Life Cycle Cost Benefit Analysis to Support the Creation of the Smart City Infrastructure Authority/New York City

Final Report

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Executive Summary

In New York City, utility infrastructure, such as water, sewer, electricity, and telecommunications are buried directly underground in a disorganized manner, so utility companies and New York City have to excavate roads to manage utilities. This situation has caused the "subsurface spaghetti problem," that has burdened the City in many ways, including the deterioration of road conditions due to repeated construction, adverse effects on traffic, and damage to the environment. Therefore, New York City has sought a sustainable solution: the installation of underground utility tunnels ("utilidors"), which enable repair and upgrade activities without excavation. This Capstone project aims to analyze if the installation of utilidors may facilitate public and private utility construction, operation and maintenance in the City and reduce the negative impact on the street users.

First, focusing on the subsurface value, the team conducted case studies of several cities (e.g., Tokyo and Singapore) to identify costs and benefits for the construction of utilidors, and cost-sharing methods between the public sector and utility companies. It revealed that several countries have legislation in place for the construction and management of utilidors, with clearly defined cost-sharing methods. For example, Tokyo has a special law on the development of utilidors, which states that the construction cost of a utilidor is to be borne not only by the public sector, as the owner of the utilidor, but also by the utility company, as the occupant of the utilidor. The amount of this burden is primarily the cost saved by installing utilities within the utilidor. Based on the findings from case studies, the team proposed a revenue model, in which revenue is generated based on two criteria: savings generated to utility providers, and cross section space that they use inside utilidors.

Second, the team conducted a Life Cycle Cost Benefit Analysis (LCCBA) of constructing utilidors with the goal of identifying the long-term value of utilidors. This LCCBA model was based on the model created in a 2020 capstone project, but with a more in-depth analysis focusing on direct costs. The team defined a counterfactual (current trenching practice) scenario and projected a model (utilidor implementation) scenario. To monetize the costs and benefits, the Beekman Street project was chosen as the base case study for both scenarios (as was the case in the 2020 capstone project). The analysis concluded that the case for utilidor implementation is economically superior to the case continuing with current trenching practices. The net present

value (NPV) of the utilidor implementation scenario is approximately $350 million, and it is $95 million lower than the NPV of current trenching practices. The total benefit of the Beekman case study project to the utility and NYC is approximately $420 million, the difference in direct costs for utility providers and New York city agencies between the utilidor installation scenario and the current trenching scenario. The total Beekman case study project cost, including construction, operation and management, and debt service cost, is approximately $325 million. As a result, the benefit-cost ratio is 1.29 and the payback period is 47 years, which is similar to values based on literature referencing experience in other countries (i.e., 50-year payback period). The LCCBA model indicates that utilidor implementation is economically superior to the continuation of the current trenching practice. However, since the costs of the utilidor implementation and current trenching practice are estimated based on a number of assumptions, the estimated results may also fluctuate if the assumptions change. Therefore, the team conducted a sensitivity analysis to simulate NPV if the assumptions were changed within an appropriate range, and we verified the robustness of the economic effects to the current methodology. Sensitivity analysis was conducted on six assumptions: 1) discount rate; 2) inflation rate; 3) construction cost of the utilidor; 4) operation and maintenance cost of the utilidor; 5) trenching cost per foot; and 6) number of street cuts. Overall, we found that the utilidor implementation practice is economically superior, at least for the assumptions we used as a basis, and that the economic advantage can be maintained even if these assumptions change to some extent.

Next, the team proposed a financing structure for utilidor implementation based on the Beekman case study project. The structure we chose was the same as the one used by the 2020 Capstone team, which was to first establish a 63-20 non-profit organization to issue a bond to finance the construction and the first years of operation, and then create a Smart-City Infrastructure Agency through state legislation to issue the long-term bonds and transit into a revenue-based financing scheme. In this model, revenue for the utilidor would come from annual fees charged to the utilities occupying the utilidor. The annual fee is calculated as a percentage of the savings between the current trenching practice and utilidor implementation scenarios, and our analysis used 80% (of savings) to calculate the fees. The annual fee is then allocated to utility providers based on each utility's cross-sectional area within the utilidor. This results in a total annual revenue of $8-9 million for the first five years. In later years, revenues are expected to increase as annual savings increase. In addition, the team proposed a debt financing approach: an initial 5-year bond issue, followed by two separate bond issues with a term of 25 years and 20 years. This financing method will maintain a coverage ratio of over 120%.

Moreover, the team analyzed the use of Information and Communication Technology (ICT) and conducted case studies on ICT-enabled water infrastructure management. Smart water management has three subsystems: data gathering, data transmission, and data governing. The team focused on data gathering and data governing, and studied advanced technologies that are actually being used around the world. In addition, the team conducted a partial cost-benefit analysis of the application of ICT to water utilities in New York City. ICT costs include hardware costs, software costs, and implementation costs. Benefits include environmental benefits and water authority benefits. Environmental benefits include reduction in carbon footprints and improvement in water quality detection. Reduction in carbon footprints could be achieved through reduced on-site maintenance and inspection work as well as promotion of water conservation behavior among users. ICT sensors could contribute to more effective water quality monitoring. On the other hand, water authorities will benefit from the reduction of pipe breaks through the use of sensors and smart water networks, and from the reduction of water waste through early detection of leaks enabled by smart water management systems. Thus, the construction of the utilidor and the use of ICT can bring more benefits to utility providers and ultimately to the citizens of New York City.

Based on the above analysis, the team concluded that the implementation of the utilidor would be beneficial and economically feasible, and that ICT application made possible with utilidors would allow for more efficient management of utilities in New York City. We believe that establishing a smart city authority to finance utilidors, manage, issue permits, and collect corresponding fees for proper utility management will be beneficial for building a better New York City. To implement and expand this capstone project, further study and coordination with interested parties will be needed in the future.

Part 1: Utilidors, Costs and Benefits

In New York City, the local government is in charge of maintaining the streets. Due to the aged subsurface infrastructure, the utility "spaghetti" problem underground is causing challenges to maintenance. And utility companies are also in charge of restoring the streets after excavation. Currently, the most common way of maintaining and repairing utilities below the street is using open trench excavation along the entire length of the underground utility, or at least most of it. Diverting traffic, and utilizing noisy equipment has significant negative environmental, social, and economic impacts. Additional costs are incurred by the need to restore the pavement and sidewalk removed during the operation. Additionally, this 'open cut' method poses a risk to nearby underground utility infrastructure.

Figure 1. Spaghetti problem

As a result, an alternative method is to build utility tunnels (utilidors) in which utility infrastructure is located. Introducing a utilidor in New York City would require a large construction cost at the beginning. In a Capstone project done by students of Columbia University SIPA in 2020, their research and financial analysis shows that it is economically beneficial to install a utilidor in the long run. Based on their research findings, our 2022 Capstone team aimed to focus more on the direct cost and direct benefit and improve upon some of their previous assumptions to better fit into reality. The same Beekman Street case used by the 2020 Capstone Project is used for our estimate of direct cost and benefit of utilidor implementation in New York City.

a. Direct Costs and Benefits

Utilidors host a wide range of urban utility transmission infrastructure such as water, steam, gas, and electricity in an accessible space which makes it easier to conduct utility inspection, maintenance, and telecommunications repairs, renovation, and extension. Subsurface and street level are the two main areas that gain increased efficiency as a result of the implementation of utilidors. The existence of a utilidor has many associated benefits, ranging from savings gained due to less excavation and easier repair to helping utility companies achieve carbon neutrality.

The direct impacts from utilidor implementation include: 1) the construction cost of building and maintaining a utilidor; 2) operational benefits with direct cost savings accrued to government agencies and public and private utilities; and 3) direct cost savings generated by the application of ICT in utilidors. To analyze the life cycle cost and benefits, the team defined a counterfactual (current trenching practice) scenario and projected a model (utilidor implementation) scenario. The counterfactual refers to what would occur if the utilidor was not constructed. In this case, it would mean that the current subsurface infrastructure remains in place, as well as the current maintenance schedules and impacts to users that come from such maintenance. As the utilidor has an expected useful life of 100 years, all costs for the counterfactual scenario are measured for a 100-year timespan.

Table 1 Details each of the direct costs and benefits

	Costs	**Benefits**
Utilidor Construction		
	• Construction Costs • Relocating Costs • Maintenance Costs	

Direct Benefit Accrued to Government Agencies		
Department of Transportation (DOT)		• Reduced maintenance cost of streets
Department of Environmental Protection (DEP) as a public utility		Through implementing ICT: • Reduced water infrastructure maintenance costs • Reduced operational loss due to unidentified leakage • Reduced cost of accidents to workers in project area
Direct Benefits Accrued to Private Utilities Companies		
Electricity Transmission (Con Edison)		• Reduced infrastructure maintenance cost • Reduced cost of accidents to workers • Reduced manhole accidents • Reduced cost of major

		accidents
Telecommunication Transmission (Verizon)		• Reduced infrastructure maintenance cost • Reduced cost of accidents to workers
Gas Transmission (ConEdison and National Grid)		• Reduced infrastructure maintenance cost • Reduced cost of accidents to workers

The utilidor construction cost includes the cost of building an off-site prefabricated utilidor; relocating existing utilities while the utilidor box is installed; and the trenching cost for installing the utilidor into the ground. Other important costs include maintenance and operational costs of the utilidor, and finance cost. Key assumptions are: 1) the time period of the LCCBA model is 100 years, as the utilidor is assumed to have an expected useful life of 100 years; 2) construction cost of a utilidor is twice as expensive as traditional trenching method; 3) post-construction operation and maintenance is 20% of the original utilidor construction cost of the prefabricated structure.

Our analysis shows that implementing utilidors would result in a decrease in direct costs accrued to New York City agencies. The Department of Transportation (DOT), which is responsible for road repair and paving, would incur less road maintenance costs since streets would be repaved less often.

Direct costs accrued to DEP, the public water and sewer utility, and private utility companies responsible for electricity, gas and telecommunication transmission are also reduced if the utilidor is built. These private utilities, such as ConEdison, National Grid and Verizon are the direct beneficiaries of utilidors as they are responsible for Manhattan’s gas, steam, and electric infrastructure. Benefits to private utilities derive from cost savings due to reductions in maintenance costs and worker accidents.

The use of information and communication technology (ICT) in utilidors could generate additional direct cost savings for DEP. DEP saves a significant amount in costs from averted water loss, Early pipe break detection and repair with unwanted water loss; increased worker safety and reduction in accidents also save costs. ICT enables real-time monitoring and data collection of tunnel environment and utility activities. It helps the city government in a variety of critical management functions and coordinate with other actors in utilidor implementation. Smart sensors could be used for monitoring non-revenue water losses due to leakage and broken pipes, measuring total daily production against total daily consumption. Geographic information systems (GIS) could help obtain more accurate mapping of the subsurface environment during the preliminary stage of utilidor construction. Further, the use of ICT allows for greater flexibility and speed in responding to unforeseen developments, and provides for better flows of information to improve efficiency.

Part 2: Subsurface Value

a. Case Studies

The history of utilidors is long, with the world's first utilidor being built in France in the mid-19th century. Since then, some utilidors have been built in Europe and other Asian countries. Although the background and objectives of these projects vary from country to country, the scale and construction costs of actual projects can be very helpful in conducting a cost-benefit analysis of the construction of a utilidor system in New York. In this paper, we focus on Asian case studies of Tokyo, Singapore, China and Taiwan, for which there is abundant data in utilidor operations to refer to. Through these case studies, we investigated the historical background and legalities, and eventually evaluated the potential costs and benefits of building utilidors in New York.

1) Japan

In Japan, the government had been considering ways to deal with the increasing number of underground utilities since the 1910s, and the Great Kanto Earthquake of 1923 triggered plans for the construction of utilidors in Tokyo as part of the Tokyo Reconstruction Project after the disaster (Suzuki & Miura, 1997). Although the initial plan was large-scale, there was opposition because it was not based on consultation with the relevant businesses, and in the end, the project was only completed on a trial basis at three locations in Tokyo, covering a distance of approximately 2.1 km (Suzuki & Miura, 1997). The largest of these projects was in Kudanzaka. The project was 270 m long with a concrete box approximately 3 m wide and 2 m high under the roadway. However, the construction of the utilidors was not carried out continuously, and due to World War II and other reasons, the maintenance of the common duct was not carried out for about 30 years (Luo et al., 2020).

Suzuki (2000) points out that in the 1960s, with the rapid economic growth period, population and industry concentrated around large cities, and the demand for gas, water, and electricity increased rapidly. Existing urban facilities were no longer able to meet this increased demand, and excavation work on roads to improve utilities also increased. Under these circumstances, the need to deal with severe traffic congestion appeared, and in 1963, after coordinating with related ministries and companies that would be forced to bear the new burden of installing utilidors, the

"Special Measures Act for Construction of Common Ducts for Utility Pipes and Cables" was enacted for the purpose of alleviating traffic congestion caused by the increase in excavation work. The Act defines the utilidor as "a facility built under a road by the road administrator to accommodate utility properties of two or more utility companies,"[1] and the road administrator, such as a prefectural government, can construct utilidors under this Act. In addition, the occupants of the utilidor were to bear a portion of the construction costs. The amount borne is primarily the cost they will save by laying utilities within the utilidor, which is defined legally as well[2].

The project in Tokyo Waterfront City, which is a subcentral area in Tokyo, is another example of a utilidor construction project, with total cost of $3.2 billion ($200,000/m) (Luo et al., 2020). In this area, a 16-km long utilidor was constructed by utilizing underground spaces such as roads and parks, and it is capable of withstanding an earthquake of the magnitude of the Great Kanto Earthquake. There are utilities such as water, sewerage, telecommunication, gas, cooling, heating, and waste pipes in the utilidor, and it is managed on a 24-hour basis to ensure the preservation of a stable lifeline.

[1] Special Measures Act for Construction of Common Ducts for Utility Pipes and Cables. §2.5. (1963). https://elaws.e-gov.go.jp/document?lawid=338AC0000000081_20171223_427AC0000000047

[2] Order for Enforcement of the Special Measures Act for Construction of Common Ducts for Utility Pipes and Cables. $2. (1963). https://elaws.e-gov.go.jp/document?lawid=338CO0000000343_20150801_000000000000000

Figure 2. Utilidor in Tokyo Waterfront City in Japan

Adapted from Security with Advanced Technology by Bureau of Port and Harbor, Tokyo Metropolitan Government, n.d. (https://www.kouwan.metro.tokyo.lg.jp/rinkai/syokai/security.html)

2) Singapore

Singapore was the first country in Southeast Asia to implement utilidors. Singapore, with its small land area, has been seeking ways to effectively utilize underground space in recent years, and the construction of the utilidor was intended to reduce noise and air pollution as well as to make effective use of the limited underground space (URA, 2006; MND, 2013).

The utilidor was constructed in the Marina Bay area in phases. This district is the center of business and tourism in Singapore, but was originally a vacant area that has been developed over the past 20 years through cooperation between the public and private sectors. One of the land use plans of this area was the construction of an underground utilidor, a 5.7 km long tunnel that was built in phases (URA,2018). Phase 1 was completed in May 2006, with a total length of 1.4 km and a total cost of $50.16 million ($35,720/m). Phase 2 was completed in about 2010 with a total length of 1.6 km and a total cost of $84.36 million ($52,440/m). Phase 3 was completed in 2016 (Luo et al., 2020). The utilidor now houses communication cables, power lines, chilled water, potable water, and pneumatic refuse collection pipes, and is in the process of planning the installation of a district heating and cooling system in the future (URA,2018).

Figure 3. The Utilidor in Marina Bay Area in Singapore

Adapted from Marina Bay: A Vision and the Backbone by Urban Redevelopment Authority, 2018 (https://www.ura.gov.sg/Corporate/Resources/Ideas-and-Trends/Marina-Bay-vision-backbone)

In 2018, a new Common Services Tunnel (CST) Act was enacted, which sets legal and regulatory practices and rules to ensure the safe and efficient operation of utilidors in Singapore. In this Act, the utilidor is defined as "a system of underground concrete structures within a common services tunnel area used or intended to be used for the purpose of the housing and distribution of utility services to land within and outside the area.[3]" In addition, under this law, utility suppliers are mandated in principle to use the utilidor when laying utility property in areas declared as a common service tunnel area[4].

3) China

The first utilidor in China was built under Tiananmen Square in Beijing in 1958 with a total length of 1.08 km. The first long utilidor, with a total length of 11.50 km, was built in Shanghai in 1994 as a signature project. After 2000, due to urbanization and the increase in population, the government has appealed to building utilidors nationwide (Li et al., 2019).

In Guangzhou University Town, a utilidor was established to assist with the operation of educational institutions nearby. The project was completed in 2003, with a total length of 17.4 km and a total cost of $362 million ($20,816/m). The utilidor houses potable water, hot water, waste water, electricity and cable. The utilidor construction costs were borne by the government completely, and a state-owned enterprise was then established to manage and operate the utilidor. The utilidor is owned by the government, and utility providers pay a one-time entry fee and annual operation fee as shown in the table below.

The annual operation costs are allocated to each utility based on the cross-sectional area of each utility, which is a method proposed by Ali Alaghbandrad and Amin Hammad (Alaghbandrad & Hammad, 2020.

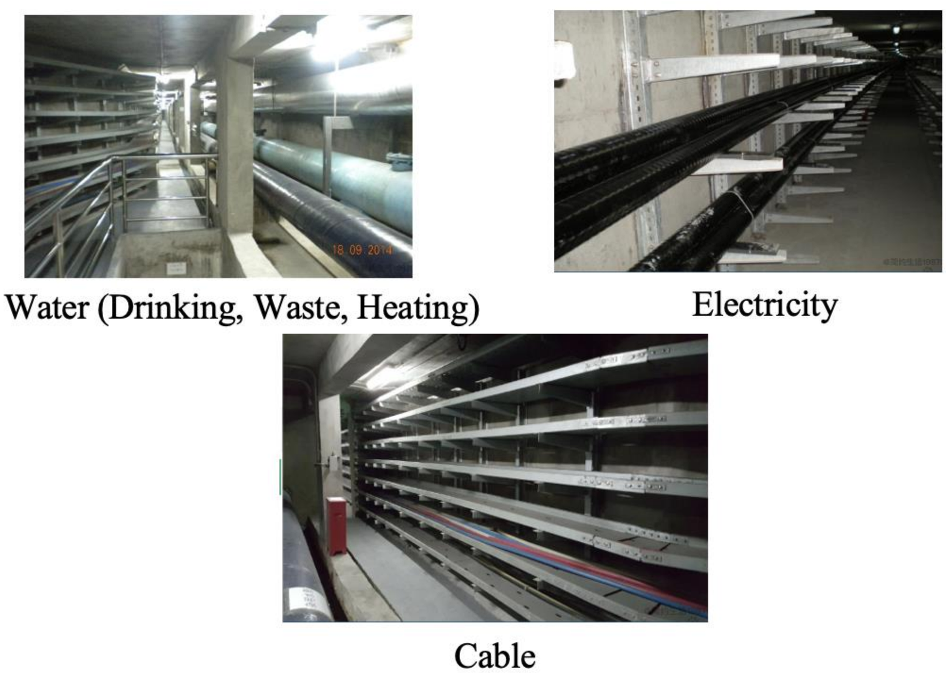
[3] Common Services Tunnel Act. §2.1 (2018) https://sso.agc.gov.sg/Acts-Supp/17-2018/Published/20190114?DocDate=20190114

[4] Common Services Tunnel Act. §13.1 (2018) https://sso.agc.gov.sg/Acts-Supp/17-2018/Published/20190114?DocDate=20190114

Table 2. Fee charged to utility providers in Guangzhou

Pipeline	Drinking water	Electricity	Cable	Waste Water	Heating Water	Total
One-time entry fee (USD/meter)	86.5	15.8	9.08	64.56	214.48	390.42
Cross-sectional area (%)	12.7	35.45	25.4	10.58	15.87	100

Figure 4. The Utilidor in Guangzhou University Town in China



Adapted from Guangzhou University Town Investment Company, 2015

(https://wenku.baidu.com/view/d735a2ca561252d381eb6e79.html)

4) Taiwan

In the 1980s, the underground utilities had been frequently damaged due to the construction of the subway. In 1989, the government visited Japan to learn from the experiences of utilidors there and started to expand the utilidor projects over Taiwan afterwards. In 2000, Taiwan issued the Law of Utilidor, specifying the cost allocation methods, management and operation, providing guidance on utilidor projects across Taiwan. Taoyuan City is located near Taipei and has the largest international airport in Taiwan. In the high-speed rail utilidor project in Taoyuan City, the total length is 7.082 km and the total cost was $68 million ($9830/m) (Kang et al., 2021).

According to the Law of Utilidor, 1/3 of the construction cost is shared by the government and 2/3 is shared by utility providers (Ministry of Interior, 2000). The utilidor is owned and managed by the local government. Construction costs are shared by the utility companies based on the size (cubic meters) of each utility. Annual operation costs are allocated to each pipeline based on the cross-sectional area of each pipeline, the same method as Guangzhou.

Figure 5. The Utilidor of the High-Speed Rail in Taoyuan City

Adapted from Department of Construction Engineering, Chaoyang University of Technology

(http://ir.lib.cyut.edu.tw:8080/bitstream/310901800/28470/1/101CYUT5512008-001.pdf)

b. Conceptual models

This report works on the basis of the 2020 Capstone project on the LCCBA and the financial option diagnosis for utilidors in New York City. The LCCBA was developed for the construction of a utilidor in Beekman Street, we updated that cost model, with a focus on direct costs and benefits, and generated an appropriate revenue model to ensure economic sustainability over time.

1) Revenue model

Utilidors need to generate enough revenue to finance the construction of the utilidor and its ongoing operation and maintenance expenses. According to our literature review, a utilidor's high initial costs are compensated by a lower operational and maintenance cost over the years (Alaghbandrad, 2020), however, it takes about 50 years for total costs to reach to a break-even point (Yang & Peng, 2016).

This report will later discuss different options for financing utilidors, but we need to consider construction costs in addition to financing, operational and maintenance costs. For the whole project to be economically feasible, an appropriate revenue model should be able to generate enough influx of money to pay for the total costs of each year.

Based on the case studies of other cities in the world, our model generates revenue based on two criteria: savings generated to utility providers, and cross-sectional area they use inside utilidors (Alaghbandrad & Hammad, 2020). As discussed previously, the current trenching method is very costly for utility providers; not only do they need to dig a trench in the streets but they also need to relocate utilities to maintain their service and restore the street to the original condition. A scenario maintaining the current trenching practice became our counterfactual scenario, which was compared to a scenario of utilidor implementation. The difference in costs between them shows that implementation of utilidors would yield very large savings for providers, resulting in a high benefit-cost ratio.

Since savings generated to providers are larger than the total cost of the project, options for a usage fee range from charging 100% of the savings to 80% of savings, just enough to cover total costs. In our model, we use fees to offset total costs, however we included a sensitivity analysis on fees going up to 100% of savings as well.

To finance the construction of utilidors, three bonds will be issued and they will be repaid with revenue generated by the utilidor's operation. After reaching the maturity term of our bonds, not having any more debt service costs would make total costs per year of operation to decrease, and utilidors will generate excess revenue. Our proposal considers keeping fees at the same level, and increasing them year-over-year by inflation, to generate said revenue excess. Over time, this revenue will allow to fund more infrastructure projects in the city and keep increasing the network of utilidor tunnels.

2) Cost model

Our utilidor LCCBA model is focusing on direct costs of the scenario with utilidors and the counterfactual scenario, which maintains the current trenching method.

For the scenario with utilidors the largest costs are the construction cost, maintenance and operational cost, and debt service cost. The construction cost includes capital cost of the pre-fabricated infrastructure, relocating utilities during the construction period and trenching cost to install the tunnel infrastructure below surface, which could be mitigated if done while the street is already excavated. Because there are no utilidors of the size and characteristics of our project in New York City, we used assumptions based on literature review and experiences around the world to estimate those costs.

For the construction cost we assumed a total cost twice as large as the traditional trenching cost for Beekman Street. According to our research, a common assumption is to estimate the total construction cost as 1.5-2.0 times the traditional trenching cost (Yang & Peng, 2016), so in order to be conservative in our estimates we decided to use the upper limit as our estimate. For the traditional trenching cost, we based our estimates on the Beekman Street project of 2010 (Project ID NYC HWMWTCA6E), the same case used by the 2020 Capstone Project on Utilidor for New York City. The location of the project is in lower Manhattan and is 1,500 feet long. We used 2010 costs and calculated their future value using a 2%[5] year by year inflation estimate to generate our 2022 cost value for the traditional trenching method.

[5] On average, inflation in the US was 1.72% year by year between 2010 and 2020, according to information provided by the US Bureau of Labor Statistics.

Having estimated the total construction cost, we separated this cost into its three major components based on estimates from Brigham Young University (2015) in Provo, Utah (BYU 2015). We assumed 17% of the total construction cost to be used for the pre-fabricated infrastructure, 37% for relocating utilities and 46% for trenching cost. These estimates are consistent with literature suggestions (Clé de Sol, 2005) and were also considered acceptable by the Utilidor Working Group.

The following step was to estimate maintenance and operational cost of the utilidors. Ali Alaghbandrad and Amin Hammad do a full numerical exercise of estimating costs for utilidors (Alaghbandrad & Hammad, 2020), which results in an operational cost of about 10% the cost of the prefabricated infrastructure. At the same time, we interviewed a ConEd employee who works on maintenance of subsurface infrastructure for New York City, who suggested that under current conditions for every $1 spent in capital, between $0.2 and $0.3 are spent in maintenance and operation (Yee-Chan, Brian K., personal interview, 2022). For a conservative approach we decided to assume a 20% of the cost of the prefabricated infrastructure, and considered doing sensitivity analysis moving this assumption down to 10% to evaluate its impact over benefits and costs of the project.

To conclude the scenario with utilidors, we estimated the financial model for this project to be viable, which analysis will be described in greater detail later in this report. The necessary bond structure generates a financial cost in the form of interest payments that needs to be paid until maturity of the debt.

The counterfactual, current trenching practice scenario is based on information from the Beekman project in 2010, including the assumption of 73 street cut permits per year, ⅓ of them leading to actual street cuts, 0.5% growth in permits per year for the first 25 years, and the average size of road work equal to ⅓ of the total length of the project, equivalent to 500 linear feet. These assumptions were taken from the 2020 Capstone project and recommendations from then Utilidor Working Group. The last key assumption is the trenching cost per linear foot for private utility providers. For this assumption we consulted ConEd’s employee for an estimate, and the suggestion was to use $900 per linear foot consistent with the trenching cost for maintenance of gas pipes in New York City (Yee-Chan, Brian K., personal interview, 2022). For maintenance of electrical lines, the suggestion was to use a slightly lower number, so we decided to use $800 per linear foot as our assumption for trenching cost of private utility providers. For its importance in determining the counterfactual cost, we decided to include this assumption in our sensitivity analysis.

The NPV of the total cost of each scenario can be seen in table 3. The difference in direct costs represents the benefit-cost ratio of building utilidors in New York City.

Part 3: Updating 2020 Results

a. LCCBA Results

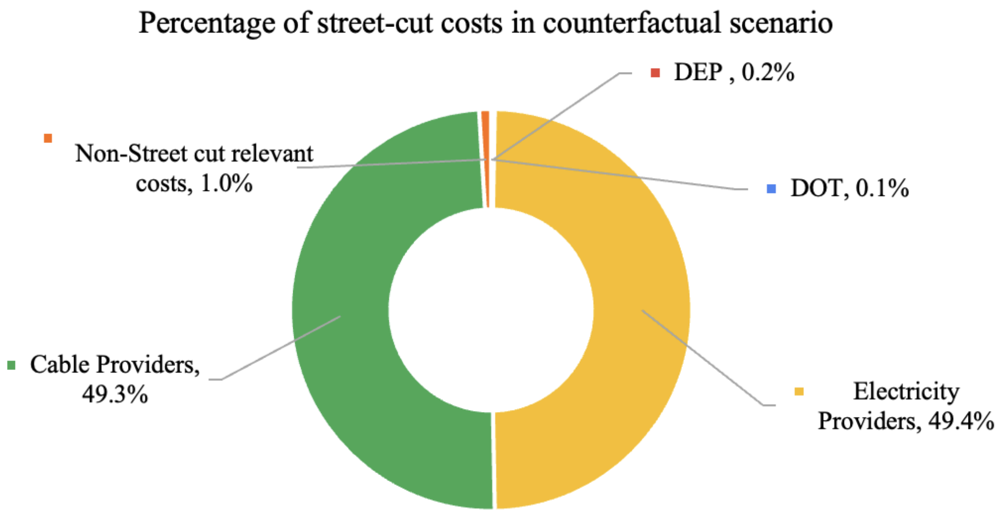
Table 3. Cost for different standings

Impact Standing	NPV of utilidor (A)	NPV of counterfactual (B)	B-A
NYC government	$170,281	$530,867	$360,586
All Utilities	$21,846,953	$444,751,957	$422,905,004
Sum	$22,017,233	$445,282,823	$423,265,590

Note: NYC government: Department of Environmental Protection; Private Utilities: Electricity and Cable Providers, Department of Environmental Protection

The LCCBA analysis focuses on the direct costs and the impacts to NYC government and private utilities as they are directly involved in the construction and operation. The result of our LCCBA shows that the cost of the current trenching practice for the next 100 years is estimated to have a NPV of $445,282,823, while the NPV of the utilidor implementation scenario is $22,017,233

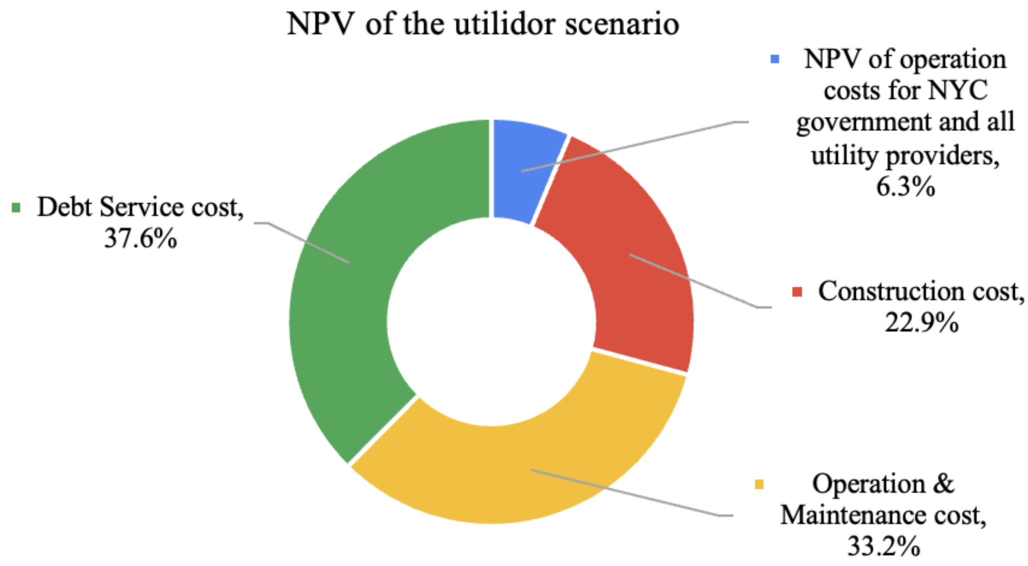
The cost of the utilidor is only 4.94 % of the counterfactual scenario. The decrease in costs is mainly due to the decrease in street cuts. In the counterfactual scenario, street cuts take up to 99% of the total costs. In the utilidor scenario, the number of street cuts will be 0. In the utilidor implementation scenario, the maintenance costs for all private utility providers will be 96% less than the counterfactual scenario.



While the above analysis shows us the NPV of costs for different stakeholders, the below analysis includes the operation and maintenance cost, construction cost and debt service cost for the utilidor during the 100-year life cycle. The construction cost will incur in the first two years of the project. Operation & maintenance cost will occur annually, and debt service cost will incur for 50 years. Overall, the project has a payback period of 47 years and a benefit-cost ratio of the utilidor is 1.29.

Table 4. NPV of utilidor with all costs

NPV of utilidor with all costs	NPV of costs
NPV of the operation costs for government and all utility providers	$22,017,233
Construction cost	$79,960,273
Operation & Maintenance cost	$116,051,402
Debt service cost	$131,180,952



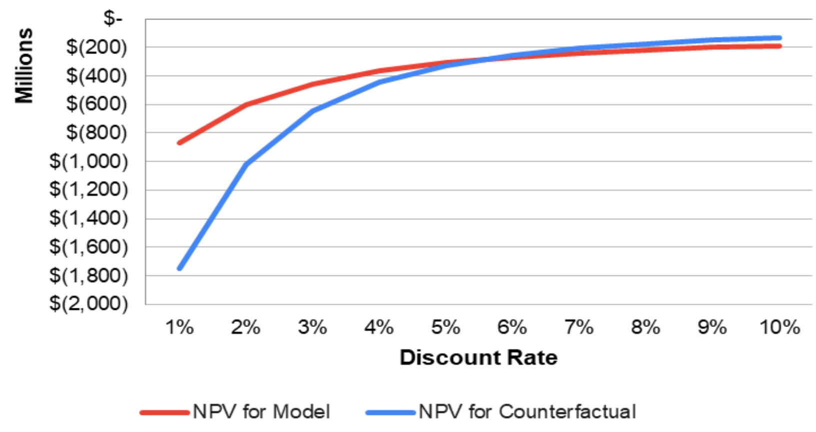
b. Sensitivity Analysis

As described above, the estimated results indicate that the utilidor implementation is economically superior to the continuation of the current trenching practice . However, since the costs in the LCCBA model and current trenching practice are estimated based on a number of assumptions, the estimated results may also fluctuate if the assumptions change. Therefore, we conducted a sensitivity analysis to simulate net present value (NPV) if the assumptions that could have a significant impact on the estimates were changed within an appropriate range, and we verified the robustness of the economic effects to the current methodology. Sensitivity analysis was conducted on six assumptions: discount rate, inflation rate, construction cost of the utilidor, operation and maintenance cost of the utilidor, trenching cost per foot, and number of street cuts, each of which suggests a break-even point.

1) Discount Rate

A discount rate is used to convert the estimated costs for each year to present value and the base is 4%. Here we compare the NPV for the case of utilidor implementation (model) and the case of maintaining the current trenching practice (counterfactual) by varying the discount rate from 1% to 10%. The results shows that when the discount rate goes from 1% to 5%, the NPV of the utilidor implementation practice is higher than the NPV of the current trenching practice, but when the discount rate is 6% or higher, the NPV of the current trenching practice exceeds the NPV of the utilidor implementation practice. This is a break-even point.

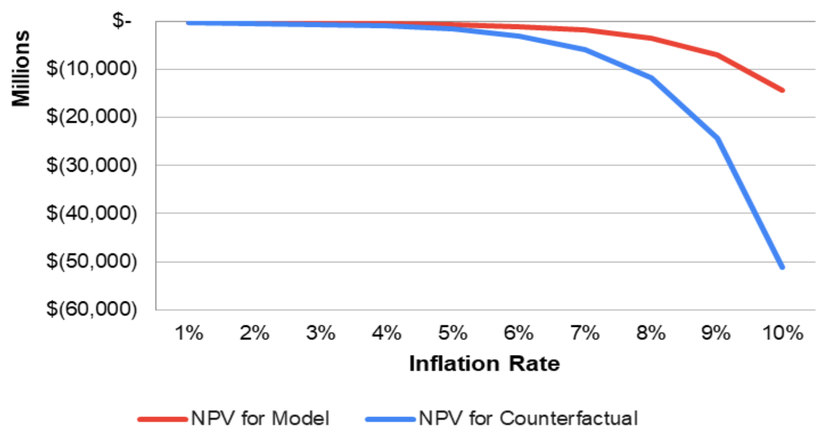
Figure 6. Sensitivity Analysis of Discount Rate



2) Inflation Rate

Inflation is used to estimate costs for each year, with a base of 2%. In this analysis, the NPVs were compared for the case of utilidor implementation (model) and for the case of maintaining the current trenching practice (counterfactual), varying the inflation rate from 1 to10%. The results indicate that the NPV of the utilidor implementation practice exceeds the NPV of the current trenching practice when the rate is higher than 2%. So the breakeven point is 2%.

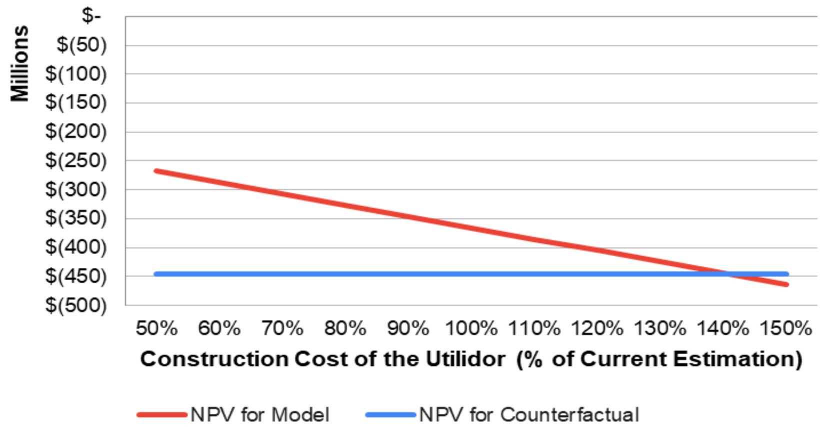
Figure 7. Sensitivity Analysis of Inflation Rate



3) Construction Cost of the Utilidor

In the LCCBA model, we estimate the construction cost of the utilidor as twice the cost of the traditional trenching method, but since this is not a cost based on a detailed design, possible variations should be considered. In this analysis, we compare the NPV of the case of utilidor implementation (model) and the case of maintaining the current trenching practice (counterfactual) with a baseline estimate of the construction cost of the utilidor as 100%, varying by 10% from 50% to 150%. Note that the cost of constructing the utilidor does not affect the current trenching practice in which the utilidor is not constructed, so the NPV of the current trenching practice is constant. The results of the sensitivity analysis show that the NPV of the utilidor implementation exceeds the NPV of the current trenching practice for the 50% to 140% range, while the NPV of the current trenching practice exceeds the NPV of the model for the 150% and above.

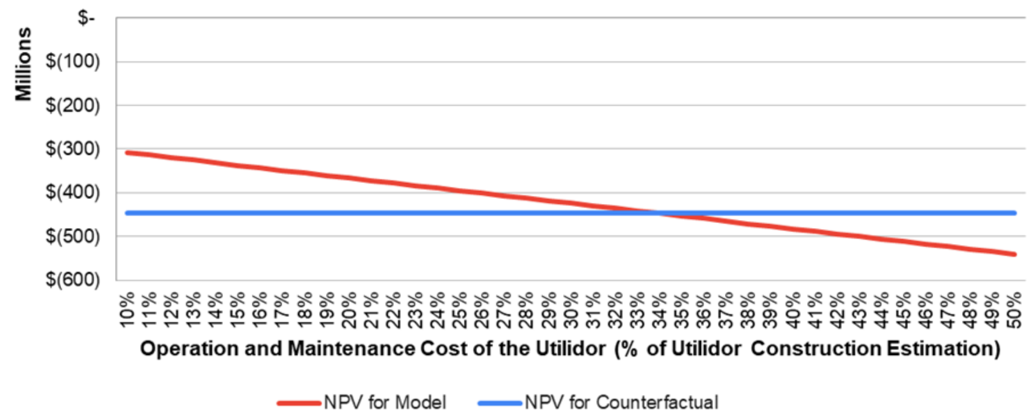
Figure 8. Sensitivity Analysis of Construction Cost of the Utilidor



4) Operation and Maintenance Cost of the Utilidor

In the LCCBA model, operation and maintenance costs of the utilidor are estimated at 20% of construction costs. In this analysis, the NPVs of the utilidor implementation and current trenching practice were compared by varying the ratio of operation and maintenance costs to construction costs from 10% to 50% in 1% increments. Note that the NPV of the current trenching practice is constant because the cost of operating and maintaining the utilidor has no effect on the current trenching practice where the utilidor does not exist. The sensitivity analysis revealed that the NPV of the utilidor implementation model exceeds the NPV of the current trenching practice in the range from 10% to 33%, including the baseline, but that the NPV of the current trenching practice exceeds the NPV of the utilidor implementation in the range from 34% to 50%.

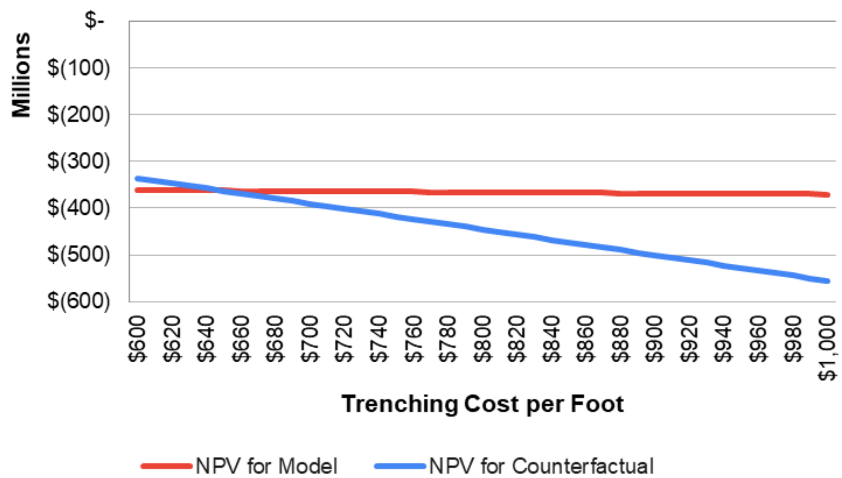
Figure 9. Sensitivity Analysis of the Operation and Maintenance Cost of the Utilidor



5) Trenching Cost per Foot

Since the actual cost of trenching one linear foot is $800, based on the interview with ConEdison, the LCCBA model uses this $800 as a baseline for trenching cost. In this section, a sensitivity analysis was performed to compare NPVs of the utilidor implementation and current trenching practice by varying the trenching cost per foot by $10 between $600 and $1000. The results show that the NPV of the utilidor implementation exceeds NPV of the current trenching practice when the cost per foot is greater than $650.

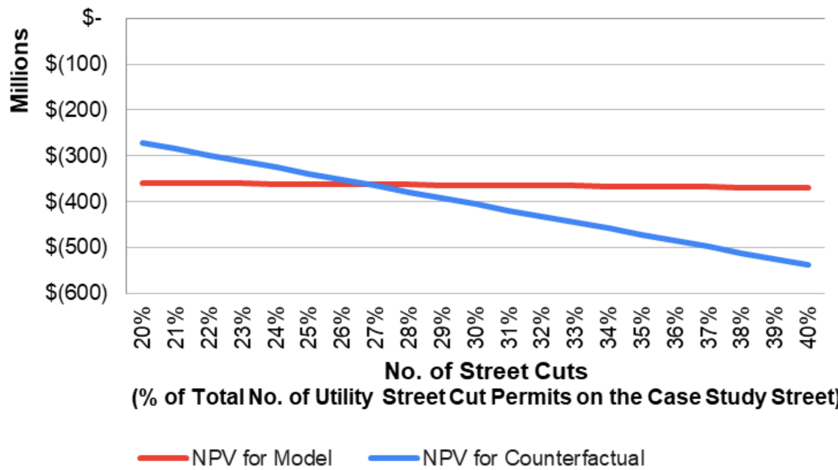
Figure 10. Sensitivity Analysis of Trenching Cost per Foot



6) Number of Street Cuts

The number of road cuts has an impact on the current trenching practice cost estimates, and for this LCCBA, the number of permits for Beekman Street that resulted in actual street cuts was assumed to be one-third of the total number of permits. This section examines the change in the NPV of the current trenching practice by changing this percentage by 1% from 20% to 40%. The results show that the NPV of the utilidor implementation exceeds the NPV of the current practice at 27% or more.

Figure 11. Sensitivity Analysis of Number of Street Cuts



For the above six assumptions, we applied various scenarios to the analysis to clarify the extent to which the NPV of constructing the utilidor can exceed the NPV of continuing with the current direct burial. We found that the utilidor model is economically superior, at least for the assumptions we used as a basis, and that the economic advantage can be maintained even if these assumptions change to some extent.

Part 4: ICT

Information and communication technologies (ICT) are the technologies that allow people and organizations to interact in the digital world. The fast-paced advancement in the ICT sector provides new possibilities for the management and development of cities. Local governments are turning to big data analytics for insights in the urban environment, and are incorporating ICT solutions for service improvement. Thus, activating ICT solutions becomes an important component in building smart cities. The implementation of utilidor would make ICT application to utilities – water, sewer, electricity, gas and telecommunication – possible.

New York City has set out to transform into a smart city. Efforts have been made to support the technological upgrade of the city's ICT infrastructure. However, more than 85% of activities are focused on building an e-government, while other application domains that smart city development represents, such as water and waste, are addressed significantly less. Our research focuses on early water leakage detection and proactive maintenance systems using ICT.

a. Smart Water Management System

Globally, research indicates that smart water management systems can save utilities up to $12.5 billion a year. A smart water system combines wireless sensor network and software analytics to improve water management resulting in cost reductions, risk mitigation, revenue capture and sustainability development. Smart water management systems based on ICT can operate and manage water infrastructures in a more resilient and efficient way. Smart water systems provide water management solutions in areas such as water quality, water quantity, leaks and flow. Smart water networks can be integrated with Supervisory Control And Data Acquisition (SCADA) systems to obtain more control over the water supply system. YSI's Integrated Systems are able to integrate data collection with the existing SCADA system in NYC to help DEP improve their water quality monitoring program. The system helps collect a wide variety of data and operate and control water system equipment remotely.

1) Wireless Sensor Network

Wireless sensor networks involve a set of sensors and a data transmission device that allow remote real-time monitoring processes in water management. Sensors involved in this network can be divided into two categories: water quality sensors and water volume sensors. Turbidity sensors and pH sensors are two main types of water quality sensors. Turbidity sensors measure the amount of light passing through the water to capture suspended solids which reflect the pollution level of water. Low turbidity levels indicate high water clarity. pH sensors measure the acidity or alkalinity of the water and its value ranges between 0-14. Two main types of water volume sensors include vibration sensors and water flow sensors. Vibration sensors capture the vibration of the water pipes while water flow sensors measure the speed of flowing water running through the pipe. A wireless circuit is a data transmission device that is used to direct collected information to the remote monitoring station which monitors and processes data.

2) Smart Water Management System

Intelligent network control and on-site monitoring (INCOM) prototype system is a system that is built for early network leak detection. The anomaly detection analysis is based upon pipe break detection, leak detection and data quality control using data collected from sensor networks. The result of the system shows: 1) confidence level of the likelihood of a leak; 2) severity of the anomaly (constant or progressive leak); 3) risk of the anomaly.

Artificial Neural Networks (ANN) is a system used for proactive maintenance. Urban water pipes age at different rates, depending on pipe material, installation method, environmental and operating conditions. Based on the data feeds on pipe condition, the system can model the failure rate and estimate the optimal replacement time for the individual pipes in an urban water distribution system. For example, the result can be seen that replacing 5% of the pipelines could avoid 50% of failures. The priorities of intervention were illustrated using the geographic information system. The risk map can assist the decision-makers in establishing a strategy for the water network rehabilitation.

A digital twin for water utilities is the virtual model of water utilities under the ground including water pipelines, sensors and wireless circuits. The system provides accurate and reliable data, helps decision makers understand how the utilities perform, and thus facilitate water infrastructure operation. Further, decision makers could use digital twins to perform what-if analyses and make informed decisions throughout the lifecycle of a water system—from long-term system vulnerability and capacity planning to immediate performance monitoring and emergency response.

b. Cost Benefit Analysis

1) Stakeholders

Before categorizing benefits and costs of implementing ICT in water management, we define who has a standing in the project. The first group is the government and authorities of NYC as the government owns and operates the water and wastewater system. New York City Department of Environmental Protection (DEP) is responsible for water system operation, facilities repair, as well as transmission infrastructure expansion. New York City Municipal Water Finance Authority (NYWFA) is a state-created city-controlled finance authority that finances the capital needs of the city's water and sewer system. New York City Water Board is responsible for setting and collecting water and sewer rates to achieve efficient financing of the water system's infrastructure.

The second key stakeholder group is the public. Rate payers are paying for water loss and avoidable infrastructure costs that ICTs would prevent. People and businesses suffering from water and sewer leaks also have a standing because water and sewer leaks can cause critical damage in public and private properties.

2) Costs for smart water management

Hardware Costs

Hardware costs consist of equipment costs and hardware setup. New York City has nearly 11,265 kilometers of water lines. According to an interview with Professor Feng (Columbia SEAS), five sensor packages are needed per kilometer to detect water activity. For each of the packages, various types of sensors such as vibration sensor, water flow sensor, turbidity sensor, PH sensors and a wireless circuit should be included. The cost of each sensor package is assumed to be $30. By multiplying the cost of the sensor package and the number of packages needed, the hardware cost is calculated to be $1,689,750. The costs of installation of hardware generally include: costs for equipment delivery; costs to prepare the worksite for hardware installation; labor costs for setup and mobilization.

Software Costs

Software costs include license costs and support and maintenance costs. Software license cost refers to the cost of actually owning and using software. There are two major software license pricing models: perpetual pricing and subscription pricing. Perpetual pricing means paying one price upfront to own the software indefinitely, which is a pricing method used for software that is downloaded and stored on a local computer or server. Subscription pricing means paying a monthly or annual subscription fee to use the software and is often used for software deployed through the cloud. Annual license costs are estimated to be $9,165 and assumptions are listed in Appendix 2. Software maintenance fee is the annual cost paid for upgrades and support of the software. The price is typically a percentage of the initial software license fee – which is usually between 16-25% of the license cost per year.

Implementation Costs

Implementation costs include costs of training, testing and operation of the data center. This includes the time and cost required for training staff to use ICT tools and the materials created or utilized for training in each training session. The cost of testing includes the expense of personnel, hardware and tools required for testing. Data centers are facilities where computer systems, data storage and associated telecommunications equipment are located as part of ICT infrastructure. Total implementation cost is estimated to be $2,174,918 per year.

3) Benefits for smart water management

Environmental Benefits

This includes reduction in carbon footprints and water quality detection. Since ICT enables remote monitoring and control, onsite maintenance and inspection activities that involve the use of vehicles could be reduced. It takes a lot of energy for water utilities to pump, treat and heat water, so water conservation could help reduce carbon footprints. ICT tools such as water loss mitigation systems could help reduce water losses during transmission. Successful leakage reduction accomplished by the Tokyo's Bureau of Waterworks have led to a fall in energy consumption of 45 million kWh between 2000 and 2013. ICT contributes to the monitoring, transmission, and management of field water-quality data to facilitate effective water quality management. Water quality monitoring systems implement sensors to measure critical water quality parameters and use collected data to develop suitable remedial measures.

Water Authority Benefits

There are two benefits for water authorities: reduction in pipe break and reduction in water waste. Firstly, smart sensors and smart water networks can be used to reduce pipe breaks through system-wide pressure management and real-time system modeling. Secondly, smart water management systems enable utilities to effectively manage wastewater and achieve water efficiency. With the implementation of ICT in water management, the mean time to leak detection would be greatly reduced and thus the volume of lost water is greatly reduced. The estimated savings from reduction in water waste and pipe break is $90 million and $70 million respectively in New York City and relevant calculations can be found in Appendix 2.

Part 5: Financing Operations

1. Revenue and Financing structure

The financing structure we chose builds upon ideas from the 2020 Capstone team. Financing of utilidors would begin with establishing a 63-20 non-profit organization to issue the first bond to finance the construction and first years of operation, and state legislation to create a Smart-City Infrastructure Authority would issue the long-term bonds and transition into a revenue-based financing scheme. The authority, in addition to issuing bonds, could also be authorized to manage all operations related to the normal functioning of the utilidors, such as determining fees to utility providers with infrastructure in the utilidor, monitoring utilidor use, utilidor maintenance, and managing the excess revenue generated for additional utilidor infrastructure to increase the reach of its subsurface network.

The expectancy is to start generating revenue after 5 years of initiating construction. This is a conservative assumption, considering construction could take less than 5 years to be completed and revenues would start being collected as soon as the utilidor is ready to be used.

In terms of who should be paying and how much for the use of utilidors, literature and international experience suggest different possible approaches. One option is to charge utility providers based on the total cost of having utilidors, and another option is to charge them based on total savings generated by the existence of utilidors compared to the current open trenching method (Alaghbandrad & Hammad, 2020). Then, it is important to find a fair way of determining how much each provider would have to pay. For this, three possible options stand out: (1) charge each provider the same proportion of their cost sharing under the current open trenching method, (2) charge providers based on the savings generated to each one, or (3) charge providers based on the cross-sectional area of their infrastructure inside the utilidor.

We decided to use a combination of options, determining fees based on the total savings generated by the existence of utilidors and how much each provider would have to pay based on the cross-section space of their infrastructure inside the utilidor. Based on our analysis, we recommend providers would pay for 80% of the total savings, generating just enough revenue to pay debt service on bonds. After bond maturity, provider fees would continue to generate excess revenue, which become available financial reserve for future smart city infrastructure projects in the city. At the same time, utility providers are benefited since they will be paying less than in the counterfactual scenario of the current open trenching method.

For the first year collecting revenues, the utilidor would generate $5,681 per linear foot, and fees would increase over time based on inflation and savings.

2. Bond Financing Process

Bond financing solutions are dependent on the revenue from the fee that is charged to utility providers. With the revenue projections, the fund gap will be evaluated to determine the amount and the term of the bonds. As mentioned in the last section, the annual fee is determined as a percentage of annual savings. The financing option below is derived based on a fee/savings rate of 80%. The analysis assumes three bond issuances, with annual interest payment and an annual coupon of 5%.

Table 5. Financing solution for the project

Bond No.	Amount (USD)	Initial year	Coupon (%)	Term (years)
1	$120,000,000	2023	5	5
2	$135,000,000	2028	5	25
3	$110,000,000	2053	5	20

The first bond of $120 million will be used to finance the construction period and the initial years of operation. The second bond of $135 million will be issued in 2028 for the repayment of the first bond and the operations in the coming years. The revenue will be generated from 2029 when the utilidor is ready for full operation and the Smart City Authority is in place with full capacity to collect fees. In 2053, a third bond of $110 million will be issued to repay the second bond and fund operations. By 2073, it is estimated that sufficient revenue will be generated to repay the debt service and support the operations until the end of the utilidor lifecycle.

It is recommended to charge a fee of at least 80% of the savings, because any rate under 80% will pose challenges to the operations, as the funding gap will be too large to be met by the issuance of bonds.

Part 6: Conclusion

This report concludes that there are positive economic results for the analysis of direct costs and benefits of having utilidors in New York City, based on the case study of Beekman Street project. Even with a high initial construction cost of 80 million USD (refer to Table 4), this project has a benefit-cost ratio of 1.29 and a payback period of 47 years.

Most of the benefits would be realized and capitalized by utility providers, which is the reason why they are expected to pay a fee for the use of utilidor infrastructure. This income will allow for payment of operation and maintenance of utilidors, the debt service cost and the principal for bonds when they reach maturity. According to our estimates, it will take 50 years to repay all debt and from that year forward, utilidors would start generating excess revenue which can be used to fund smarter city infrastructure in the future.

Our results are robust, aligned with utilidor practices in other countries around the world and to major assumptions suggested by literature. This exercise can be considered as a conservative scenario, given that social benefits could be even greater than the direct benefits resulting from having utilidors. Probably the most important social benefit of having utilidors will be the reduction in carbon footprints, enabling the city and utility providers to achieve their carbon neutrality plans in the near future.

The path for New York City to remain as one of the most influential cities in the world has to include smart city infrastructure and the use of ICT is critical to achieve this goal. Utilidors will enable the use of ICT, generating direct benefits for the Water Authority and New York citizens, as well as environmental benefits including a reduction in carbon footprints and improvement in water quality detection. Our analysis focused on early water leakage detection and proactive maintenance on the water system, through the use of a wireless sensor network and a smart water management system. The theoretic exercise conducted for the water system can be extrapolated to other utilities, increasing the total benefit for stakeholders.

Our results are robust, as shown by our sensitivity analysis. Changing some of the most impactful variables of our model (discount rate, inflation rate, construction cost, O&M cost, trenching cost for private utility providers, and percentage of permits that translates to street cuts) results in utilidors being still economically superior for stakeholders. However, because of the high initial construction cost and the assumption that it will take 5 years to start generating revenues, financing this project will generate high debt service costs. A three-bond structure of 5/25/20 years would be necessary. Construction is funded with the first bond, while the second and third bonds provide enough cash to sustain operation and interest payment. After the payback period, excess revenue would be generated, which would go to a fund for future smart city infrastructure.

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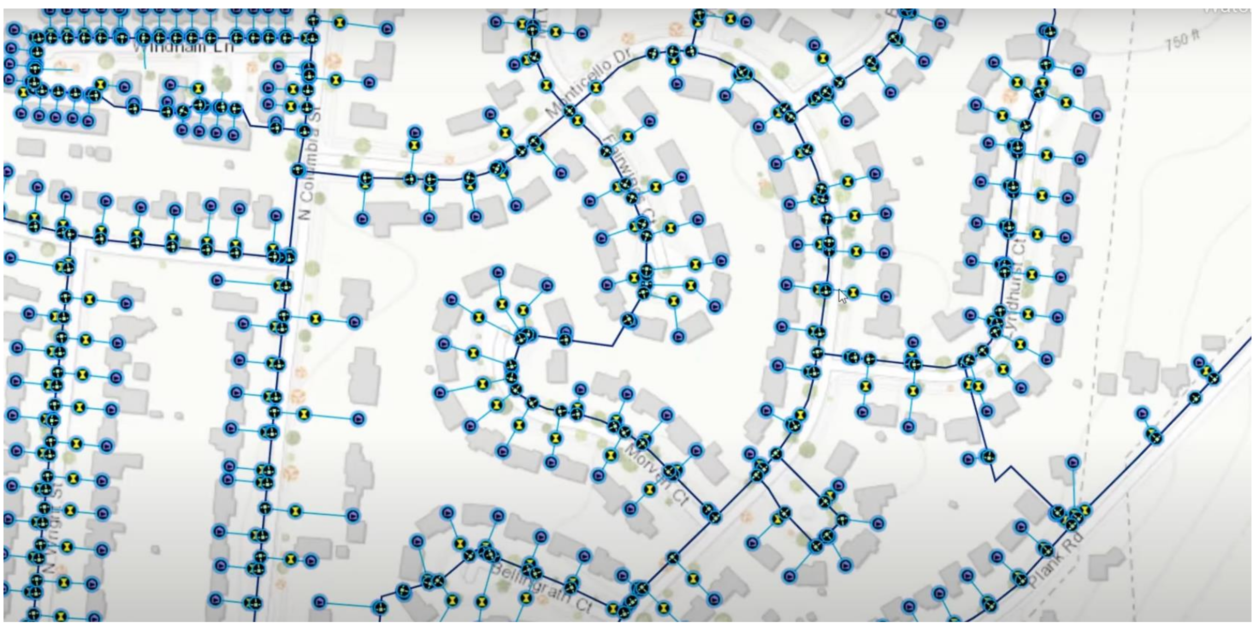
Appendix 1. Geographic Information System

Geographic information system (GIS) enables intelligent water management through the use of digital maps to collect, monitor and share real-time data and information about water and sewer infrastructure in a specific urban area. GIS could help improve the accuracy of subsurface mapping to better locate utilities underground to serve construction projects. Large amounts of geospatial data sets stored in GIS could also help generate reports to advance studies and improve business operations. Mainframes, personal computers and workstations are the fundamental computer platforms used to run GIS software. Some of the key applications of GIS include: data management and data visualization, water quality control, water utility operation and management and water resource decision support systems.

Esri's ArcGIS Utility Network is a useful GIS tool that visualizes key components of utilities such as mains and pressure zones for management authorities to track flows within the water distribution system and analyze effects of real-world events on utility devices.



Cityworks is another GIS-centric application especially designed for utility companies and government organizations to effectively plan, manage, and assess public infrastructure assets.

When estimating GIS costs, these categories should be considered: startup; application development; data development; hardware/software/communication network; installation; testing, training and ongoing operation. These categories of benefits should also be included in the analysis: increased efficiency, cost avoidance, better decision making and increased revenue.

Appendix 2. Assumptions of the Cost Benefit Analysis for ICT Application

Estimation of the savings is based on the following assumptions: 1) sensors are already installed on the 11,265 kilometers of pipe; 2) these sensors could transmit a signal successfully and send data to the cloud; 3) sensors can detect something that distinguishes a leak from flowing water from a train that is rumbling down the tracks; 4) reliable power is available to the sensors so batteries are not needed to be replaced.

A state audit has found that New York City's dilapidated drinking water system is losing 35 million gallons a day through leaks, suggesting a loss of 12.775 billion gallons per year. The volume of water lost is determined by the rate of leak, time to detect leak and time to repair. With the ICT implementation, time to detect leaks reduced and thus reduced annual loss. Residential water rates are assumed at $0.014 per gallon. If we assume the loss of water is reduced by 50%, then the annual loss is reduced from 12.78 billion to 6.39 billion.

For license costs per year, we refer to the pricing of the 12-month subscription fee of the Utilities WorkSuiten, which is $9,165. It is assumed that software maintenance fee is 20% of the initial annual license cost.

The cost of building a data center is about $1,000 a square foot and we assume 1,500 square feet is needed for a data center.

The table below outlines the groups impacted by the plan:

Table 6. Groups impacted by the plan

	Who is included?	Justification of Standing
Government	New York City	• Owns and operates water and wastewater system
	Department of Environmental Protection	• Responsible for water system operation

		• Responsible for repairing and replacement of equipment and facilities in water management • Responsible for expansion in transmission infrastructure
	NYC Municipal Water Finance Authority	• Finance the capital needs of NYC's water and sewer system
	NY Water Board	• Set and collect water and sewer rates
Public	Rate Payers	• Responsible for paying avoidable infrastructure costs
	People and businesses suffering from water and sewer leak	• Impacted by water and sewer leakage incidents

Appendix 3. Case Studies for ICT

ICT technology has been proved very successful in water management cases around the world. These successful cases could be great examples for New York to incorporate a data management system to manage underground utilities.

a) Geographic Information System Case in France

In Wattrelos, a city in the north of France, they have been collecting data from a geographic information system for 14 years to see the effectiveness of Artificial Neural Networks (ANN). The network database is constructed by collecting available data such as historical faults, pipeline properties, hydraulic pressure, soil type and pipeline location.

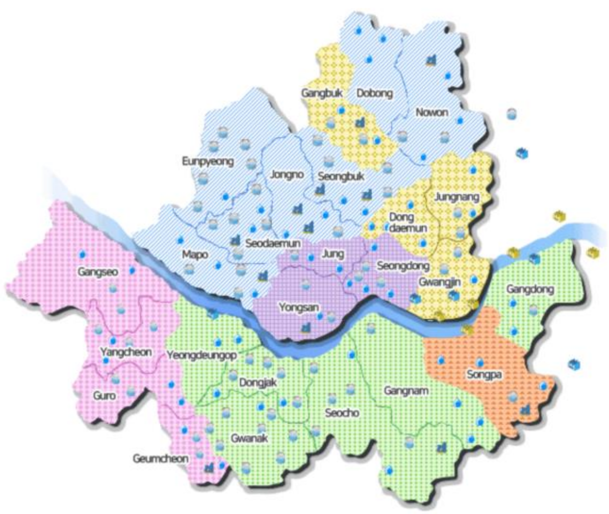
Urban water pipes age at different rates, depending on pipe material, installation method, environmental and operating conditions. The spatial redistribution of degradation risk was illustrated using the geographic information system (GIS), an effective tool for developing strategies to restore water systems. This approach is inspired by neurons in the brain and is based on a network of interconnected processing units.

GIS mainly collects data according to three categories: physical (material, length, diameter, thickness, age), environmental (soil type, street location) and operational (pressure and protection).

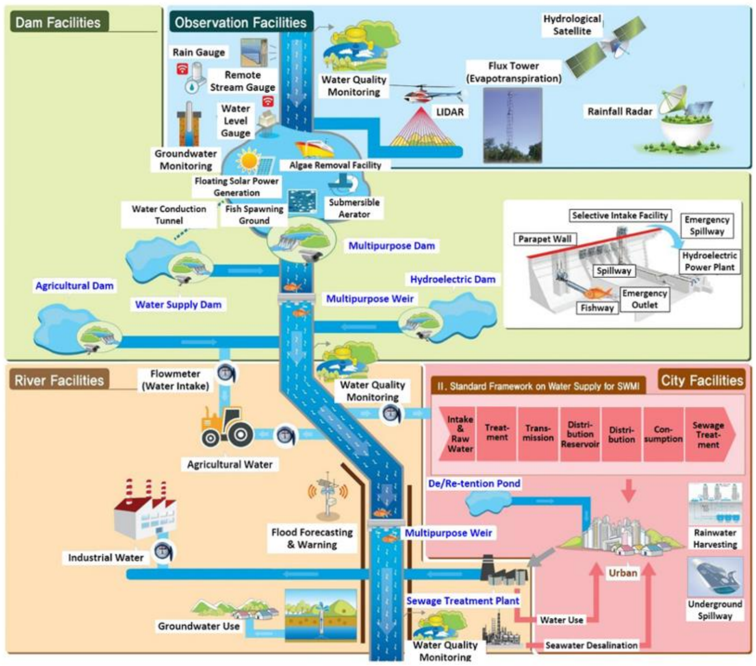
ANN can monitor the failure rate and best replacement time for water mains. The prediction of water leak and rehabilitation is conducted by data analysis. Data management and data visualization allow the city government to have a more efficient workflow and decision making. In this way, the local operation team could create a better strategy over maintenance and rehabilitation priority. It can be seen that replacing 5% of the pipelines ranked hierarchically by the model could avoid 51% of failures and replacing 10% of the pipelines could avoid 68% of failures.

b) Smart Water Management in Korea

The Seoul Water-Now System is an automatic supervisional system of Arisu, Korean direct drinking water. It started in 2004, to prevent water contamination. It checks all the processes of producing and supplying Arisu. It used a new technology named Smart Water Management Initiative (SWMI).



The Seoul Water-Now System monitored water resources, diagnosed problems, improved efficiency and coordinated management to provide a more sustainable everyday water supply for the local citizens. It collected data not only from rain gauges installed on the ground but also from precipitation data and satellites. The information and signals collected from various water management facilities and systemized equipment could predict the water level underground.



Also, Seoul Water-Now System collected water data from different kinds of resources including underground water, sea water and rainwater. In this way, it is able to evaluate not only the water supply but also natural water and reused water without large additional equipment. In ICT projects, SWMI can effectively provide timely information underground and provide accurate prediction which can serve as information signals for pipe production, and demand-supply balance. As the decision process has been faster, water management has been easier in Seoul.