15. For inspection tasks, the MUT project uses robots that can work all the time. When in emergencies, robots can extinguish fires instead of humans. In addition, for unusual climate (e.g. heavy rainfall and snow) permeable concrete is used to adsorb and direct water to pipes under green lands. The project will provide an opportunity to use big data collected from sensors for future analysis (Guancha Syndicate, 2017).

Figure 0-15. Cross-section of MUT in Shenzhen "City of the future" project (Guancha Syndicate, 2017)

7.1.7 MUTs in Hong Kong

Hong Kong is a city with extremely limited space for its high population density. As a result, the Civil Engineering and Development Department of Hong Kong government focuses on the enhanced use of underground space and long-term strategy for cavern development (CEDD, n.d.; Wallace, 2017). Since Hong Kong is a mountainous city with flood and typhoon hazards, the underground traffic system and drainage tunnels are advanced. Hong Kong has gas tunnels such as Braemar Hill Tunnel which is 2.6 km and former Beacon Hill Tunnel which is 2.2 km. In addition, there are 23 km of underground cable tunnels. There are also 58 km of drainage and sewage tunnels by 2009 and additional 49 km which will be completed by 2020. Moreover, the water transfer tunnels are 210 km in total and the longest one is 24.5 km (Wallace, 2017).

Appendix II. Enforcement Rules of Common Duct Act in Taiwan

Article 1 These enforcement rules are prescribed in accordance with Article 33 of Common Duct Act (The Act).

Article 2 While the competent authorities at municipal and hsien (city) levels announce the Common Duct system to the public in accordance with Paragraph 1 Article 8 of the Act shall give 30 days of announcement, and then inform local related public works authorities and utility agencies (or organization). The same applies to any changes or annulment.

The Common Duct system may be announced in sections and also be stated by words or tables to illustrate the following items:

1.Administrative jurisdiction and the range of planned area.

2.Locations, name, and category of Common Ducts.

3.Project target years.

4.Planning maps of Common Duct system.

5.Related urban planning and regional planning.

The target years of item 3 shall not be less than 25 years; the scale of the planning maps of item 4 shall not be less than 1:10000.

Article 3 Upon the announcement of Common Duct system, the applicators for the systematical excavation of the road in the system shall propose to the competent authorities at municipal and hsien (or city) levels the review plan according to following regulations:

1.For those utility agencies (or organizations) which have not been included in the Common Duct system shall submit the review plan of piping and wire network to match the Common Duct system, when applying for excavation.

2.For those utility agencies (or organizations) which have been included in the Common Duct system shall submit construction schedule review plan to match the Common Duct system, when applying for excavation.

3.The authority of public works shall submit construction schedule review plan to match the Common Duct system, when applying for excavation.

Article 4 While the competent authorities at municipal and hsien (or city) levels reviewing the overall plan of Common Duct system pursuant to Item 3 Article 8 of the Act shall take the following factors into considerations:

1.Coordinating with the changes of urban planning or city development plan.

2.Coordinating the new construction of transportation facilities and with the renewal of road system.

3.Coordinating with the network establishment of Common Duct system.

4.Suggestions given by utility agencies (or organizations).

5.Other public works related to the Common Duct system.

Article 5 While the competent authorities at municipal and hsien (or city) levels prescribing the execution plan in accordance with the first sentence of Article 9 of the Act shall indicate the following items by words or tables based on actual situation:

1.Name of the project.

2.Administrative jurisdiction and the range of planned area.

3.Project target years.

4.Population and economy development projection in the project target years.

5.Distribution and restriction on residence, commerce, industry and other land use.

6.Road system and related construction plan.

7.Existing system of utility piping and wires.

8.Projections of demand on all utility systems in project's target years.

9.Construction schedule, cost and financial plans.

10.Category and plane of Common Ducts; the scale of the plane shall not be less than 1:1000.

11.Sections of Common Ducts.

12.Proposed utility agencies (or organizations) and their using portions.

13.Forbidden range and duration of road excavation.

Article 6 The prescription of project target years aforementioned in Item 3 of Article 5 shall take the following factors into consideration:

Coordinating with the project target years of regional planning or urban planning.

Demanding years of utility piping and wires.

Structure's life span of Common Duct.

Planning years of road construction.

Category of Common Duct.

Article 7 All utility agencies (or organizations) shall cooperate with the competent authorities at municipal and hsien (or city) levels while prescribing execution plan in accordance with the first sentence of Article 9 of the Act.

Article 8 The actual demands referred to in the first sentence of Article 10 of the Act are the demands in coordinating with city development, transportation construction, utility construction, natural disaster, accident or other public works.

Article 9 Relevant authority (or organization) in submitting the application to the competent authority in accordance with the first sentence of Article 10 of the Act shall attach the planning reports and drawings of Common Duct system and of execution plan.

Aforementioned planning reports and drawings of Common Duct system shall indicate the announced items set forth pursuant to Item 2 of Article 2; the execution plan and drawings shall indicate the contents listed in Article 5.

Article 10 While the competent authorities announcing the forbidden range of road excavation in accordance with Article 13 of the Act shall indicate the following items:

1.Category of Common Duct.

2.Construction schedule of Common Duct.

3.Forbidden range and duration of road excavation.

Article 11 Utility agencies (or organizations) in submitting loan application in accordance with the first sentence of Article 23 of the Act shall attach the following documents:

1.Construction plan or investment plan, and cost estimation.

2.The loans amount of application and repay plan.

3.Other necessary documentation as required by the central competent authority.

Article 12 After the completion of Common Duct works the competent authority shall set up files to record the following data:

1.Plane of Common Duct works.

2.Dates of commencement and completion of the construction, and also the as-built drawings.

3.Daily report on Common Duct works.

4.Table of quantity of utility piping and wires contained in Common Duct.

5.Cross-sections on utility piping and wires contained in Common Duct, and the table of quantity.

6.Other necessary items regarding the operation, maintenance, and management of Common Duct.

Article 13 Reports and formats referred to in the Act shall be prescribed by the central competent authority.

Article 14 These enforcement rules shall become enforceable upon the date of promulgation.

(https://www.cpami.gov.tw/public-information/laws-regulations/10-public-works/10778-enforcement-rules-of-common-duct-act%EF%BC%88%E5%85%B1%E5%90%8C%E7%AE%A1%E9%81%93%E6%B3%95%E6%96%BD%E8%A1%8C%E7%B4%B0%E5%89%87%EF%BC%89.html)

Appendix III. Design Standard of Common Duct in Taiwan

Article 1 This standard is prescribed in accordance with Article 33 of Common Duct Act (The Act).

Article 2 Terms used in this Standard are defined as follows:

1.Duct: Independent spaces that form Common Duct.

2.Main Ducts: Ducts that contain the facilitating regional public utilities (piping and wires), and reach to the users by means of the supplier ducts.

3.Supplier Ducts: Ducts that contain the feeding piping and wires to users, including the Branch Duct, CAB, and C.C.Box etc.

4.Standard Section: General section of Common Duct.

5.Non-typical Section: Section with variation changes and non-standard sections including entrance, ventilation exit, material access, and divergence of piping and wires.

Article 3 Common Duct works shall make the following investigations:

1.Investigation of topography.

2.Investigation of geology.

3.Investigation of underground water.

4.Investigation on land use.

5.Investigation of buried structures and utilities of piping and wires.

6.Investigation of road traffic volumes.

7.Other investigation as required by the competent authority.

Article 4 While planning the Common Duct system under the jurisdiction in accordance with Article 8 of this Act, the competent authority shall plan the settings of main duct and supplier duct based on road status, related projects of public works, and coordinating plan proposed by utility agencies (or organizations).

Main ducts shall be installed under the road median or underneath the lanes, the supplier ducts underneath the sidewalk or both sidelanes.

Article 5 The alignment of Common Duct shall meet the following requirements:

1.Align the same plane with the road, and adjust it based on road ststus, the situation of underground embedment and related project of public works.

2.The longitudinal slope shall coincide with the slope of the road with minimum slope not less than 0.2%, except the part of non-typical sections.

3.On curved portion the curvature shall not exceed the maximum allowed radians of the contained utility of piping and wires.

Article 6 The distance between common duct's exterior wall and right of way shall not be less than one (1) meter. However, in case of road alignment change or width limitation of the sidewalk, necessary adjustment may be made upon approval of the competent authority.

Article 7 The interior space and dimensions shall meet the following requirements:

1.Net height: Main duct shall have minimum dimension of two hundred and twenty (220) cm; supplier duct shall not exceed one-hundred and fifty (150) cm. However, based on the requirement of pipe capacity, road alignment change or width limitation of the sidewalk, branch ducts can be excluded from these regulations with the approval of the competent authority.

2.Net width: Dased on the need and operation space of contained piping and wires. The width of the aisle shall not be less than eighty (80) cm.

Article 8 Cover depth in-between the upper part of top slab of main duct and road paving shall not be less than two hundred and fifty (250) cm for standard section, one hundred (100) cm for non-typical section.

Article 9 In processing the structural design of Common Ducts, following cases shall be considered:

1.Influences of settlement at soft soil layer.

2.Influences of uplift force caused by underground water.

3.Influences of earthquake.

4.Influences of soil liquefaction.

5.Influences to adjacent structures.

Article 10 Water proof design of Common Duct shall meet the following requirements:

1.Watertight concrete shall be used in concrete structures, exterior waterproof material in surfaces, and water stop at joints to prevent the duct from seepage of underground water.

2.Hindering measurements shall be taken for exposed facilities at non-typical section of Common Duct to prevent the duct from entering of surface water.

Article 11 Common duct shall have joints and meet the following requirements:

1.Joints shall have water stop strip and filler materials to prevent the seepage of underground water.

2.While locating at homogeneous and sound geological site, the expansion joint may be used as the joint, and the interval shall not exceed thirty (30) meters.

3.At the site of soft soil layer, geologically sudden changes or possible site of liquefaction, the joint shall be flexible and the interval shall be less than fifteen (15) meters.•

Article 12 Facilities at non-typical sections of Common Duct shall meet the following requirements:

1.Entrance and ventilation exit may be set at the sidewalk or road median. But not to interfere the pedestrians and traffic safety.

2.The exits of the natural ventilation and forced air ventilation shall be alternatively located.

3.While the natural ventilation exit is used also for entrance, good ventilated grid plate shall be adopted, and steps or ladders shall be installed in accordance with actual needs.

4.As for reserved locations and sizes of material access and diverging room, utility agencies (or organizations) shall submit their demanding forecast and make an integrated plan.

5.Coordinating with the landscaping design of road.

Article 13 At lower points of Common Duct, water collection wells shall be planned together with grid cover and pumping equipment. The water collection wells shall be capable of separating sand and clay off.

Article 14 The cover plate of Common Duct shall meet the following requirements:

1.Able to bear design loading and uplift stresses.

2.With adequate weight and not easy to be opened.

3.Coordinating with the drainage slope of sidewalk and having watertight joint at interface of sidewalk pavement to prevent the entering of surface water.

4.Coordinating with the landscape and beautifying program of sidewalk.

Article 15 Common Duct shall meet the following safety requirements:

1.Fire protection: Electric cables shall have fire-retarded cover or wrapped with fireproof material; fires extinguish equipment or fireproof compartment shall be planned in accordance with actual needs.

2.Blast proof: Facilities in the ducts shall be capable of preventing from explosion.

3.Anti-sabotage: Blockage facilities shall be installed at the openings of duct; oil collector shall be devised at the entrance, staircase, and underneath of ventilation exits.

4.Flood proof: The openings of ducts shall be located above the flood level.

Article 16 Common Duct shall equip with the following facilities in accordance with actual needs:

1.Ventilation equipment.

2.Lightening equipment.

3.Water supplying equipment.

4.Power distributing equipment.

5.Fire-fighting equipment.

6.Toxic air detecting equipment.

7.Alarming equipment.

8.Symbols.

9.Control center

10.Other necessary equipment as required by the competent authority.

Article 17 Design specification of Common Duct shall be separately prescribed by the central competent authority.

Article 18 This standard shall become enforceable upon the date of promulgation.

(https://www.cpami.gov.tw/public-information/laws-regulations/10-public-works/10780-design-standard-of-common-duct%EF%BC%88%E5%85%B1%E5%90%8C%E7%AE%A1%E9%81%93%E5%B7%A5%E7%A8%8B%E8%A8%AD%E8%A8%88%E6%A8%99%E6%BA%96%EF%BC%89.html)

Appendix IV. Regulations on Cost Allotment of Common Duct Construction and Management in Taiwan

Article 1 These regulations are prescribed in accordance with the first sentence of Article 21 of Common Duct Act (The Act).

Article 2 The engineering authority shall share one third (1/3) of the project cost on Common Duct construction, the utility agencies (or organizations) two thirds (2/3) in accordance with their participated categories in Common Duct.

The aforementioned allotment of participated utilities shall use the following formulae:

Regulations on Cost Allotment of Common Duct Construction and Management

Rj The ratio of allotment for category j utility agency.

Vj The volume occupied by category j utility. (Cubic Meters)

Cj Traditional construction cost per excavated cubic meter (NT$ / Cu. M) on category j utility, prescribed by the engineering authority after consultation with the relevant utility agencies (or organizations).

Vj×Cj Traditional value of occupied volume for category j utility.

n Number of categories of participated utility in Common Duct.

Article 3 Three (3) months after the completion of Common Duct, the engineering authority and participated utility agencies (or organizations) shall appropriate five (5) % of total construction cost to set up a special account for the management and maintenance of Common Duct. The payment of the aforementioned special account is limited to this particular purpose.

The allotting manner of aforementioned appropriation shall follow the formulae set forth in Article 2.

Article 4 The participated utility agencies (or organizations) shall share one third (1/3) of the management and maintenance fee of Common duct starting from the second year after completion of the construction. The rest two thirds (2/3) shall be shared by utility agencies (or organizations) according to the used duration of time or number of usage, after the consultation organized by the competent authority.

Article 5 The aforementioned maintenance and management fee shall exclude staff costs in the organic structure of competent authority.

Article 6 All participated utility agencies (or organizations) shall deposit, prior to 1st of February each year, into the special account 80 % of the allotted portion in accordance with the cost and ratio set in the preceding year. In case an insufficient amount exists upon the settlement of account in the end of the year, the concerned participated utility agencies (or organizations) shall deposit the insufficient portion prior to 1st of February the following year.

Article 7 These regulations shall become enforceable upon the date of promulgation.

(https://www.cpami.gov.tw/public-information/laws-regulations/10-public-works/10777-regulations-on-cost-allotment-of-common-duct-construction-and-management%EF%BC%88%E5%85%B1%E5%90%8C%E7%AE%A1%E9%81%93%E5%BB%BA%E8%A8%AD%E5%8F%8A%E7%AE%A1%E7%90%86%E7%B6%93%E8%B2%BB%E5%88%86%E6%94%A4%E8%BE%A6%E6%B3%95%EF%BC%89.html)

Appendix V. GIS data of Montreal

7.6.1 Data received

The information of GIS data layers is shown in *Table 0-1* including type, layer, data type, useful attributes, attributes request, comments and layer name. Layers with green background is from City of Montreal open source data, and the other data are directly from City of Montreal geomatique department. Useful attributes are attributes from the received data that can be used in the analysis, and attributes request are still needed for analysis. For some layers, length attribute is added in ArcGIS which are indicated in comments, and the comments also show data sources. Names in Layer column are layer names displayed in ArcGIS, and names in Layer name column are layer names in the source data.

In *Table 0-1*, GIS data layers from the geomatique department include roads (roads, sidewalk, intersections and central island), Hydro Quebec, gas, water, sewage and CSEM. GIS data layers from open source data include roads lines, sidewalk lines, STM, land use, residential density, fire stations, buildings, several future plans and public facilities (health facilities, colleges and universities). Other data layers from the geomatique department include CSEM and Reseau_Revision_AQU_EGO. The yellow highlights are attributes lack description.

For Roads data, due to lack of length in GIS data layers from the geomatique department, roads and sidewalk lines from open source data were used to add length to existing layers. Roads layers lack several attributes such as width, status, slope and future plans. For utilities data including Hydro Quebec, gas, water and sewage, pipe diameter, materials, length of pipe lines are received as well as type and installation date for some layers. But depth, status, inspection and maintenance data and future plans are missing.

The STM data does not have frequency for high traffic density analysis. The classes of land use data have overlaps which is not clear for land use selection. The residential density refers to average number of houses per hectare instead of population which is less accurate to estimate population density. The building polygons does not have the number of floors above ground or underground.

For future plans data, only road projects, action plan for water, sewage and roads, and lands to build and to transform can be found in the open source data, but all future plans data lacks plan period information. In addition, other future intervention plans including metro and utilities are needed as well for route selection analysis.

Data layers including public facilities (health facilities, colleges, universities), city planning, and counting vehicles and pedestrians at intersections are also downloaded from open source data for future analysis.

Table 0-1 Information of GIS data layers

#	Type	Layer	Data type	Useful attributes	Attributes request	Comments	Layer name

1	Roads	Roads	Polygons	Perimeter, area, utilization, construction date, material	Width, status, slope, future plans		ATI_GEOMATIQUE_VOI_CHAUSSEE_S_C22
2		Roads-open source data	Lines	Length, class, direction		Length added; http://donnees.ville.montreal.qc.ca/dataset/geobase	Géobase - réseau routier
3		Sidewalk	Polygons	Perimeter, area, construction date	Width, status, inspection and maintenance data, future plans		ATI_GEOMATIQUE_VOI_TROTTOIR_S_T12
4		Sidewalk-open source data	Lines	Length, direction		Length added; http://donnees.ville.montreal.qc.ca/dataset/geobase-double	Geobase_double
5		Intersections	Polygons	Construction date, perimeter, area			ATI_GEOMATIQUE_VOI_INTERSECTION_S_N12
6		Central islands	Polygons	Construction date, perimeter, area			ATI_GEOMATIQUE_VOI_ILOT_S_M12
#	**Type**	**Layer**	**Data type**	**Useful attributes**	**Attributes request**	**Comments**	**Layer name**
7	Water	Water pipes	Lines	Diameter, material, length	Depth, status, inspection and maintenance data, future plans		AQU_SEGMENT_P_J_VM
8		Manhole	Points	Installation date, DATEINSTALLPREC_REF, status, type, elevation		DATEINSTALLPREC_REF?	AQU_REGARD_P_J_VM
9		Connection	Points	Status, type, elevation			AQU_RACCORD_P_J_VM
10		Valve	Points	Installation date, DATEINSTALLPREC_REF, status, type, elevation		DATEINSTALLPREC_REF?	AQU_VANNE_P_J_VM

11		Fire hydrant	Points	Installation date, DATEINSTALLPREC_REF, status, elevation		DATEINSTALLPREC_REF?	AQU_BORNEINCENDIE_P_J_VM
12		Accessory	Points	Status, type, elevation			AQU_ACCESSOIRE_P_J_VM
13		Compartment	Polygons	Status, type, perimeter, area			AQU_CHAMBRE_P_J_VM
#	**Type**	**Layer**	**Data type**	**Useful attributes**	**Attributes request**	**Comments**	**Layer name**
14	Sewage	Sewages pipes	Lines	Diameter, material, length, installation date, DATEINSTALLPREC_REF, segment form, status, segment type, network type, RADIERAMONT, RADIERAVAL	Depth, slope, inspection and maintenance data, future plans	DATEINSTALLPREC_REF? RADIERAMONT, RADIERAVAL?	ECO_SEGMENT_P_J_VM
15		Manhole	Points	Installation date, DATEINSTALLPREC_REF, status, type, elevation		DATEINSTALLPREC_REF?	EGO_REGARD_P_J_VM
16		Connection	Points	Status, type, elevation			EGO_RACCORD_P_J_VM
17		Sump	Points	Installation date, DATEINSTALLPREC_REF, status, type, elevation		DATEINSTALLPREC_REF?	EGO_PUISARD_P_J_VM
18		Accessory	Points	Status, type, elevation			EGO_ACCESSOIRE_P_J_VM
19		Compartment	Polygons	Status, type, SHAPE_Length, SHAPE_Area			EGO_CHAMBRE_P_J_VM
20		Basin retention	Polygons	Status, type, SHAPE_Length, SHAPE_Area			EGO_BASSINRETENTION_P_J_VM
#	**Type**	**Layer**	**Data type**	**Useful attributes**	**Attributes request**	**Comments**	**Layer name**
21	Hydro Quebec	RTU (HQ)	Lines	Voltage, type (above ground/underground)	Depth, status, inspection		HQ_ligne

				, length, description (main/branch/…)	and maintenance data, future plans		
22	Gas	Gas pipes	Lines	Diameter, material, length, pressure, installation date	Depth, status, inspection and maintenance data, future plans		Conduite
23	STM	Bus and metro-open source data	Polylines	Route number, direction	Frequency		STMlines
24	Land use	Land use	Polygons	Class, area	Classes not clear, have overlaps	Area added; http://donnees.ville.montreal.qc.ca/dataset/affectation-du-sol	AffectationPU
25	Residential density	Number of houses	Polygons	Average number of houses per hectare	Polygons too large, prefer population rather than number of houses	http://donnees.ville.montreal.qc.ca/dataset/schema-affectation-densite/resource/f8a45dc4-d964-48e4-add2-c274960d7087	DensiteAireTOD
26	Fire stations	Fire stations	Points	Borough, latitude, longitude		http://donnees.ville.montreal.qc.ca/dataset/casernes-pompiers/resource/c061981b-0b85-49c8-a891-f8460381be2d	casernes
#	**Type**	**Layer**	**Data type**	**Useful attributes**	**Attributes request**	**Comments**	**Layer name**
27	Buildings	Building roof border	Polygons	Area, EQM_plani	Number of floor above ground/underground, land use	EQM_plani, http://donnees.ville.montreal.qc.ca/dataset/batiment-2d	CARTO-BAT-TOIT
28		Building points	Points	Elevation		http://donnees.ville.montreal.qc.ca/dataset/batiment-2d	CARTO-BAT-COTE
29	Future plans	Road projects	Polygons	Type	Plan period	http://donnees.ville.montreal.qc.ca/dataset/schema-transport/resource/7ce2aff7-a084-4266-9fcb-478613b2056b	ProjetRoutier

30		Action plan for water, sewage and roads	Polylines	Length, type	Plan period	http://donnees.ville.montreal.qc.ca/dataset/resultats-plan-intervention-actifs-eau-voirie	PIM_TRONCON_UNIFIE_L_J
31		Land to build and to transform	Polygons	Type, area	Plan period	http://donnees.ville.montreal.qc.ca/dataset/schema-affectation-densite/resource/9ca9cccd-eda8-4cb8-abf3-cc8cb8bce561	TerrainsConstTrans
#	**Type**	**Layer**	**Data type**	**Useful attributes**	**Attributes request**	**Comments**	**Layer name**
32	Public facilities	Health facilities	Points	Type, agglomeration/metropolitain		http://donnees.ville.montreal.qc.ca/dataset/schema-equipements-collectifs/resource/8ae05e24-b319-434b-bdb1-4a5a5bd9fcbe	EqSante
33		Colleges	Points			http://donnees.ville.montreal.qc.ca/dataset/schema-equipements-collectifs/resource/56631474-334f-4a8d-b3f9-c128f13809cb	EqCollegial
34		Universities	Points			http://donnees.ville.montreal.qc.ca/dataset/schema-equipements-collectifs/resource/1fe98db2-4e02-4d01-9bd2-e40321b86023	EqUniversitaire
35	City planning	Priority areas of densification	Polygons	Priority, area		http://donnees.ville.montreal.qc.ca/dataset/schema-affectation-densite/resource/21202cc8-ab87-4ac5-9b52-0fdb815989f4	secteursdensification
36	Traffic	Traffic lights - counting vehicles and pedestrians at intersections with lights	Points	Period, number (vehicles and pedestrians)		http://donnees.ville.montreal.qc.ca/dataset/comptage-vehicules-pietons	comptages_feux
37	CSEM	CSEM-Point	Points				
38		CSEM-Annotation	Annotation				

39		CSEM-Polyline	Polylines				
40		CSEM-Polygon	Polygons				
41		CSEM-MultiPatch	Polygons				
42	Reseau_Revision_AQU_EGO	IMA_MAJ_NUMERISATION_S_polygon	Polygons				

7.6.2 Layer description

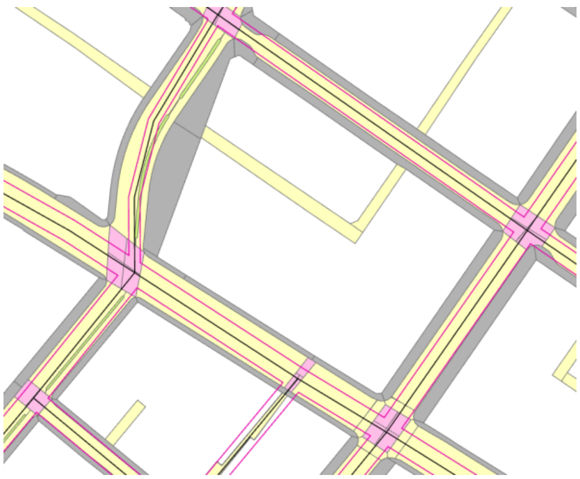
Table 0-2 Layer Symbology

Symbol	Layer	Comments
●	CARTO-BAT-COTE	Buildings
●	EqUniveritaire	University
●	EqCollegial	College
●	EqSante	Hospitals
●	Comptages_feux	Counting vehicles and pedestrians
	casernes	Fire stations
— — — ____	Roads	Roads
— — — ____	Geobase_double	Sidewalk & curb
— — — ____	STMlines	STM bus and metro lines
— — — ____	PIM_TRONCON_UNIFIE_L_J	Action plan for water, sewage and roads

— — — ____	Conduite	Gas
— — — ____	HQ_ligne	Hydro lines
— — — ____	AQU_SEGMENT_L_J_VM	Water segment
— — — ____	EGO_SEGMENT_L_J_VM	Sewage segment
	ATI_GEOMATIQUE_VOI_TROTTOIR_S_T12	Sidewalk
	ATI_GEOMATIQUE_VOI_INTERSECTION_S_N12	Intersection
	ATI_GEOMATIQUE_VOI_ILOT_S_M12	Central islands
	ATI_GEOMATIQUE_VOI_CHAUSSEE_S_C22	Roadway
●	AQU_REGARD_P_J_VM	Water manhole
●	AQU_RACCORD_P_J_VM	Water connection
●	AQU_VANNE_P_J_VM	Water valve
●	AQU_BORNEINCENDIE_P_J_VM	Water fire hydrant
●	AQU_ACCESSOIRE_P_J_VM	Water accessory
	AQU_CHAMBRE_S_J_VM	Water compartment
●	EGO_REGARD_P_J_VM	Sewage manhole
●	EGO_RACCORD_P_J_VM	Sewage connection
●	EGO_PUISARD_P_J_VM	Sewage sump
●	EGO_ACCESSOIRE_P_J_VM	Sewage accessory
	EGO_CHAMBRE_S_J_VM	Sewage compartment
	EGO_BASSINRETENTION_S_J_VM	Sewage basin retention
	CARTO-BAT-TOIT	Buildings
	Land use	Land use
	ProjetRoutier	Road projects

	TerrainsConstTrans	Land to build and to transform
	SecteursDensification	Priority areas
	IMA_MAJ_NUMERISATION_S_polygon	

7.6.2.1 Roads, sidewalk & curb



7.6.2.1.1 Roads

Among all attributes of Roads polygon layer (*Table 0-3*), DATECONSTRUCTION (construction date), MATERIAUCHAUSSEE_REF (materials), PROPRIETAIRE_REF (owner), UTILISATION_REF, SHAPE_Length and SHAPE_Area are attributes may useful for route planning. And one of the attributes DATERESURFACAGE is not clear and has lots of missing data.

Table 0-3 Information of Roads layer (polygon)

ATI_GEOMATIQUE_VOI_CHAUSSEE_S_C22

Field name	**Data type**	**Value range**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_VOI_CHAUSSEE_AGR	Long		
CATEGORIECHAUSSEE_REF	Text	Autoroute, Autoroute accotement, Bretelle, Bretelle accotement, Rue, Ruelle	
DATECONSTRUCTION	Date	1965-2017	
DATECONSTRUCTIONPREC_REF	Text	Null, DATE construction +/- 100 ans maximum, DATE construction +/- 5 ans maximum, DATE construction dans année courante, DATE construction precise, DATE construction précise au mois courant	
DATERESURFACAGE	Date	1989-2018	Lots of missing data
MATERIAUCHAUSSEE_REF	Text	Aménagement paysager, Asphalte, Asphalte et béton, Asphalte et pave, Béton, Béton et pave, Pavé, Pierre concassée (Gravier)	
POSITION_REF	Text	Actif de voirie (1) situé au-dessus d'autres actifs (ancien 101), Actif de voirie (2) situé sous un actif de voirie de position 1, Actif de voirie (3) situé sous un actif de voirie de position 2, Actif de voirie (5) situé au sol (ancien 100), Actif de voirie (6) situé en dessous d'autres actifs (ancien 99), Actif de voirie (7) situé sous un actif de voirie de position 6, Actif de voirie (8) situé sous un actif de voirie de position 7	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc …	
TYPEFONDATION_REF	Text	Null, Inconnu, Rigide, Souple	
TYPEUSAGECYCLABLE_REF	Text	Null, Bande cyclable avec mail, Chaussée designee, Piste cyclable sans mail, Traverse de piétons – vélo, Trottoir désigné, Voie cyclable - Bande cyclable, Voie cyclable - Piste cyclable	
UTILISATION_REF	Text	Null, Aménagement, Traverse de piétons, Voie cyclable, Véhicule	
DATE_VERSION	Date	7/15/18	
SHAPE_Length	Double	4.8-2988.4	Perimeter (m)

SHAPE_Area	Double	0.39-19694.6	m^2
24313 items			

Table 0-4 Information of Roads layer (polyline)

Géobase - réseau routier (open source data)-polylines			
Field name	**Data type**	**Value range**	**Comments**
FID	Object ID		
Shape	Geometry		
ID_TRC	Long	Longueuil: 1-499,000 Laval: 500,000-999,999 Montreal: 1,000,000-9,999,999	
DEB_GCH	Long	Actual civic number located at the beginning and the left of the section	
FIN_GCH	Long	Actual civic number located at the end and to the left of the section	
ARR_GCH	Text	Administrative limit of the borough located to the left of the section (N / A if not applicable because outside the City of Montreal)	
SENS_CIR	Double	The direction of flow is defined according to the scanning direction as follows: 1 -> one way in the direction of digitization -1 -> one way in the opposite direction of digitization 0 -> double meaning	
CLASSE	Double	classe 9 - Rue projetée classe 8 - Autoroutes classe 7 - Artères principales classe 6 - Artères secondaires classe 5 - Collectrices classe 4 - Privée classe 3 - Quai classe 2 - Places d'affaire	

		classe 1 - Certaines voies piétonnières classe 0 - Rues locales	
LIE_VOIE	Text	Particle of official place names, without abbreviation	
TYP_VOIE	Text	Generic official place name, without abbreviation	
DIR_VOIE	Text	Orientation of official place names, without abbreviation	
NOM_VOIE	Text	Specific for official place names, without abbreviation	
DEB_DRT	Long	Actual civic number located at the beginning and the right of the section	
FIN_DRT	Long	Actual civic number located at the end and to the right of the section	
ARR_DRT	Text	Administrative limit of the borough located to the right of the section (N / A if not applicable because outside the City of Montreal)	
LIM_GCH	Text	Administrative limit (municipality) located to the left of the section	
LIM_DRT	Text	Administrative limit (municipality) located to the right of the section	
LENGTH	Double	3.209-3322.187	add using add geometry attributes (m)
45790 items			

7.6.2.1.2 Sidewalk & curb

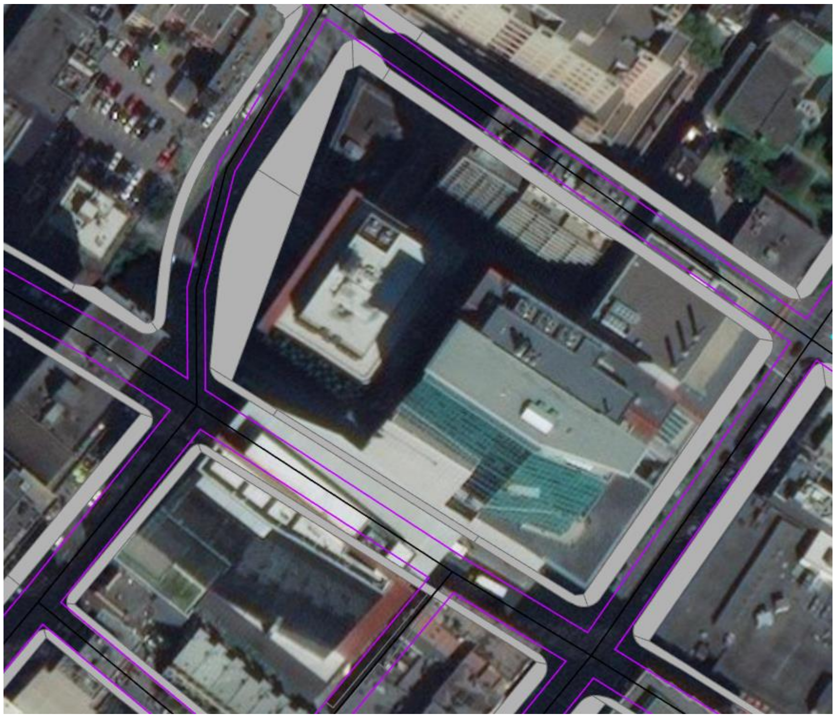


Table 0-5 Information of Sidewalk layer (polygon)

ATI_GEOMATIQUE_VOI_TROTTOIR_S_T12			
Field name	**Data type**	**Value range**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_VOI_TROTTOIR	Long		
CATEGORIETROTTOIR_REF	Text	Bordure, Bordure – autoroute, Trottoir, Trottoir – autoroute, Voie cyclable	
DATECONSTRUCTION	Date	1965-2017	
DATECONSTRUCTIONPREC_REF	Text	Null, DATE construction +/- 100 ans maximum, DATE construction +/- 5 ans maximum, DATE construction dans année courante, DATE	

		construction precise, DATE construction précise au mois courant	
MATERIAUBORDURE_REF	Text	Null, Asphalte, Béton, Granit, Inconnu, Non applicable	
MATERIAUINSER_REF	Text	Aménagement paysager, Asphalte, Béton, Gazon, Granit, Inconnu, Non applicable, Pavé, Pierre concassée (Gravier)	
MATERIAUTROTTOIR_REF	Text	Agrégat, Aménagement paysager, Asphalte, Asphalte et béton, Asphalte et pave, Béton, Inconnu, Non applicable, Pavé, Pierre concassée (Gravier)	
POSITION_REF	Text	Actif de voirie (1) situé au-dessus d'autres actifs (ancien 101), Actif de voirie (2) situé sous un actif de voirie de position 1, Actif de voirie (3) situé sous un actif de voirie de position 2, Actif de voirie (5) situé au sol (ancien 100), Actif de voirie (6) situé en dessous d'autres actifs (ancien 99), Actif de voirie (7) situé sous un actif de voirie de position 6, Actif de voirie (8) situé sous un actif de voirie de position 7	
PRESENCEARBRE_REF	Text	INC, Non, Non applicable, Oui	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc …	
TYPEBORDURE_REF	Text	Null, Bordure simple, Bordure surélevée (New Jersey), Bordure virtuelle, Bordure-caniveau, Inconnu, Mur de soutènement, Muret, Non applicable	
TYPETROTTOIR_REF	Text	Inconnu, Non applicable, Trottoir boulevard, Trottoir monolithe, Trottoir simple	
TYPEUSAGECYCLABLE_REF	Text	Null, Inconnu, Non applicable, Trottoir - Voie cyclable, Trottoir désigné	
DATE_VERSION	Date	7/15/18	
SHAPE_Length	Double	0.766-2926.403	Perimeter (m)
SHAPE_Area	Double	0.019-3037.198	m^2

30003 items

Geobase_double (open source)			
Field name	**Data type**	**Value range**	**Comments**
FID	Object ID		
Shape	Geometry		
COT_RUE_ID	Double		
ID_TRC	Double		
ID_VOIE	Double		
NOM_VOIE	Text		
NOM_VILLE	Text	BDU, BEA, CSL, DDO, DOR, HAM, IDO, KIR, MTE, MTL, MTO, PCL, SAB, SEN, VMR, WES	
DEBUT_ADRE	Double		
FIN_ADRESS	Double		
COTE	Text	Droite, Gauche	
TYPE_F	Text	Lane, allée, autoroute, avenue…	
SENS_CIR	Double	-1, 0, 1	1 -> one way in the direction of digitization -1 -> one way in the opposite direction of digitization 0 -> double meaning
LENGTH	Double	0.041-2034.960	add using add geometry attributes (m)
85739 items			

7.6.2.1.3 Intersections

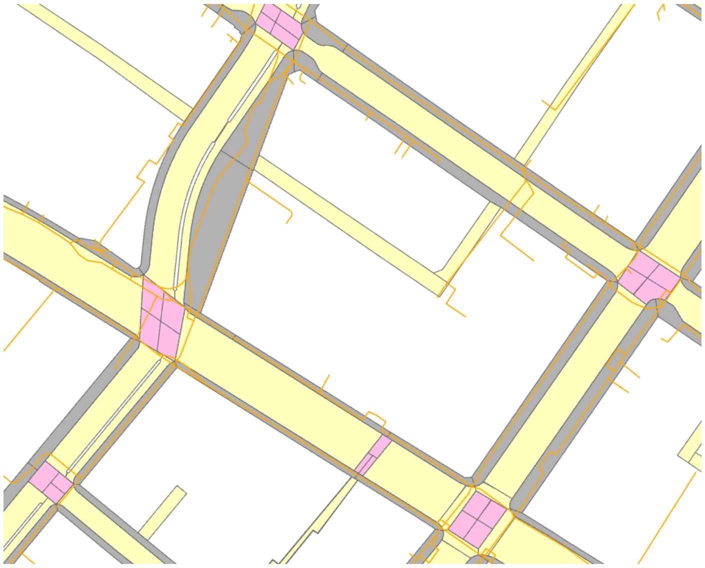
ATI_GEOMATIQUE_VOI_INTERSECTION_S_N12			
Field name	**Data type**	**Value range**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_VOI_INTERSECTION	Long		
DATECONSTRUCTION	Date	1959-2017, 01/01/28	
DATECONSTRUCTIONPREC_REF	Text	Null, DATE construction +/- 100 ans maximum, DATE construction +/- 5 ans maximum, DATE construction dans année courante, DATE construction precise, DATE construction précise au mois courant	
DATERESURFACAGE	Date	1989-2018	
MATERIAUINTER_REF	Text	Asphalte, Asphalte et pave, Béton, Pavé, Pierre concassée (Gravier)	
POSITION_REF	Text	Actif de voirie (1) situé au-dessus d'autres actifs (ancien 101), Actif de voirie (5) situé au sol (ancien 100), Actif de voirie (6) situé en dessous d'autres actifs (ancien 99)	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, …	
TYPEFONDATION_REF	Text	Null, Inconnu, Rigide, Souple	
TYPEINTERSECTION_REF	Text	Accès - Passage de piétons avec feux de circulation, Intersection de rues	
TYPEUSAGECYCLABLE_REF	Text	Null, Chaussée désignée	
DATE_VERSION	Date	Null, 07/15/18	
SHAPE_Length	Double	6.329-138.609	Perimeter (m)
SHAPE_Area	Double	2.376-699.227	m^2
22625 items			

7.6.2.1.4 Central Island

ATI_GEOMATIQUE_VOI_ILOT_S_M12

Field name	**Data type**	**Value range**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_VOI_ILOT	Long		
DATECONSTRUCTION	Date	2001-2017	
DATECONSTRUCTIONPREC_REF	Text	Null, DATE construction +/- 5 ans maximum, DATE construction dans année courante,	
MATERIAUBORDURE_REF	Text	Null, N/A, Béton, Granit, Inconnu	
MATERIAUILOT_REF	Text	N/A, Aménagement paysager, Asphalte, Béton, Gazon, Inconnu, Pavé, Pierre concassée (Gravier)	
MATERIAUINSERILOT_REF	Text	Null, N/A, Inconnu	
POSITION_REF	Text	Actif de voirie (1) situé au-dessus d'autres actifs (ancien 101), Actif de voirie (5) situé au sol (ancien 100), Actif de voirie (6) situé en dessous d'autres actifs (ancien 99), Actif de voirie (7) situé sous un actif de voirie de position 6, Actif de voirie (8) situé sous un actif de voirie de position 7	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, …	
TYPEBORDURE_REF	Text	N/A, Bordure simple, Bordure surélevée (New Jersey), Inconnu, Muret	
TYPEILOT_REF	Text	Ilot central, Ilot central giratoire, Ilot déviateur, Ilot séparateur, Terre-plein central, Terre-plein central – autoroute, Terre-plein latéral – autoroute, Terre-plein latéral – cyclable, Terre-plein latéral - voirie	
DATE_VERSION	Date	Null, 07/15/18	
SHAPE_Length	Double	6.329-138.609	Perimeter (m)
SHAPE_Area	Double	2.376-699.227	m^2
2709 items			

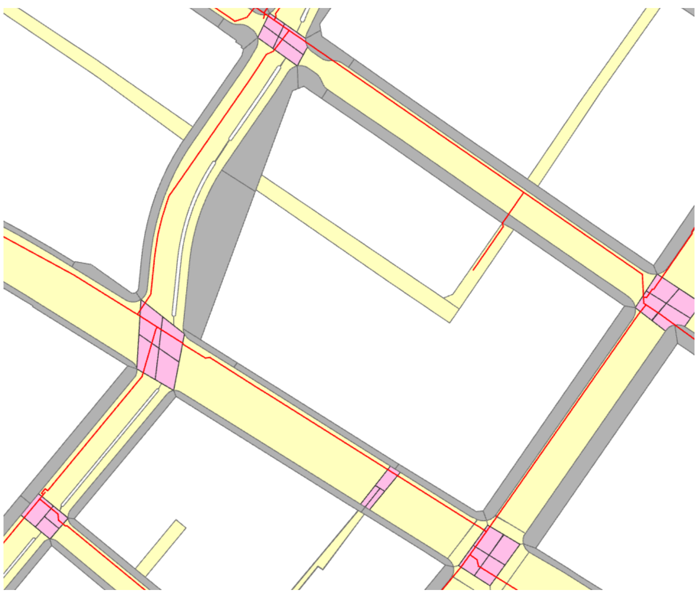
7.6.2.2 HQ



HQ_ligne			
Field name	**Data type**	**Value range**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
LIGNE	Text		
TYPE	Text	Aérien, Souterrain	
NOMBRE_SUP	Text	0, 1, 2, 3, 4, 7, 10, 11, 15, 16, 22, 50, 51, 53, 80, 113, 114, -9999	
ETAT	Text	Exploité, NULL	exploited
PROPRIO	Text	HQTE, NULL	
TENSION	Text	120, 315, basse, moyenne	Low (basse), medium (moyenne)
VERSION	Text	V2012-12-01, V2017-01-03	
poly	Text	63	

DESCRIPTION	Text	Null, Biphasé, Branchement, Monophasé, Neutre, Non renseigné, Secondaire principal, Triphasé, Éclairage	Null, Biphasic, Connection, Single Phase, Neutral, N/A, Main Secondary, Three Phase, lighting
SHAPE_Length	Double	0.078-9045.248	m
472326 items			

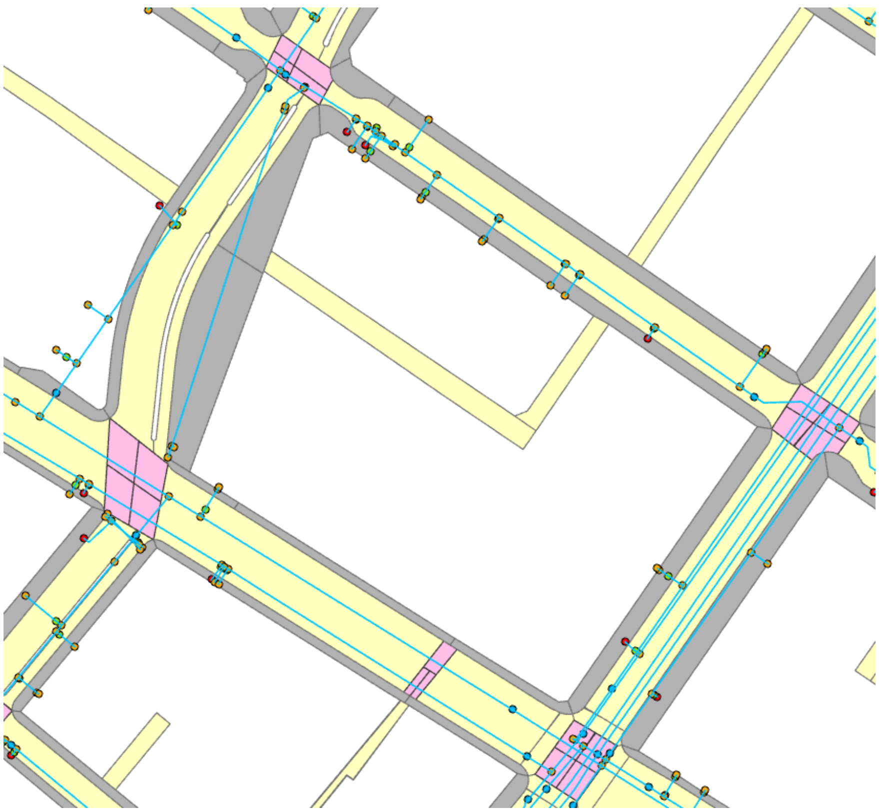
7.6.2.3 GazMetro



Conduite			
Field name	**Data type**	**Values**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
classe_pression (pressure class)	Text	175, 275, 400, 1000, 2400, Null (999)	Pa?
date_installation	Text	1953-2017	
diametre	Text	15.9, 26.7, 42.2, 60.3, 88.9, 114.3, 168.3, 219.1, 273.1, 323.9, 406.4, 508.0	mm?

G3E_FID	Text	Null	
materiel	Text	ACIER (Steel), Plastique	
SHAPE_Length	Double	0.216 to 542.139	m
54467 items			

7.6.2.4 AQU



Voici quelques définitions et précisions sur certains champs se rapportant à l'eau (AQU_EGO);

DATEINSTALLPREC_REF: Ce champ apporte une précision sur la date d'installation de l'élément.

RADIERAMONT: C'est l'élévation en mètres par rapport au niveau moyen des mers de l'amont de la conduite d'égout.

RADIERAVAL: C'est l'élévation en mètres par rapport au niveau moyen des mers de l'aval de la conduite d'égout.

DIAMETREI_REF: Diamètre nominal de la conduite d'aqueduc en impérial (pouces).

DIAMETREM_REF: Diamètre nominal de la conduite d'aqueduc en métrique (millimètres).

DIAMETREHORIZONTALI_REF: Diamètre horizontal nominal de la conduite d'égout en impérial (pouces).

DIAMETREHORIZONTALM_REF: Diamètre horizontal nominal de la conduite d'égout en métrique (millimètres).

DIAMETREVERTICALI_REF: Diamètre vertical nominal de la conduite d'égout en impérial (pouces).

DIAMETREVERTICALM_REF: Diamètre vertical nominal de la conduite d'égout en métrique (millimètres).

AQU_SEGMENT_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
DATEINSTALL	Date	1955-2018	
DATEINSTALLPREC_REF	Text	Date installation +/- 10 ans maximum, Date installation +/- 100 ans maximum, Date installation +/- 25 ans maximum, Date installation +/- 5 ans maximum, Date installation +/- 6 mois maximum, Date installation dans année courante, Date installation precise, Date installation précise au mois courant, Inconnu	
DIAMETREI_REF	Double	-1, 0.5, 0.75, 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 9, 10, 12, 14, 15, 16, 18, 20, 21, 24, 30, 34, 36, 42, 48, 54, 60, 66, 72, 84, 96, 108, 144, 156	mm? inner diameter?
DIAMETREM_REF	Long	-1, 15, 20, 25, 30, 35, 50, 60, 75, 100, 125, 150, 200, 225, 250, 300, 350, 375, 400, 450, 500, 525, 600, 750, 850, 900, 1050, 1200, 1350, 1500, 1650, 1800, 2100, 2400, 2700, 3600, 3900	mm? outer diameter?
ID_AQU_SEGMENT	Long	159- 11189037	
JURIDICTION_REF	Text	Agglomération, Inconnu, Loc Ctre-ville, Locale, Non applicable	
MATERIAUSEGMENT_REF	Text	Acier, Acier inoxydable, Acier-insertion-Acier Béton, Béton armé, Béton non-armé, Béton précontraint, Chlorure de polyvinyle, Cuivre, Fer galvanise, Fonte ductile, Fonte grise, Inconnu, Polyéthylène, À valider, Non applicable	

PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc, …	
STATUT_REF	Text	Abandonné, Existant, À valider	
TYPESEGMENT_REF	Text	Amenee, Branchement borne incendie, Branchement de purge, Branchement de vidange, Branchement feu, Branchement gicleur, Branchement service eau, Branchement service eau et gicleur, Dérivation, Inconnu, Raccordement, Réseau	Provided, Fire hydrant connection, Drain connection, Drain connection, Fire connection, Spray connection, Water service connection, Water and jet service connection, Bypass, Unknown, Connection, Network (Supply, Fire hydrant connection, Fire connection, Sprinkler connection, Water service connection, Network)
SHAPE_Length	Double	0.053-6504.865	
127716 items			

AQU_REGARD_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
DATEINSTALL	Date	1955-2018	
DATEINSTALLPREC_REF	Text	Date installation +/- 10 ans maximum, Date installation +/- 100 ans maximum, Date installation +/- 25 ans maximum, Date installation +/- 5 ans maximum, Date installation +/- 6 mois maximum, Date installation dans année courante, Date installation precise, Date installation précise au mois courant, Inconnu	
ID_AQU_REGARD	Long		
JURIDICTION_REF	Text	Agglomération, Inconnu, Loc Ctre-ville, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	

STATUT_REF	Text	Abandonné, Existant, À valider, Non applicable	
TYPEREGARD_REF	Text	Acces anode, Acces chamber, boitier acces vanne, regard, virtuel	anode access, room access, box valve access, look, virtual
ELEVATION	Double	0-194.554	m
ALTITUDE	Double	All Null	
15784 items			

AQU_RACCORD_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_AQU_RACCORD	Long		
JURIDICTION_REF	Text	Agglomération, Inconnu, Loc Ctre-ville, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider, Non applicable	
TYPERACCORD_REF	Text	Bouchon, Bouchon virtuel - fin de cadastre, Branchement service, Croix, Inconnu, Manchon, Noeud changement de pente DEP, Noeud fictive, Noeud fictif boucle, Noeud fictif date, Noeud fictif rehabilitation, Noeud fictif tunnel, Noeud pente verticale 22.5, Noeud pente verticale 45, Noeud pente verticale 90, Noeud pente verticale inconnue, Noeud union matériaux, Réducteur, Sellette, Sellette branchement service, Té, Y	
ELEVATION	Double	Null, 0, 13.72, 13.9, 14.015, 14.68, 14.72, 15.814, 16.846, 26.458, 43.245, 67.365	m
ALTITUDE	Double	Null, 0-347.72	
88794 items			

AQU_VANNE_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
DATEINSTALL	Date	1955-2018	
DATEINSTALLPREC_REF	Text	Date installation +/- 10 ans maximum, Date installation +/- 100 ans maximum, Date installation +/- 25 ans maximum, Date installation +/- 5 ans maximum, Date installation +/- 6 mois maximum, Date installation dans année courante, Date installation precise, Date installation précise au mois courant, Inconnu, Non applicable	
ID_AQU_VANNE	Long	19 to 11049100	
JURIDICTION_REF	Text	Agglomération, Inconnu, Loc Ctre-ville, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, Hors d'usage, Proposé, À valider	
TYPEVANNE_REF	Text	Maintenance, Reseau, service	
ELEVATION	Double	Null, 0-197.909	m
ALTITUDE	Double	Null, 0-345.41	
		49974 items	

AQU_BORNEINCENDIE_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
DATEINSTALL	Date	1962-2018	

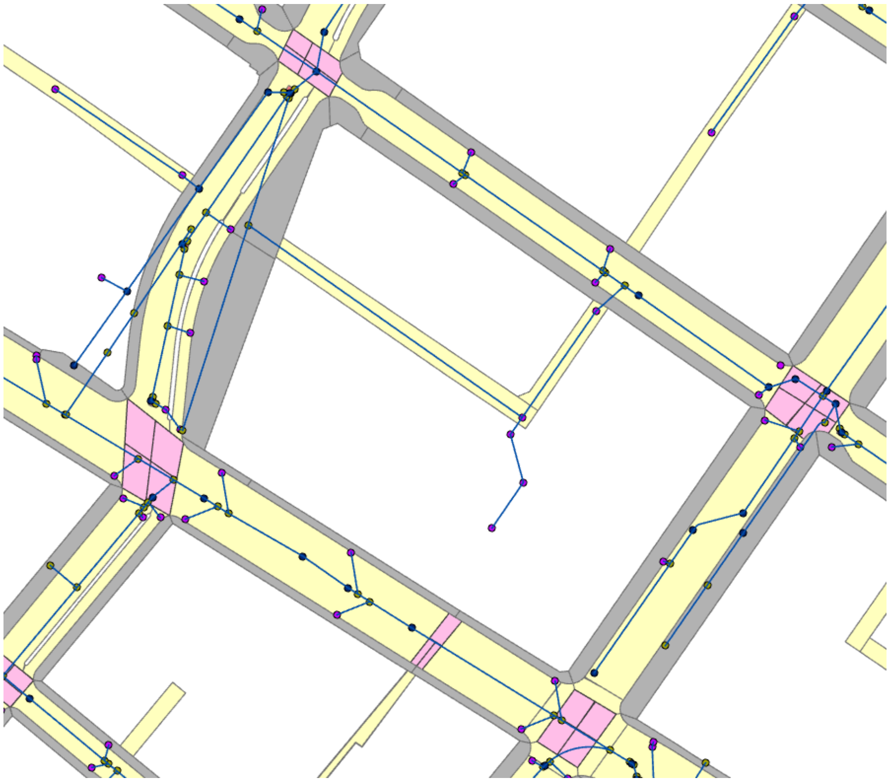
DATEINSTALLPREC_REF	Text	Date installation +/- 10 ans maximum, Date installation +/- 100 ans maximum, Date installation +/- 25 ans maximum, Date installation +/- 5 ans maximum, Date installation +/- 6 mois maximum, Date installation dans année courante, Date installation precise, Date installation précise au mois courant, Inconnu	
ID_AQU_BORNEINCENDIE	Long	13-10008247	
JURIDICTION_REF	Text	Agglomération, Inconnu, Loc Ctre-ville, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider	
ELEVATION	Double	0-199.843	m
10298 items			

AQU_ACCESSOIRE_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_AQU_ACCESSOIRE	Long		
JURIDICTION_REF	Text	Agglomération, Inconnu, Loc Ctre-ville, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider	
TYPEACCESSOIRE_REF	Text	Abreuvoir, Autre accessoire, Boyau, Compteur chamber, Compteur non-chambré, Pompe, Puits de pompage, Purge d'air automatique, Robinet, Robinet de pitomètre, Trou inspection	
ELEVATION	Double	Null, 0, 11.775, 13.024, 13.477, 13.651, 15.201, 16.324, 16.379, 17.124, 25.282, 29.884, 30.649, 31.511, 32.054, 32.748, 33.394, 36.207, 44.308, 45.219, 45.535, 49.48, 50.291, 51.224, 51.425, 51.558, 65.454, 66.499, 82.821, 83.561, 105.3	

ALTITUDE	Double	Null, 0, 39.66, 48.77, 58.11, 58.61, 64.3, 101.41, 101.8, 103, 127.41, 148.94, 209, 253.5, 286.41, 326.26	
3856 items			

AQU_CHAMBRE_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_AQU_CHAMBRE	Long	170-10029536	
JURIDICTION_REF	Text	Agglomération, Inconnu, Loc Ctre-ville, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider	
TYPECHAMBRE_REF	Text	Aqueduc, Boyau, Bâtiment, Compteur, Détendeur, Pitomètre, Point de verification, Purge air, Raccordement, Régulation, Station de pompage, Vanne, Vidange	
SHAPE_Length	Double	0.416-1510.426	m
SHAPE_Area	Double	0.002-25351.992	m^2
14320 items			

7.6.2.5 EGO



EGO_SEGMENT_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
DATEINSTALL	Date	1930-2018	
DATEINSTALLPREC_REF	Text	Date installation +/- 10 ans maximum, Date installation +/- 100 ans maximum, Date installation +/- 25 ans maximum, Date installation +/- 5 ans maximum, Date installation +/- 6 mois maximum, Date installation dans année courante, Date installation precise, Date installation précise au mois courant, Inconnu, Non applicable	

DIAMETREHORIZONTALI_REF	Double	-2, -1, 0.5, 1.5, 2, 3, …, 213	mm? inner diameter?
DIAMETREHORIZONTALM_REF	Long	-2, -1, 15, 35, 50, 75, …, 5325	mm? outer diameter?
DIAMETREVERTICALI_REF	Double	-2, -1, 0.5, 1.5, 2, 3, …, 240	mm? inner diameter?
DIAMETREVERTICALM_REF	Long	-2, -1, 15, 35, 50, 75, …, 6000	mm? outer diameter?
FORMESEGMENT_REF	Text	Circulaire, Fer à cheval, Ovoide, Rectangulaire, Semi-elliptique, Inconnu, Non applicable	
ID_EGO_SEGMENT	Long	27- 10135063	
JURIDICTION_REF	Text	Agglomération, Locale, Non applicable	
MATERIAUSEGMENT_REF	Text	Acier, Acier ondulé goudronné, Amiante-ciment (Transite), Argile vitrifiée, Bois, Brique, Béton armé, Béton non-armé, Béton précontraint (Hyprescon), Chlorure de polyvinyle, Fer galvanise, Fonte ductile, Fonte grise, GRES, Pierre, Plastique (Bigo), Polyoléfine thermoplastique, Polyéthylène haute densité, Tuyau de tole ondulé aluminise, Tuyau de tole ondulé galvanise, À valider, Inconnu, Non applicable	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider, Non applicable	
TYPESEGMENT_REF	Text	Collecteur, Conduite de raccordement, Drain, Drain perforé, Dérivation, Fossé, Intercepteur, Lien de continuité de chamber, Ponceau, Refoulement, Réseau, Trop plein, Émissaire	
TYPERESEAU_REF	Text	Combiné (combined) Pluvial (rain) Sanitaire (sanitary) Inconnu Non applicable	
RADIERAMONT	Double	-26.8, -26.34, …, 0, …, 253.64, 270.6, 11626, …, 48167	
RADIERAVAL	Double	-27.333-106713	
SHAPE_Length	Double	0.020-2029.059	m

119857 items	

EGO_REGARD_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
DATEINSTALL	Date	1941-2017, 05/04/1524	
DATEINSTALLPREC_REF	Text	Date installation +/- 10 ans maximum, Date installation +/- 100 ans maximum, Date installation +/- 25 ans maximum, Date installation +/- 5 ans maximum, Date installation +/- 6 mois maximum, Date installation dans année courante, Date installation precise, Date installation précise au mois courant, Inconnu, Non applicable	
ID_EGO_REGARD	Long		
JURIDICTION_REF	Text	Agglomération, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider, Non applicable	
TYPEREGARD_REF	Text	Accès chamber, Boitier accès vanne, Regard, Regard-puisard, Virtuel	
ELEVATION	Double	0-225.969	m
ALTITUDE	Double	-25.52-222.025	m
32290 items			

EGO_RACCORD_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		

SHAPE	Geometry		
ID_EGO_RACCORD	Long		
JURIDICTION_REF	Text	Agglomération, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider, Non applicable	
TYPERACCORD_REF	Text	Bouchon, Bouchon virtuel, Croix, Manchon, Mur, Noeud fictive, Noeud fictif ba, Noeud fictif da, Noeud fictif de, Noeud fictif jo, Noeud fictif ré, Noeud union mat, Réducteur, Segment fossé, Segment ponceau, Té, Y, de Puisard, Inconnu	
ELEVATION	Double	Null, 0, 44.605	
ALTITUDE	Double	Null, -23.93-221.98	
79175 items			

EGO_PUISARD_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
DATEINSTALL	Date		
DATEINSTALLPREC_REF	Text	Date installation +/- 10 ans maximum, Date installation +/- 100 ans maximum, Date installation +/- 25 ans maximum, Date installation +/- 5 ans maximum, Date installation +/- 6 mois maximum, Date installation dans année courante, Date installation precise, Date installation précise au mois courant, Inconnu	
ID_EGO_PUISARD	Long		
JURIDICTION_REF	Text	Agglomération, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider	
TYPEPUISARD_REF	Text	Circulaire, Rectangulaire, de Trottoir, Inconnu	

ELEVATION	Double	Null, 0-223.558	
ALTITUDE	Double	Null, 0, 14.249, 14.261, 14.437, 14.494, 14.618, 14.706, 15.087, 15.316, 15.392, 15.648, 16.005, 16.431, 16.462, 16.76, 28.666, 29.199, 41.148, 45.18, 114.38	
65497 items			

EGO_ACCESSOIRE_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_EGO_ACCESSOIRE	Long		
JURIDICTION_REF	Text	Agglomération, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider	
TYPEACCESSOIRE_REF	Text	Autre accessoire, Grille, Grille de drain de chambre aqueduct, Grille émissaire, Pompe, Régulateur de debit, Vanne, Vanne clapet, Vanne glissière, Vanne murale, Inconnu	
ELEVATION	Double	Null, 0, 6.062, 6.417, 8.304, 8.335, 8.76, 9.659, 9.77, 9.98, 10.488, 11.217, 11.246, 11.34, 11.431, 11.545, 11.706, 12.046, 14.288	
ALTITUDE	Double	Null, -12.188, -4.73, 0, 7.49, 9, 53.465, 53.64, 54.203, 59.871	
1128 items			

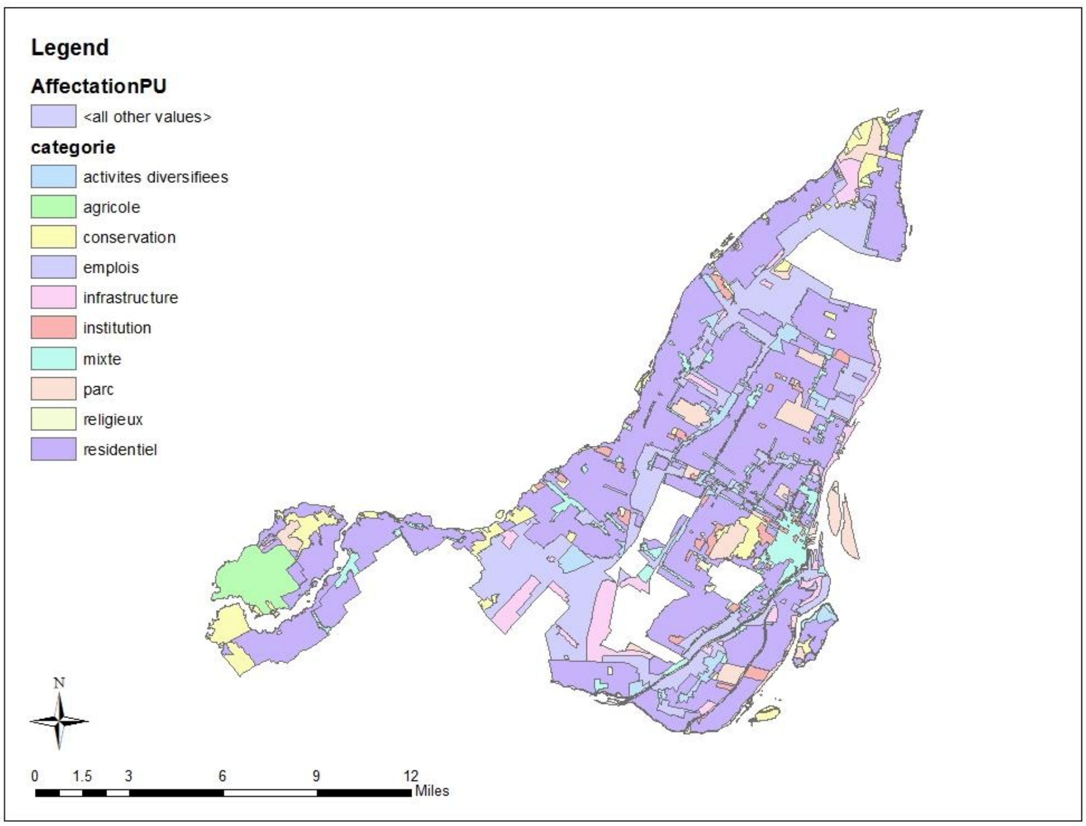
EGO_CHAMBRE_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		

SHAPE	Geometry		
ID_EGO_CHAMBRE	Long		
JURIDICTION_REF	Text	Agglomération, Locale, Non applicable	
PROPRIETAIRE_REF	Text	Anjou, Côte-Des-Neiges - Notre-Dame-de-Grâce, Côte-Saint-Luc…	
STATUT_REF	Text	Abandonné, Existant, À valider, Non applicable	
TYPECHAMBRE_REF	Text	Bâtiment, Chute à neige, Dérivation, Déversoir clapet, Poste de pompage, Raccordement, Régulation, Rétention, Égout, Inconnu	
SHAPE_Length	Double	0.021-164.060	m
SHAPE_Area	Double	0.000005-961.348	m^2
32664 items			

EGO_BASSINRETENTION_P_J_VM			
Field name	**Data type**	**Value ranges**	**Comments**
OBJECTID	Object ID		
SHAPE	Geometry		
ID_EGO_BASSIN	Long		
JURIDICTION_REF	Text	Agglomération, Locale	
PROPRIETAIRE_REF	Text	Côte-Des-Neiges - Notre-Dame-de-Grâce, Lasalle, …	
STATUT_REF	Text	Existant	
TYPEBASSIN_REF	Text	Inconnu	
SHAPE_Length	Double	22.377-682.977	m
SHAPE_Area	Double	31.229-12004.447	m^2
19 items			

7.6.2.6 Land use

AffectationPU			
Field name	**Data type**	**Values**	**Comments**
FID	OBJECTID		
Shape	SHAPE		
categorie	Text	Activites Diversifiees, Agricole, Conservation, Emplois, Infrastructure, Institution, Mixe, Parc, Religieux, Residential	
AREA	Long	117-37690483	m^2



Class	Count
Activites Diversifiees	53
Agricole	1
Conservation	82
Emplois	39
Infrastructure	22
Institution	53
Mixe	84
Parc	138
Religieux	31
Residential	75

http://ville.montreal.qc.ca/pls/portal/docs/PAGE/PLAN_URBANISME_FR/MEDIA/DOCUMENTS/160125_3_2.PDF

CATÉGORIE ET DESCRIPTION	COMPOSANTES	NOTES
SECTEUR RÉSIDENTIEL Aire à vocation principalement résidentielle comportant aussi des portions mixtes, notamment des rues de commerces et d'habitation.	■ Habitation ■ Commerce ■ Équipement collectif ou institutionnel ■ Équipement et construction requis pour la mise en service du réservoir d'eau potable souterrain existant dans le parc local Étienne-Desmarteau	La réglementation assure le découpage en zones distinctes des secteurs essentiellement résidentiels, des secteurs à caractère commercial et des ensembles occupés par des équipements collectifs ou institutionnels. Elle détermine les catégories d'usages selon la nature des milieux et le caractère de l'arrondissement. Elle assure, par les modes de gestion des usages, l'insertion harmonieuse des activités non résidentielles : les types d'usages autorisés de plein droit, les usages conditionnels, les limites de superficie, l'obligation de continuité commerciale, le contingentement de certains usages, etc.
SECTEUR MIXTE Aire diversifiée comportant une composition variée d'activités et de l'habitation. Plusieurs de ces secteurs recouvrent des aires présentant un potentiel d'intensification du nombre delogements ou du nombre d'emplois.	■ Habitation ■ Commerce ■ Bureau ■ Équipement collectif ou institutionnel ■ Dans le respect de la cohérence des milieux et en assurant une saine cohabitation des usages, la réglementation reconnaît ponctuellement certaines occupations à caractère industriel présentes lors de l'adoption du Schéma d'aménagement le 29 janvier 2015	La réglementation définit les zones et détermine les usages autorisés dans chacune selon la nature des milieux, notamment de manière à assurer l'interface entre les ensembles à dominance résidentielle et les zones d'activités plus intensives.
SECTEUR D'ACTIVITÉS DIVERSIFIÉES Aire à dominante économique qui peut accueillir, sous certaines conditions, l'intégration d'un usage résidentiel à proximité du réseau de transport collectif.	■ Commerce ■ Bureau ■ Industrie légère ■ Équipement collectif ou institutionnel ■ Habitation, si compatible avec les usages, l'intensité des nuisances et des risques et la nature du cadre bâti	Afin de permettre un usage résidentiel dans une zone, une étude de sa compatibilité doit être effectuée en regard des autres usages, de l'intensité des nuisances et des risques et de la nature du cadre bâti.
SECTEUR D'EMPLOIS Aire à vocation économique comportant principalement des activités à caractère industriel ou commercial. Les secteurs d'emplois correspondent à des aires où l'habitation est exclue.	■ Industrie ■ Bureau ■ Commerce ■ Équipement collectif ou institutionnel	La réglementation définit les zones et détermine les types d'usages autorisés selon la nature des milieux, notamment de manière à limiter aux secteurs d'emplois à caractère industriel les types d'usages générateurs de nuisances majeures.

CATÉGORIE ET DESCRIPTION	COMPOSANTES	NOTES
AGRICOLE Aire réservée à l'agriculture et aux activités agricoles au sens de la LPTAA, qui comprend la culture du sol et des végétaux, l'horticulture, l'acériculture ainsi que l'élevage.	■ Agriculture et activité agricole ■ Habitation unifamiliale conforme aux droits et privilèges précisés dans la LPTAA ■ Commerce et industrie légère complémentaires à l'exploitation agricole, en vertu de la LPTAA ■ Installation, équipement ou aménagement de récréation extensive, complémentaires à l'exploitation agricole ■ Installation de recherche, d'éducation, de prélèvement scientifique ou d'interprétation qui est reliée à la nature	
CONSERVATION Aire réservée à la protection, au rehaussement et à la mise en valeur de la biodiversité ainsi que du patrimoine naturel et paysager, située à l'intérieur du périmètre d'urbanisation ou en zone agricole permanente.	■ Installation de recherche, d'éducation, de prélèvement scientifique ou d'interprétation reliée à la nature ■ Installation, équipement ou aménagement de récréation extensive ■ Aménagement des milieux naturels visant la gestion écologique et l'amélioration de la biodiversité	En zone agricole permanente sont permises les activités agricoles au sens de la LPTAA. Dans les habitats floristiques désignés en vertu de la *Loi sur les espèces menacées ou vulnérables* ainsi que dans les réserves naturelles établies en vertu de la *Loi sur la conservation du patrimoine naturel*, les usages et activités devront être restreints à ceux autorisés par ces lois.

CATÉGORIE ET DESCRIPTION	COMPOSANTES	NOTES
GRAND ÉQUIPEMENT INSTITUTIONNEL Aire comportant des constructions et des terrains réservés à des activités institutionnelles qui jouent un important rôle de service dans la communauté montréalaise.	■ Grand équipement institutionnel (enseignement, soins de santé, sport et culture) ■ Équipement collectif ou institutionnel ■ Commerce et habitation complémentaires ■ Commerce situé au rez-de chaussée en bordure d'une rue du Centre identifiée à la carte 2.1.2 où la continuité commerciale est exigée, ou situés à même le réseau piéton souterrain, à la condition que de tels commerces soient autorisés par un règlement adopté en vertu de l'article 89 de la Charte de la Ville de Montréal ou par une résolution de projet particulier de construction, de modification ou d'occupation d'un immeuble	
COUVENT, MONASTÈRE OU LIEU DE CULTE Aire comportant des constructions et des terrains réservés à des établissements conventuels ou à des lieux de culte.	■ Immeuble voué aux activités des communautés religieuses comportant des lieux de résidence ■ Lieu de culte ■ Équipement collectif ou institutionnel ■ Commerce et habitation complémentaires	Même s'ils ne sont pas identifiés par une aire d'affectation à la carte 3.1.1, sont visés par cette catégorie d'affectation les lieux de culte compris dans les listes de bâtiments d'intérêt patrimonial et architectural de la Partie II. Dans l'arrondissement de Ville-Marie, cette affectation permet les commerces uniquement dans un local occupé à cette fin avant l'entrée en vigueur du Plan d'urbanisme de la Ville de Montréal, en novembre 2004, à la condition que de tels commerces soient autorisés par un règlement adopté en vertu de l'article 89 de la Charte de la Ville de Montréal ou par une résolution de projet particulier de construction, de modification ou d'occupation d'un immeuble.

CATÉGORIE ET DESCRIPTION	COMPOSANTES	NOTES
GRAND ESPACE VERT OU PARC RIVERAIN Aire réservée aux espaces verts ou naturels d'envergure montréalaise ou situés en rive ainsi qu'aux grands cimetières.	■ Grand parc ■ Parc local ■ Parc-nature ■ Lieu public ■ Réserve naturelle ■ Berge et île publiques ■ Golf ■ Équipement collectif ou institutionnel ■ Commerce ou bureau complémentaires aux installations de récréation ■ Équipement collectif Casino, commerces et installations complémentaires	La réglementation n'autorise l'équipement collectif Casino, commerces et installations complémentaires que sur les lots 2 988 178, 2 988 179 et 2 988 180 du cadastre du Québec et prévoit cet usage sans limite de superficie de plancher.
GRANDE EMPRISE OU GRANDE INFRASTRUCTURE PUBLIQUE Aire vouée aux activités de transport et aux équipements à l'usage des services publics pouvant générer des nuisances importantes pour le voisinage.	■ Infrastructure portuaire, ferroviaire ou aéroportuaire ■ Équipement ou infrastructure d'assainissement et de traitement des eaux ■ Équipement majeur de collecte, de tri, de valorisation et d'élimination de matières résiduelles ■ Équipement majeur d'entreposage et d'élimination des neiges usées	

7.6.2.7 Buildings

CARTO-BAT-TOIT (polygons)			
Field name	**Data type**	**Values**	**Comments**
FID	OBJECTID		
Shape	SHAPE		
calque	Text	CARTO-BAT-TOIT	
projection	Text	Mercator transverse modifiée, fuseau 8	
reference	Text	NAD83 SCRS / C-GVD28 (NMM)	
EQM_plani	Text	ND, ± 30 à ± 40 cm	
EQM_alti	Text	ND	
MAJ	Text	avril 2016, novembre 2015, validé en avril 2016	
methode	Text	modélisation automatique, numérisé sur orthophoto, photogrammétrie	
source	Text	LiDAR aérien, Ville de Montréal, orthophoto, Ville de Montréal, photo aérienne, (C) Communauté métropolitaine de Montréal	
producteur	Text	Division de la géomatique, Ville de Montréal	
superficie	Text	0.0-9970.3	
3617 items			

CARTO-BAT-COTE			
Field name	**Data type**	**Values**	**Comments**
FID	OBJECTID		
Shape	SHAPE		
calque	Text	CARTO-BAT-COTE	

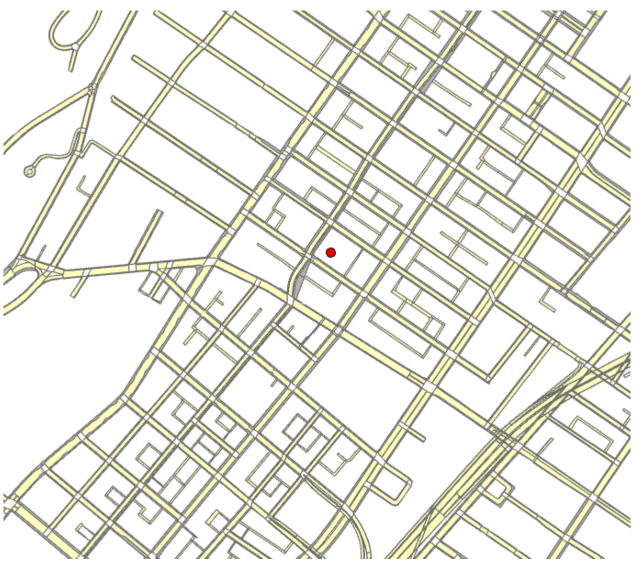
projection	Text	Mercator transverse modifiée, fuseau 8	
reference	Text	NAD83 SCRS / C-GVD28 (NMM)	
EQM_plani	Text	ND	
EQM_alti	Text	± 45 à ± 60 cm	
MAJ	Text	avril 2016	
methode	Text	photogrammétrie	
source	Text	photo aérienne, (C) Communauté métropolitaine de Montréal	
producteur	Text	Division de la géomatique, Ville de Montréal	
elevation	Text	10.7-169.8	
3617 items			

7.6.2.8 Public facilities

7.6.2.8.1 Health facilities

7.6.2.8.2 Colleges

7.6.2.8.3 Universities



7.6.2.9 Inspection and Intervention data

7.6.2.9.1 Roads

gb_tra_l_j (roads) -polylines			
Field name	**Data type**	**Value range**	**Comments**
FID	Object ID		
Shape	Geometry		
ID_TRC	Double	1,080,034-4,014,802	
DEBUT_GAUC	Double		
FIN_GAUCHE	Double		
ARRONDIS00	Text		Borough or municipality
ARRONDIS01	Text		Borough or municipality
CODE_ARRON	Text		Borough code
NOM_VILLE_	Text		
SENS_CIR	Double	The direction of flow is defined according to the scanning direction as follows: 1 -> one way in the direction of digitization -1 -> one way in the opposite direction of digitization 0 -> double meaning	Same as open data
CLASSE	Double	classe 9 - Rue projetée classe 8 - Autoroutes classe 7 - Artères principales classe 6 - Artères secondaires classe 5 - Collectrices classe 4 - Privée classe 3 - Quai classe 2 - Places d'affaire classe 1 - Certaines voies piétonnières classe 0 - Rues locales	Same as open data
NOM_VOIE	Text		
DEBUT_DROI	Double		

FIN_DROITE	Double		
VILLE_G_20	Text		
VILLE_D_20	Text		
CIR_BUS	Double	0,1	
15905 items			

7.6.2.9.2 Roads intervention plan

TRC_PI (intervention plan)-polylines			
Field name	**Data type**	**Value range**	**Comments**
FID	Object ID		
Shape	Geometry		
ID_TRC_PI	Double	4101-40000	=ID_TRC in roads layer?
CARTE_ETIQ	Text		
CARTE_LEGE	Text	1 ou 2 actifs critiques dont au moins un en reconstruction, 3 actifs critiques dont au moins un en reconstruction, Aucune intervention, R, R(habilitation chaussae critique, sans r habilitation de l'eau potable ni de l'hgout, R(habilitation de l'eau potable ou de l' gout, avec ou sans ruhabilitation de chauss	
ARRONDISSE	Text		
LONGUEUR	Double		
9377 items			

7.6.2.9.3 Roads intervention plan (table)

TABLE- RÉSEAUX DE VOIRIE PAR POLYGONE DE CHAUSSÉE & INTERVENTIONS À COURT TERME 0-5 ANS (2016-2020) (roads intervention plan)			
	Field name	**Value range**	**Comments**
DÉSIGNATION DU TRONÇON UNIFIÉ	"ABRÉV. VILLE / ARROND."		
	Arrondissement de Montréal ou Ville-liée		

	Tronçon unifié		Same as Chaussée PI
	Rue		
	De		
	À		
DONNÉES PHYSIQUES DE LA CHAUSSÉE	Chaussée PI	4455-37318	="ID_TRC_PI" in TRC_PI (road intervention plan layer)?
	Type chaussée	Rigide, Souple	
	Revêtement	Asphalte, …	road material
	Date construction	1899-2014	
	Longueur (m)		
	Superficie (m2)		
	Année insp.	2015	Inspection year
	Orniérage (mm)		
	Catégorisation	A, B, C, D, E	
	"Hiérarchie (Guide MAMOT)"	I, II, III	I-important II-moyen III-faible
	Juri.		
INDICATEURS DONNÉES D'ÉTAT	PCI	1-100	Pavement Condition Index (Excellent, Bon, Moyen, Mauvais, Tres mauvais)
	IRI	0-13.9	International Roughness Index (Excellent, Bon, Moyen, Mauvais, Tres mauvais)
	Susceptibilité au gel (Cote)	All null	
	Capacité structurale en fonction de la durée de vie résiduelle (Cote)	All null	
"ÉVALUATION STATIQUE SELON LE GUIDE DU MAMOT	"Statut initial (selon le PCI ou l'IRI)"	Excellent, Bon, Moyen, Mauvais, Tres mauvais	
	Classe d'intervention préliminaire	A, C, D	

(NOVEMBRE 2013) (aucune dégradation projetée)"	Valeur de remplacement en dollars constants 2016		Replacement costs (cost of replacement for this road segment)
"ÉVALUATION DYNAMIQUE RÉSULTATS DU SIAD (incluant la dégradation modélisée)"	CH critique	Oui, null	Need intervention?
	PCI estimé		PCI estimate in 2020?
	IRI estimé		
	"Intervention intégrée SIAD"		
	Date d'échéance SIAD		Date d'échéance SIAD
	Coûts d'intervention en dollars constants 2016 (2016-2020)		Intervention costs (what is the differences between replacement costs and intervention costs since these two numbers are different and not all intervention costs larger than replacement costs?)
	Motif détaillé de l'intervention		Reasons for intervention
	Classe d'intervention intégrée CH		Integrated intervention class (overall intervention class?)
7873 items			

7.6.2.9.4 Water intervention plan (table)

TABLE- RÉSEAU D'EAU POTABLE PAR CONDUITE & INTERVENTIONS À COURT TERME 0-5 ANS (2016-2020) (water intervention plan)			
	Field name	**Value range**	**Comments**
DÉSIGNATION DU TRONÇON UNIFIÉ	Arrondissement de Montréal ou Ville-liée		
	Tronçon unifié	4455-38905	Same as in roads intervention plan
	Rue		
	De		
	À		
DONNÉES PHYSIQUES DE LA CHAUSSÉE	Conduite PI	9547-94569	
	Matériau	Acier…	
	Date installation	1899-2015	
	Diamètre (mm)	100, 150, 200, 250…2700	

	Longueur de la conduite (m)		
	Possibilité d'entrées de service en plomb	Oui	
	"Hiérarchie (Guide MAMOT)"	I, II, III	Levels of prioritization of infrastructures I-important II-moyen III-faible
	Juri.	A, L	
INDICATEURS DONNÉES D'ÉTAT	NB. réparations historiques	0-15	Number of historical repairs
	Cote	1-5	
	NB réparations 5 pires années sur 10 ans	0-11	
	Taux de réparations (rép./km/an)	0-17.97	Repair rates
	Cote	1-5	
	Durée de vie écoulée	0%-168%	
	Cote	1-4	
"ÉVALUATION STATIQUE SELON LE GUIDE DU MAMOT (NOVEMBRE 2013) (aucune dégradation projetée)"	"Statut initial (selon le PCI ou l'IRI)"	Excellent, Bon, Moyen, Mauvais, Tres mauvais	
	Classe d'intervention préliminaire	0, A, B	
	Durée de vie restante (années)		Remaining life (for long-term planning)
	Valeur de remplacement en dollars constants 2016		Replacement costs (cost of replacement for this water pipe)
	Besoin annuel maintien d'actif en dollars constants 2016 ($/an)		Annual maintenance fee
	Classe d'intervention intégrée EP		Integrated intervention class (overall intervention class?)
10001 items			

7.6.2.9.5 Sewage inspection

Inspection_egout_l_j (sewage inspection)-polylines			
Field name	**Data type**	**Value range**	**Comments**
FID	Object ID		
Shape	Geometry		
NO_CONDUIT	Long	5252212-15051104	5701 same with EGO_SEGMENT in attribute "ID_EGO_SEGMENT"
ID_INSPECT	Long	9-603375	
MATERIAU_R	Text	Brick, steel…(18)	
DATE_HEURE	Date	98-18	
TYPEINSPEC	Text	Caméra conventionnelle, Sonore CCTV, Téléobjectif	
NOMENCLATU	Text	PACP, PACP Version 4.2.6, PACP Version 7.0.2…(9)	Pipeline Assessment and Certification Program
CIS	Long	1,2,3,4,5	
CPB	Long	0, 1,2,3,4,5	
POINTAGERA	Text		
POINTAGE00	Text		
29572 items			

7.6.2.9.6 Sewage intervention plan (table)

TABLE- RÉSEAUX D'ÉGOUTS POUR LES EAUX USÉES PAR CONDUITES & INTERVENTIONS À COURT TERME 0-5 ANS (2016-2020) (sewage intervention plan)			
	Field name	**Value range**	**Comments**
DÉSIGNATION DU TRONÇON UNIFIÉ	Arrondissement de Montréal ou Ville-liée		
	Tronçon unifié	4455-38905	Same as in roads intervention plan
	Rue		
	De		
	À		

DONNÉES PHYSIQUES DE LA CHAUSSÉE	Conduite	9547-94569	
	Matériau	Acier…	
	Date installation	1899-2015	
	Dia. vertical (mm)	100, 150, 200, 250…5325	
	Dia. horizontal (mm)	100, 150, 200, 250…5325	
	Longueur de la conduite (m)		
	Durée de vie écoulée (%)	0%-348%	
	Type de réseau	Combiné, Sanitaire	
	Année insp.	1998-2016	
	Type insp.	CCTV, SC, TO	
	Cote rapide structurale PACP		
	"Hiérarchie (Guide MAMOT)"	I, II, III	Levels of prioritization of infrastructures I-important II-moyen III-faible
	Juri.	A, L	
INDICATEURS DONNÉES D'ÉTAT	Pire CIS PACP	1-5	
	Code d'anomalie structurale	BSV…..	PACP Conditions
	Cote	1-5	
"ÉVALUATION STATIQUE SELON LE GUIDE DU MAMOT (NOVEMBRE 2013) (aucune dégradation projetée)"	"Statut initial (selon le PCI ou l'IRI)"	Excellent, Bon, Moyen, Mauvais, Tres mauvais	
	Classe d'intervention préliminaire	0, A, B	
	Durée de vie restante (années)		Remaining life (for long-term planning)
	Valeur de remplacement en dollars constants 2016		Replacement costs (cost of replacement for this water pipe)

	Besoin annuel maintien d'actif en dollars constants 2016 ($/an)		Annual maintenance fee
	Classe d'intervention intégrée EP		Integrated intervention class (overall intervention class?)
33476 items			

7.6.2.9.7 Sewage condition assessment

CODE_R (Condition assessment of sewage)-points			
Field name	**Data type**	**Value range**	**Comments**
FID	Object ID		
Shape	Geometry		
DATE_HEURE	Date		
ARRONDISSE			
NOM_VOIE			
NOMFICHIER			
TYPEINSPEC			
NO_CONDUIT			
DISTANCE			
CODE_R			
CIS			
CPB			
X			
Y			
508341 items			

CODE_p_j (Condition assessment of sewage)-points			
Field name	**Data type**	**Value range**	**Comments**
FID	Object ID		
Shape	Geometry		
ID_CONDITI	Long	201514-1408094	
ID_INSPECT	Long		Link to layer Inspection_egout_l_j
DISTANCE	Double		
POSITION_	Double		
CODE_R	Text		PACP condition
DEFAUTCONT	Text		
MESUREDIME	Double		
MESUREDI_1	Double		
MESUREPOUR	Double		
JOINT_R	Text	NON, OUI	
REFERENCEH	Long		
REFERENC_1	Long		
REMARQUE	Text		
TEMPSVIDEO	Text		
CIS	Long	0, 1,2,3,4,5	
CPB	Long	0, 1,2,3,4,5	
MATERIAU_R	Text		
DATE_HEURE	Date	2010-2018	
TYPEINSPEC	Text	Caméra conventionnelle, Téléobjectif	
NOMENCLATU	Text	PACP Version 4.2.6, PACP Version 7.0.2…(5)	
POINTAGERA	Text		
POINTAGE00	Text		

X	Double		
Y	Double		
383963 items			

7.6.2.9.8 Storm water intervention plan (table)

TABLE- RÉSEAUX D'ÉGOUTS POUR LES EAUX PLUVIALES PAR CONDUITES & INTERVENTIONS À COURT TERME 0-5 ANS (2016-2020) (storm water intervention plan)			
	Field name	**Value range**	**Comments**
DÉSIGNATION DU TRONÇON UNIFIÉ	Arrondissement de Montréal ou Ville-liée		
	Tronçon unifié	4455-38905	Same as in roads intervention plan
	Rue		
	De		
	À		
DONNÉES PHYSIQUES DE LA CHAUSSÉE	Conduite	9547-94569	
	Matériau	Acier…	
	Date installation	1893-2015	
	Dia. vertical (mm)	150, 200, 250…3150	
	Dia. horizontal (mm)	150, 200, 250…4050	
	Longueur de la conduite (m)		
	Durée de vie écoulée (%)	0%-204%	
	Type de réseau	Pluvial	
	Année insp.	1998-2016	
	Type insp.	CCTV, TO	
	Cote rapide structurale PACP		
	"Hiérarchie (Guide MAMOT)"	I, II, III	Levels of prioritization of infrastructures I-important II-moyen

			III-faible
	Juri.	A, L	
INDICATEURS DONNÉES D'ÉTAT	Pire CIS PACP	1-5	
	Code d'anomalie structurale	BSV…..	PACP Conditions
	Cote	1-5	
"ÉVALUATION STATIQUE SELON LE GUIDE DU MAMOT (NOVEMBRE 2013) (aucune dégradation projetée)"	"Statut initial (selon le PCI ou l'IRI)"	Excellent, Bon, Moyen, Mauvais, Tres mauvais	
	Classe d'intervention préliminaire	0, A, B	
	Durée de vie restante (années)	1-162	Remaining life (for long-term planning)
	Valeur de remplacement en dollars constants 2016		Replacement costs (cost of replacement for this water pipe)
	Besoin annuel maintien d'actif en dollars constants 2016 ($/an)		Annual maintenance fee
	Classe d'intervention intégrée EP		Integrated intervention class (overall intervention class?)
1970 items			

7.6.2.9.9 TRONÇON UNIFIÉ (table)

TABLE- ANALYSE DES PROJETS PAR TRONÇON UNIFIÉ & INTERVENTIONS À COURT TERME 0-5 ANS (2016-2020)			
	Field name	**Value range**	**Comments**
DÉSIGNATION DU TRONÇON UNIFIÉ	Arrondissement de Montréal ou Ville-liée		
	Tronçon unifié	4455-38905	Same as in roads intervention plan
	Rue		
	De		
	À		

	Longueur TU (m)		
INDICATEURS DONNÉES D'ÉTATS INITIALES (EP : EAU POTBLE)	Longueur totale de conduites (m)		
	Nb conduites dans le TU		
	"Nb. bris historique max."		Number of max historical breakage
	"Taux de bris max. (Nb/km/an)"		Max breakage rate
	"Hiéra. EP Nb bris historique max."		Number of max historical breakage class?
	Possibilité d'entrées de service en plomb		
	Durée de vie écoulée		
	"Juri. EP Nb bris historique max."		
EAUX USÉES	Longueur totale de conduites (m)		
	Nb conduites dans le TU		Number of pipes in the TU
	"O&E PACP modifié inspectée max."		
	"CIS inspectée max. "		
	"Hiéra. EU CIS inspectée max."		
	"Juri. EU CIS inspectée max"		
EAUX PLUVIALES	Longueur totale de conduites (m)		
	Nb conduites dans le TU		
	"O&E PACP modifié inspectée max."		
	"CIS inspectée max. "		

	"Hiéra. EPL CIS inspectée max."		
	"Juri. EPL CIS inspectée max"		
CH (roads)	Superficie chaussée (m²)		Road area
	Date inspecté		Inspection date
	PCI mesuré		
	IRI mesuré		
	Catégo.		
	"Hiérarchie (Guide MAMOT)"		
	Juri. CH		
CLASSES D'INTERVENTIONS INTÉGRÉES	EP	A, C, D, S.O.	
	EU	0, A, B, S.O.	
	EPL	0, A, B, S.O.	
	CH	A, C, D, S.O.	
ACTIFS CRITIQUES SELON LA MODÉLISATION (CRITICAL ASSETS ACCORDING TO MODELING?)	EP		
	EU		
	EPL		
	CH		
"PLANIFICATION DES TRAVAUX - 5 ANS SELON LA MODÉLISATION" (5 year work	EP Types de travaux EP		
	EU Types de travaux EU		
	EPL Types de travaux EPL		

planning)	CH Types de travaux VO		
	" Coût total en dollars constants 2016 "		Total costs
	Date d'échéance SIAD		
	TU en intervention par dégradation modélisée		TU in modeled degradation intervention
10274 items			

7.6.2.9.10 Stratégie résorption déficit (table)

TABLE-ANALYSE DES PROJETS PAR TRONÇON UNIFIÉ & INTERVENTIONS À COURT TERME 0-5 ANS (2016-2020)			
	Field name	**Value range**	**Comments**
DÉSIGNATION DU TRONÇON UNIFIÉ	Arrondissement de Montréal ou Ville-liée		
	Tronçon unifié		
	Rue		
	De		
	À		
	Longueur TU et des chaussées (m)		
INDICATEURS DONNÉES D'ÉTATS INITIALES (EP : EAU POTBLE)	Longueur totale de conduites (m)		
	Hiéra. EP		
	"État max Taux de bris et Nombre de bris (Déficit)"		
	Possibilité d'entrées de service en plomb		
	Nombre d'entrées en Plomb (entrées publiques)		
	Possibilité de secteur Wartime		
	Durée de vie écoulée		

	Augmentation de diamètre (recommandation d'étude hydraulique dans la conduite locale) Juri. EP		
EAUX USÉES	Longueur totale de conduites (m)		
	État cote structurale CIS EU-1 (Déficit)		
	Inspection CCTV complète dans le tronçon unifié		
	Code d'anomalie structurale (CIS - EU)		
	Augmentation de diamètre (recommandation d'étude hydraulique dans la conduite locale)		
	Hiéra. EU CIS inspectée max.		
	Juri. EU CIS inspectée max		
EAUX PLUVIALES	Longueur totale de conduites (m)		
	État cote structurale CIS EPL-1 (Déficit)		
	Inspection CCTV complète dans le tronçon unifié		
	Code d'anomalie structurale (CIS - EPL)		
	Augmentation de diamètre (recommandation d'étude hydraulique dans la conduite locale)		
	Hiéra. EPL CIS inspectée max.		
	Juri. EPL CIS inspectée max		
CH (roads)	Superficie chaussée (m²)		

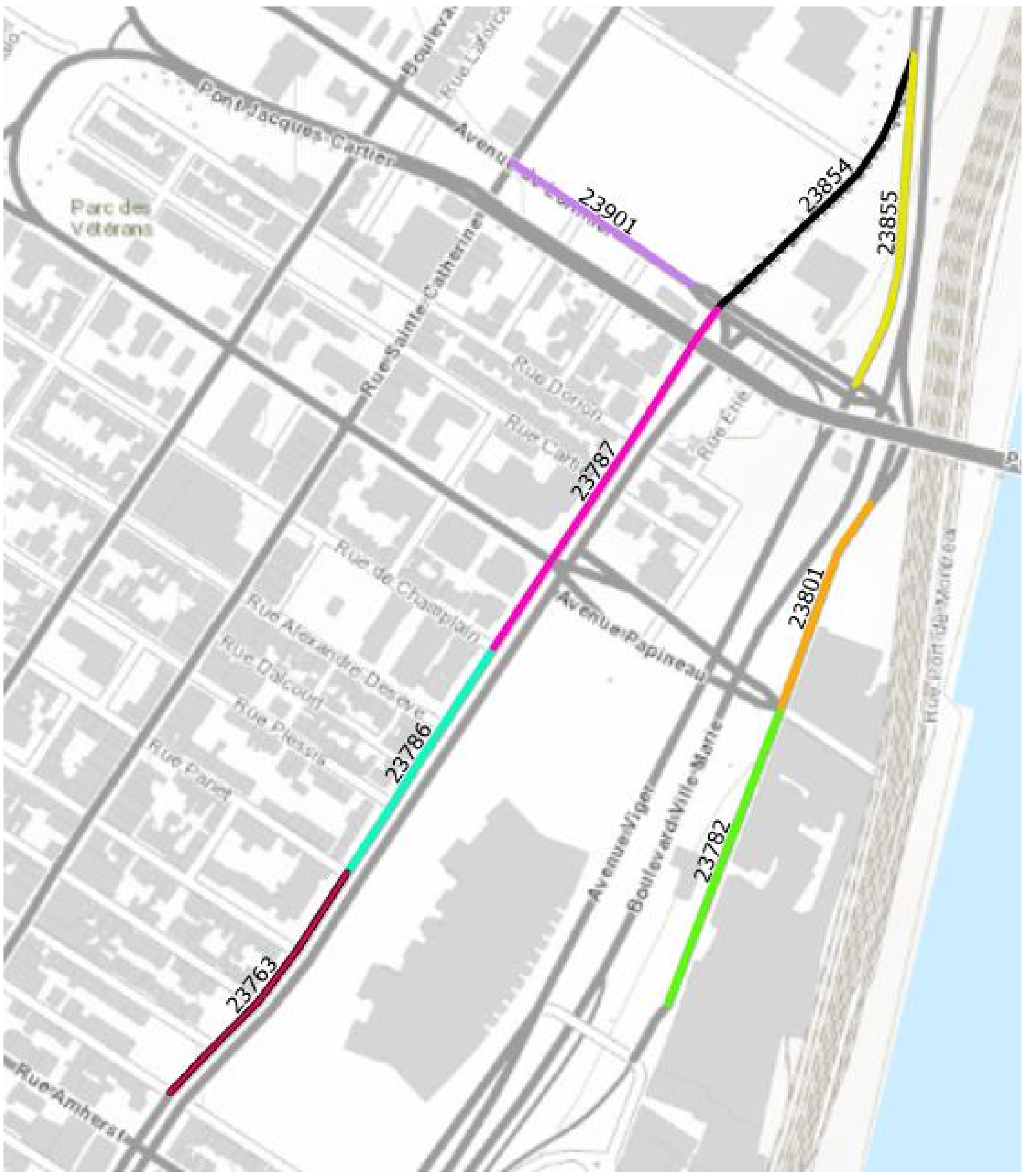
	Date inspecté		
	PCI mesuré		
	IRI mesuré		
	Catégo.		
	"Hiérarchie (Guide MAMOT)"		
	Juri. CH		
CLASSES D'INTERVENTIONS INTÉGRÉES	EP		
	EU		
	EPL		
	CH		
ACTIFS CRITIQUES SELON LA MODÉLISATION (CRITICAL ASSETS ACCORDING TO MODELING?)	EP		
	EU		
	EPL		
	CH		
"PLANIFICATION DES TRAVAUX - 5 ANS SELON LA MODÉLISATION" (5 year work planning)			
10273 items			

Appendix VI. Experts participated in the AHP questionnaire

Name	Company	Department
Pierre Boulé	Hydro Quebec	
Lucie Larose	Hydro Quebec	Chef plan de réseau mtl
Jonathan Grenier	Hydro Quebec	
Walid Bouchareb	Bell	Gestionnaire de projets
Patrice Tetreault	Bell	Manager - Right of way and Municipal Affairs
Jason Sobey	Bell	
Dominic Chenier	Bell	Gestionnaire structure civil
Eric Sauvé	Videotron	
Dan Nicolae Haiduc	Videotron	Gestionnaire principal
Willy Eloy	Videotron	Directeur Conception réseau
Gilles Guénette	Videotron	Superviseur conception fibre
Martin Gaudette	Ville de Montreal	Chef de division Bureau d'intégration et de la coordination - BIC Service des infrastructures du réseau routier
Jean-Pierre Bosse	Ville de Montreal	
Yvan Peloquin	Ville de Montreal	Chef de division conception des travaux, Direction des infrastructures
Daniel Beaulieu	Ville de Montreal	Ingénieur Chargé de Planification (project manager)
Jean Carrier	Ville de Montreal	Asset management
Michel Saindon	CERIU	Chargé de projets
Salamatou Modieli Amadou	CERIU	Coordonnatrice de projet

Appendix VII. Case study of Faubourgs area

As shown in the following figure, 8 road segments are selected for the case study in Faubourgs area. The road IDs are labelled in the figure and used in the flowing table.

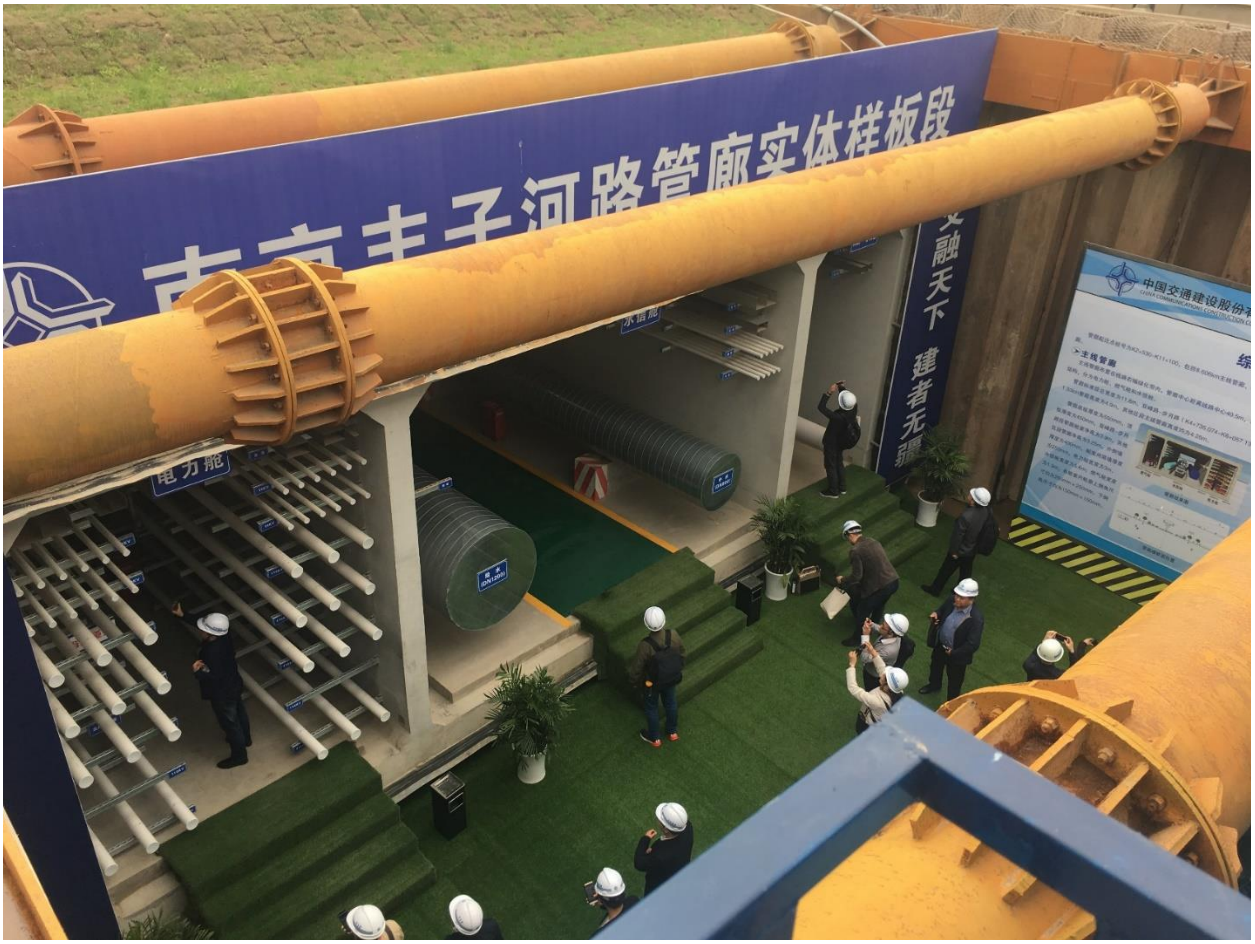


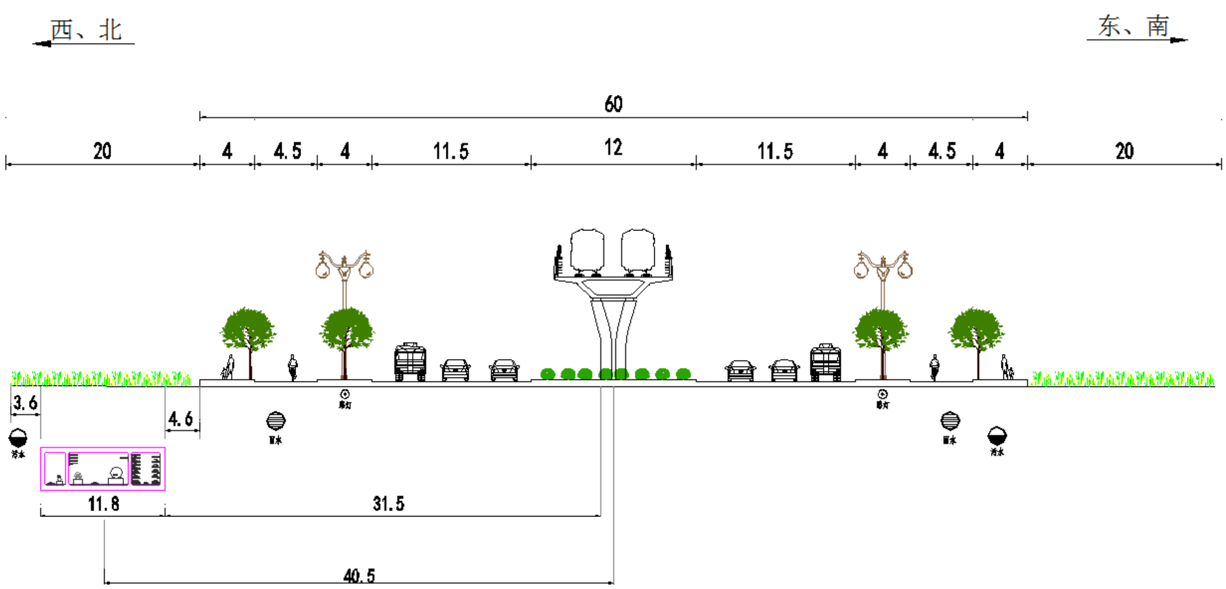
In the following table, the road ID can be referred to the figure above. The lengths of the road segments are also indicated in the table. The scores of each criterion of each road segment are indicated in the table. The normalization of the scores are using the values of the selected road segments instead of all road segments in Montreal. So, the results only show relative importance level among the selected road segments. The weights are from the AHP questionnaire in the previous meeting.

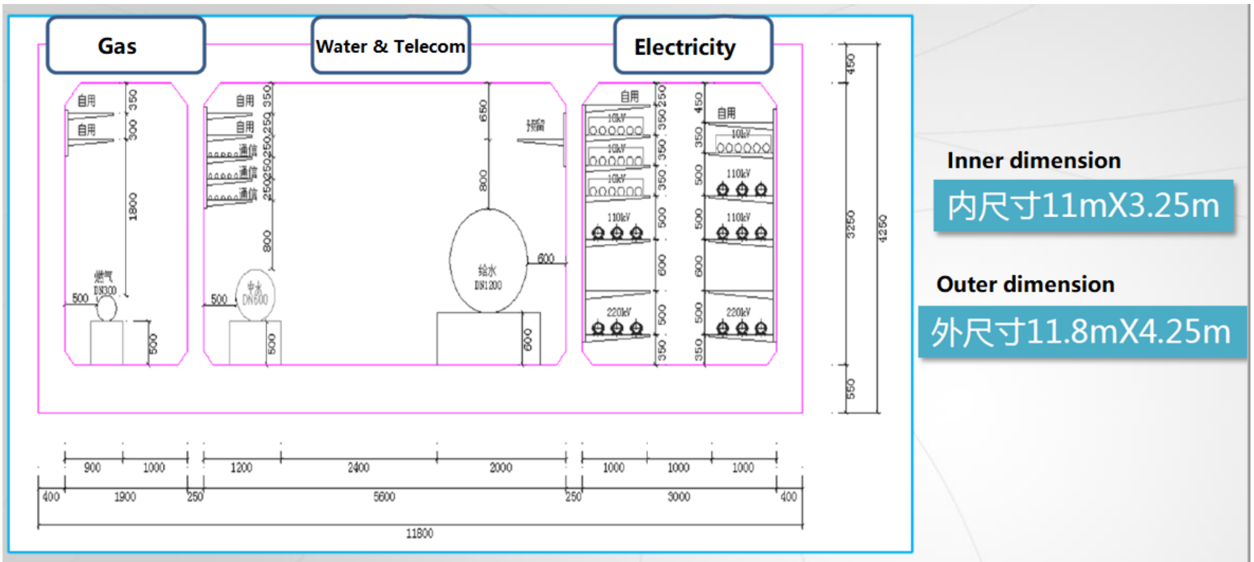
The weighted total scores are within a range of 0 to 1. The highlighted road segments have higher scores than other road segments. The last row which is Average score for the same road is the combined score for longer road segments. In the Faubourgs case study, three roads are considered which are René-Lévesque, De Lorimier and Notre-Dame. Based on the analysis, René-Lévesque may be a better location for applying MUT.

		Weights from AHP (%)	René-Lévesque (Wolfe to Panet)	René-Lévesque (Panet to De Champlain)	René-Lévesque (De Champlain to De Lorimier)	René-Lévesque (De Lorimier to Notre-Dame)	De Lorimier (#901-05 De Lorimier to Sainte-Catherine)	Notre-Dame (#1500-670 Notre-Dame to Avenue Papineau)	Notre-Dame (Avenue Papineau to #1806-2000 Notre-Dame)	Notre-Dame (De Lorimier to René-Lévesque)
Road ID			**23763**	**23786**	**23787**	**23854**	**23901**	**23782**	**23801**	**23855**
Length (m)			267.39	254.16	383.12	309.40	204.50	300.64	210.72	320.03
Criteria	AADT	15.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Road class	3.7	1.00	1.00	1.00	1.00	1.00	0.80	0.80	1.00
	Utility density	12.3	0.77	0.45	0.49	0.18	1.00	0.63	0.33	0.36
	Expected excavation number (using water pipe breakage rate)	23.6	0.99	0.00	0.00	0.44	0.00	1.00	0.70	0.00
	Future development projects	19.3	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00
	Population density	7.6	0.69	0.84	1.00	0.63	0.76	0.39	0.90	0.63
	Land use	10.3	0.60	0.60	0.78	0.80	0.80	1.00	1.00	0.80
	Number of public facilities/high-rise buildings	8.1	0.67	0.67	0.33	0.33	0.00	1.00	0.67	0.33
Total Score			**0.878**	**0.616**	**0.625**	**0.664**	**0.644**	**0.707**	**0.612**	**0.389**
Average score for the same road			**0.6886336**				**0.644**	**0.560837593**		

Appendix VIII. Visit to China National MUT Conference and example MUTs







Gas
Water & Telecom
Electricity
Inner dimension
内尺寸11mX3.25m
Outer dimension
外尺寸11.8mX4.25m