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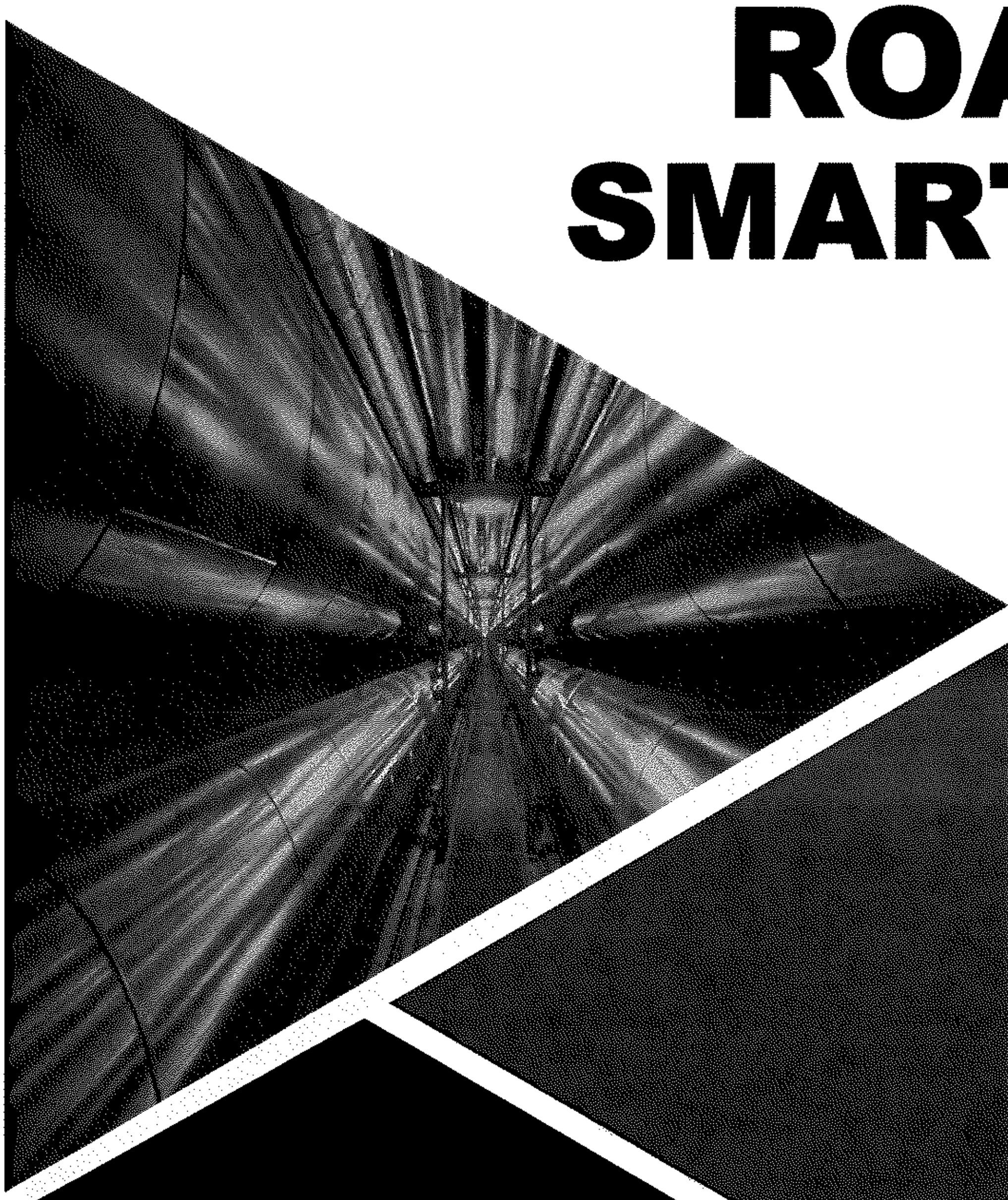

LIFE CYCLE COST BENEFIT ANALYSIS & FINANCING OPTIONS DIAGNOSIS OF NYC'S UTILIDOR PROJECT

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This report was produced for Town+Gown:NYC (Town+Gown), a city-wide research program resident at the New York City Department of Design and Construction (DDC), and Barclays; in conjunction with Columbia University's School of International and Public Affairs (SIPA) as a Capstone consulting project. Any view expressed herein are the authors' own and do not necessarily represent those of SIPA.

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Road to a Smart City

A Life Cycle Cost Benefit Analysis of Utilidor Infrastructure in New York City

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Executive Summary

The underground incorporates the fundamental functions of any city. Water, drainage, communications, and energy services share the tunnels and tubes below the streets, in a labyrinth of aging infrastructure that has a direct physical impact on the *surface* quality. Every day, operation and maintenance services require cutting the asphalt to maintain the telecommunications, electricity, gas, or steam networks.

In New York City, both utility companies and the local government are in charge of maintaining their lines also by cutting open the streets, diverting traffic, and utilizing noisy equipment, causing significant negative environmental, social, and economic impact on the City's streets and on its inhabitants.

Implementing an alternative, such a utilidor or a series of utilidors in New York, may be a more sustainable approach to keep operating these fundamental services for the City.

The present project aims to analyze if the use of this multi-utility system, may facilitate public and private utility installation, maintenance, and renewal in the City and reduce the negative impact on the street users. The report consists of a Life Cycle Cost Benefit Analysis (LCCBA) and an analysis of financing options to evaluate the viability of utilidors in NYC.

In order to conduct the LCCBA we defined four categories of stakeholders that are directly impacted by the current practice and by the implementation of a utilidor: NYC Government Agencies and Authorities, Private Utilities, Traveling Public (Drivers, Cyclists, Pedestrians and Public Transportation Passengers) and Residents. To determine the current costs the stakeholders are facing, and to evaluate the costs and benefits associated with the potential implementation of the utilidor, the team defined a counterfactual (current practice) scenario and projected a model (utilidor) scenario. The *Beekman Street* Project (a roadwork that took place from 2008 to 2010 on Beekman Street) was chosen as both cases to monetize costs and benefits.

The results of the analysis show that the utilidor project makes more economic sense than continuing current utility maintenance practices. The LCCBA shows that the cost of current practice for the next 100 years is estimated to be about $24 billion (NPV), while with a utilidor, it significantly is reduced to $429 million (NPV); it is only 1.78% of the cost with counterfactual. In all impact categories, we see almost 90% or more reduction in costs with the utilidor compared to current practice, and the main reason for that is for the outstanding decrease in street cuts. Furthermore, there is a Benefit Cost ratio of 377.2, suggesting that the net savings for the environment, government, nearby residents and businesses, traveling public, and utilities justify improving subsurface infrastructure management through this intervention.

The project was built on several necessary and well-founded assumptions, such as no occurrence of street cuts relevant to utility repair purposes after the utilidor is installed, a 2.77% increase rate in street cuts for the current practice, a 50% discount on Property Tax for Private Utilities, annual inflation of 4%, among others. With these assumptions applied, the resulting costs with the implementation of a utilidor in all standing categories become significantly lower.

In order to consider future variation and new information, the team tested the results with a sensitivity analysis. We examined four factors and in each scenario, NPV of the utilidor project is greater than NPV of Counterfactual: 1) The utilidor construction cost, up to 600% of the current estimate, 2) the utilidor maintenance cost up to 20% of the current estimate to equate the cost of maintenance, 3) the number of street cuts down to only 5% to 7% of the permits equated to actual the number, and 4) we increased the discount rate from 1-10%. In all scenarios, the project still has a positive NPV (Net Present Value).

Nevertheless, introducing a utilidor in New York City would require financing a large initial construction cost to be procured. Through the LCCBA the team confirmed it is economically beneficial to install a utilidor in the long run, it is not necessary to establish a financial plan to determine the final feasibility of the project.

The team developed a two-phase financing system where, first, a 63-20 non-profit organization is established and starts issuing bonds for the initial construction and installation of the utilidor. Secondly, a Smart City Infrastructure Agency is established through the state legislature to transit to a scheme of revenue credit to support the implementation and maintenance of this infrastructure. The team also built a financial model that shows that the new revenue agency will need to collect at least $5.9 million annually of user fees. Given the results in our CBA model, User fee, in total, is 87% of the projection of property tax that utilities are currently paying. The NPV of total user fees, 114 million, is also reasonable given the total cost avoidance of 1,040 million for utilities. Thus, the proposed system is feasible and that private utilities should be willing to participate.

Although our findings show that the utilidor system would be better than continuing with the current practice, further exploration will be necessary to assess the viability of implementing a pilot program and its expansion to other areas of the City. In this paper, the cost estimations did not include costs associated with MTA subway tunnels, surrounding businesses, the underground use of public spaces such as public parks, and those costs associated with higher traffic levels. To implement and expand a pilot project of the utilidor, more coordination will be needed between the Government of New York City, Private utilities, and other agencies such as the MTA.

Introduction

Utility companies and the City of New York currently maintain underground infrastructure by having to cut open the street, divert traffic, and utilize noisy equipment, causing significant negative environmental, social, and economic impact. This Capstone was initiated by our clients -- Town+Gown:NYC (Town+Gown), a city-wide research program resident at the New York City Department of Design and Construction (DDC); and Barclays -- to evaluate the economic feasibility of a long-term program to implement underground multi-utility tunnels ("utilidors") in New York City (NYC), as part of NYC's ongoing roadway reconstruction program, with the goal of avoiding recurrent roadwork and increasing efficiency to the way utility infrastructure is maintained.

The report consists of a Life Cycle Cost Benefit Analysis (LCCBA) and an analysis of financing options to evaluate the viability of utilidors in NYC. Utilidors allow access to subsurface utility infrastructure for maintenance purposes without having to perform maintenance on the aboveground street. Part I of this report will set the stage for understanding subsurface systems in NYC. The complexity of operating and maintaining underground utilities is costly, regardless of whether or not a utilidor is built. This section will discuss some of the considerations that must be accounted for in designing, building, and maintaining the systems associated with a utilidor.

Part II will discuss LCCBA methodology, including stakeholder standing, impact categorization, and justification for each stakeholder. In Part III, we will discuss the results of LCCBA. In this section we will provide the assumptions underpinning the conceptual design of the utilidor as well as our estimation of the costs of the project.

Finally, Part IV will discuss various financial options which can be used to implement the utilidor. Introducing a utilidor system in NYC requires a significant initial construction cost. Even if the utilidor project is economically beneficial in the long run, the project cannot be declared as feasible until a financial plan is established.

Part I. Subsurface Systems and Utilidor Technical Elements

To understand the opportunities that a utilidor could afford, it is important to discuss the relevance of the subsurface in urban areas, particularly in a city as complex as New York. The underground is a "technical space" that incorporates the fundamental functions of the city, such as water, drainage, communications, and energy that have a direct physical impact on the "surface" quality.[1]

In most cities, many underground services are not coordinated, and different utilities access their lines following different protocols, cutting the street wherever is needed. Those aforementioned "traditional methods" are becoming un-economical, socially disruptive, environmentally damaging, and are ultimately unsustainable.[2] By its nature of being an old city, there is a significant amount of unused infrastructure, ranging from old trolley tracks to wooden pipes that have not been excavated from the ground. According to Al Leidner, who we had the opportunity to interview, the lack of awareness and coordination of the subsurface increases the cost of capital projects.[3]

In fact, according to numerous stakeholders we consulted for the project, New York's utility subsurface infrastructure is described as "incoherent,"[4] and likened to "ancient and modern spaghetti" underground.[5] We had the opportunity to interview stakeholders from Con Edison (ConEd) and the Department of Environmental Protection (DEP), both of whom spoke to the challenges of maintaining aging infrastructure in NYC.[6] One additional complicating factor is that certain materials of infrastructure of varying ages require different frequencies of maintenance, suggesting that the inability to readily monitor the system presents huge problem for these stakeholders.

According to the Common Ground Alliance, a coalition of utility stakeholders which collects data on damage information reporting, accidental damage to utilities from excavation is in part a product of poor coordination.[7] Many of these challenges are related to the fact that there is no single authority overseeing the subsurface, and as a result there is inertia and lack of coordination.[8] Our interviews and published literature confirm that there is a reluctance to share proprietary data and there is a

[1] Hooimeijer, F. L., & Maring, L. (2018). The significance of the subsurface in urban renewal. Journal of Urbanism. https://doi.org/10.1080/17549175.2017.1422532
[2] Rogers C.D.F. and Hunt D.V.L. (2006). Sustainable Utility Infrastructure via Multi-Utility Tunnels. School of Engineering, University of Birmingham, Birmingham, UK.
[3] A Leidner. Personal Communication. 2020.
[4] A Leidner. Personal Communication. 2020.
[5] https://www.nytimes.com/interactive/2016/08/18/nyregion/new-york-101-streets-repair-and-maintenance.html
[6] Town+Gown NYC. Under the Ground: Planning, Management, and Utilization. January 29,2020
[7] Common Ground Alliance. "Damage Information Reporting Tool."
[8] Town+Gown NYC. Under the Ground: Planning, Management, and Utilization. January 29,2020.

significant incentive not to cooperate, given the upfront costs associated with reorganizing the subsurface.[9]

A utilidor is a more sustainable approach: the use of multi-utility tunnels facilitates public and private utility installation, maintenance, and renewal.[10] In NYC this problem is particularly acute. Although locative technology exists, utilities often inadvertently cause damage to other utilities.[11]

Furthermore, planning of utility tunnel networks requires an examination of the relationships among the various scales of urbanizations, the transportation systems serving them, and the utility networks. The feasibility of developing utilidors in conjunction with those networks will rely in part on the compatibility of both systems.[12][13] Their inclusion is considered questionable without a safety analysis for each case.

Establishing the Base Case

To determine the current and future costs the City and the stakeholders face, we needed to establish a baseline case that could be used as a reference for the counterfactual (current practice) scenario. We use this base case to evaluate the costs and benefits associated with the potential implementation of the utilidor. Establishing this base case was a key prerequisite for us to estimate the cost of the utilidor itself, as well as to predict the disruption that such a project might have.

We considered five capital construction projects completed by the City that could be used as potential case studies. These projects quickly became riddled with recurrent utility roadwork, as utilities needed to return to the project area to conduct maintenance. These utilities needed to return to the street hundreds of times in the following years, superseding the permit embargo that accompanies capital reconstruction projects to avoid degradation of the useful life of the street.[14]

The team defined criteria to determine which among those five projects had the best potential viability for the project based on five main elements:

1. Project Capital Cost: the total amount expended by the City during the original project
2. Subsequent Roadwork: in terms of the number of permits issued after the original completion
3. Zoning: primary official land use of the project area

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[9] Town+Gown NYC. Under the Ground: Planning, Management, and Utilization. January 29,2020.
[10] Rogers C.D.F. and Hunt D.V.L. (2006). Sustainable Utility Infrastructure via Multi-Utility Tunnels. School of Engineering, University of Birmingham, Birmingham, UK.
[11] Common Ground Alliance. "Damage Information Reporting Tool."
[12] Canto-Perello, J., & Curiel-Esparza, J. (2013). Assessing governance issues of urban utility tunnels. *Tunnelling and Underground Space Technology*, *33*, 82-87.
[13] Town+Gown NYC. Under the Ground: Planning, Management, and Utilization. January 29,2020
[14] New York City Department of Transportation "Street Design Manual" Retrieved from: https://www1.nyc.gov/html/dot/html/pedestrians/streetdesignmanual.shtml

4. Traffic Level and Public Transportation: the level of vehicle congestion
5. Impacts on Residents: determined as the actual number of different complaint types.

After applying our criteria to all case studies[15], the team chose the *Beekman Street* Project (Project ID NYC HWMWTCA6E). For further detail on our selection criteria, please see Appendix 1. The project took place between August 5 2008 to May 18 2010, on Beekman Street from Gold Street to Park Row and on Park Place from Broadway to West Broadway. See Appendix for map -- the purple area on Appendix 1). The City Capital Costs for all the work involved in this project was $17,455,612.76, the second most costly project for DDC among the five case studies. Some parts of the project area that required reconstruction were funded by the USDOT- FHWA Relief Program for Lower Manhattan to restore streets damaged by 9-11.

In terms of subsequent roadwork, the City issued 681 permits after the original completion of the Beekman project. These are "street opening" permits that authorize cutting into the pavement by major utilities and also to plumbers and other services and organizations that must obtain permits before cutting into the street. The Beekman project had the third-largest number of permits among the case studies.

Regarding zoning practices, the entire project area is within three zoning districts categorized as Commercial (C6-4, C5-5, and C5-3), with a small fraction of zone R8 classified as residential (Red area in Appendix 2 from NYC Planning). All the other case study projects were within commercial zones as well.

Concerning traffic levels, the area has a high level of congestion, with an average of 11,775 vehicles circulating Beekman and Park Place streets every day[16]. There are three hours daily between 12:00 pm and 3:00 pm where significantly decreased traffic speeds occur.[17] It is the second most congested area among the case studies and has the highest number of average daily vehicles. In terms of public transportation, subway lines 2 and 3 run under Beekman Street from William Street to Park Row and under Park Place from Broadway to West Broadway, with Park Place Station in the corner of Park Place and Church Street (Appendix 2). There are no bus lines running through the project area. However, numerous bus lines are impacted by traffic spillover on adjacent streets.

Finally, in terms of assessing the impact on residents, we used NYC's 311 complaints dataset for 2016.[18] For noise (purple dots on the map), we ranked the five case studies (with the first having the most noise complaints and the last having the least noise complaints). The chosen Beekman Project ranked 4th in our distribution. However, the area had a large number of complaints, such as blocked driveway, illegal parking, and street light condition.[19]

[15] A table with a summary of the applied criteria on all potential projects can be found on Appendix
[16] https://on.ny.gov/2RGzrSf
[17] Project Area Google Map. Google Maps https://bit.ly/3bkjQPQ. Accessed 2020.
[18] NYC 311. (2020) Retrieved 9 April 2020, from NYC Open Data: https://data.cityofnewyork.us/
[19] "Mapping Last Year's 311 Complaints" Retrieved from: https://bit.ly/2VH2wOq

Overall, given the costs for the City, the number of related permits issued (that involved several agencies within the government), the combination of residential and commercial land uses, the level of traffic and public transportation, as well as the level of impacts to residents, we considered the *Beekman* Project was an adequate case study to analyze and determine potential costs and benefits of a utilidor.

Technical Considerations of a Utilidor

The technical elements of a utilidor are critically important to understanding which utilities can be accommodated, the size of the project, as well as the street selection process. We surveyed professional and academic literature on utilidor infrastructure, NYC's Value Engineering report, and interviews with stakeholders in determining very preliminary design criteria for the utilidor.

There is nothing in the United States that matches the complexity that would be required in constructing a utilidor in Lower Manhattan. Our cost estimate was developed following advice shared by stakeholders involved in the project and using guidelines from RS Means, a nationally representative database of construction, labor, materials, and equipment data.

Below, the technical aspects that were considered for our project are discussed.

Size: A "culvert box" is the structure comprising the utilidor. Across the whole project area, it will have 3 access points.[20] Ideally, the utilidor would be large enough for a person to easily access and walk in (Image X). It would also accommodate safe employee access and working conditions, as well as a flexible design to integrate future demands in space requirements.[21] Some experts suggest that walkability within tunnels can be achieved with a tunnel height of 1.3m. The highest shelves should not exceed 1.9m, and the shelf depth should not exceed 0.3m (above the shoulder), 0.6m (at the shoulder to waist), and 0.45m (below the waist).[22] The total size should also consider the use of trenchless technologies or others to carry out future maintenance or expansion required.[23]

Depth: Utilidors have been constructed at varying depths categorized here as flush-fitting (0.0m cover), shallow (0.5 - 2.0m cover), and deep (2m - 80m cover). Location, connection ability, and future maintenance or expansion are crucial when considering depth.[24] We have concluded that the utilidor in NYC will be 15 feet deep, to accommodate the various design considerations that we detail later in our analysis, including the need to repave the street, house several utilities, and have sufficient access to the system.

Short-term economic costs for the initial utility installation are dependent on its total size, shape, material, and depth. It also must consider what utilities are included, and all of those requirements may be complicated in large cities with old infrastructure, such as NYC. The installation of utilidors in other countries has usually been where utility infrastructure has not previously existed, and where economic, social, and environmental costs associated with the construction were not very high.[25]

Where utilidors do exist in the United States, they have been constructed for institutions like convention centers, universities, and notably, Disney World. In the rarer instance where municipalities have housed multiple utility types, it has typically been for sewage or to avert water pipe freezing.[26]

Dealing with already developed areas as NYC requires better cooperation between urban developers and subsurface specialists in the early project stages. Considering that such cooperation does not yet exist, it is our hope that the interviews we had with stakeholders will shed some light on the design

[20] J. Fell. Personal Communication. 2020.
[21] Matthews, Terri (2019). Toward "Smart" Cities: Case Study of Three Cities' Implementation of Utilidor Infrastructure and Relation to "Smarter" City Efficiencies. CE-GY 7843 Urban Infrastructure Systems Management.
[22] ibid
[23] Rogers C.D.F. and Hunt D.V.L. (2006). Sustainable Utility Infrastructure via Multi-Utility Tunnels. School of Engineering, University of Birmingham, Birmingham, UK.
[24] Rogers C.D.F. and Hunt D.V.L. (2006). Sustainable Utility Infrastructure via Multi-Utility Tunnels. School of Engineering, University of Birmingham, Birmingham, UK. p. 3
[25] ibid
[26] Corey, J. B. (1972). Feasibility of Utility Tunnels. Journal-American Water Works Association, 64(4), 226-229.

necessities of the project. In our case study, it is abundantly clear that the utilidor will need to be fabricated off-site and installed in segments.

According to Canto-Perello and Curiel-Esparza, at least a common wall should separate utility tunnels and underground transportation systems.[27] Although this constraint will not apply to our case study, the importance of physical separation from other utilities was stressed in our meetings with various stakeholders. For example, ConEd would be less inclined to share space with water and sewer lines, due to the potential damage that utility failure could cause.

This is the most technically viable approach, given the complexities of NYC, but it also is a request made by our client at DDC.[28] Our interviews with our clients and other experts, including AECOM, as well as ConEd, have confirmed that offsite fabrication has a number of critical advantages.

For instance, it would avoid a significantly prolonged disruption to service by utilities that would be required to construct the infrastructure onsite. However, that advantage has technical limitations as well. Off-site fabrication requires higher transportation costs. Further, due to the limited space available in the case study area, we estimate that installation would take place in ten-foot increments. This would be the only way to accommodate the construction equipment, fill material, and labor necessary to install the infrastructure into the ground.[29]

Further, offsite fabrication would assure that utility installation would be better coordinated than traditional trenching techniques of installing utilities.[30] According to Sterling, cut and cover installation is best suited for a new or large-scale development area.[31] Further, constructing the utilidor through tunneling and/or drilling may pose greater risk to underground infrastructure that already exists, such as subway lines.[32] Regardless, urban planners and engineers would need to work together to identify more sustainable redevelopment strategies and to ensure that the correct data is integrated and that the range of new technological options in the project is considered.[33]

Furthermore, utilidors have unique design specifications that must be adhered to in order to realize its benefits. This is a project without precedent, and although companies do have experience constructing utilidors, most companies lack the experience in this complex of an environment.[34] Building this infrastructure needs to account for complex design criteria unique for each utility and the basic needs of the tunnel. Some electrical infrastructure has a high bend radii,[35] and steam infrastructure needs a

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[27] Canto-Perello, J., & Curiel-Esparza, J. (2013). Assessing governance issues of urban utility tunnels. *Tunneling and Underground Space Technology*, *33*, 82-87.
[28] Matthews, T. Personal Communication. March 24, 2020.
[29] J. Fell, Personal Communication. April 4, 2020
[30] Canto-Perello, J., & Curiel-Esparza, J. (2013). Assessing governance issues of urban utility tunnels. *Tunnelling and Underground Space Technology*, *33*, 82-87.
[31] Town+Gown NYC. Under the Ground: Planning, Management, and Utilization. January 29,2020
[32] *Ibid*
[33] Hooimeijer, F. L., & Maring, L. (2018). The significance of the subsurface in urban renewal. Journal of Urbanism. https://doi.org/10.1080/17549175.2017.1422532
[34] Corey, J. B. (1972). Feasibility of Utility Tunnels. *Journal-American Water Works Association*, *64*(4), 226-229.
[35] Town+Gown NYC. Under the Ground: Planning, Management, and Utilization. January 29,2020

greater amount of space.[36] Additionally, the tunnel requires sloped floors to minimize water on walking surfaces.[37] It also requires adequate natural ventilation, as well as storm drainage of water entering through the manhole.[38]

Utilidors allow the installation of technology and monitoring systems intended to deliver information and computer technology (ICT). They help utilities increase and optimize the delivery of their commodities (such as condition monitoring, leak detection, and location), permitting early identification and reducing the potential of failure and, most importantly, adding predictive capacity.[39] In order to include all the techniques mentioned, the service tunnels are designed to be transitable structures which permit the servicing with no necessity of carrying out any excavation.[40] This implies that the structure is traversable by people and, in some cases, traversable by some sort of vehicle as well.[41] A portion of our cost estimate is derived by estimating the cost of these technologies, which are detailed further in the Appendix.

Prefabrication of the infrastructure offsite will allow for the utilidor to meet the needs of the project. We estimated that over 10,000 feet of utilities will be replaced within the utilidor. Our estimate also provides for hangers and other forms of infrastructure that would support the utilities. Additional design specifications are outlined below. A walkable utilidor is ideal, but the actual design considerations take into account the constraints created by conditions on the ground. A plan with a much more detailed design is necessary. Other specifications include: how the utilities will be housed, the requirements each stakeholder has, and development of policies to secure each stakeholder's assets.

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[36] *Brian Yee-Chan and Aidan Mallamo. Personal Communication. 2020.*
[37] 354th Civil Engineering Squadron. (2017) "General Utilidor Construction Criteria" Retrieved from: https://www.poa.usace.army.mil/Portals/34/docs/ppmd/10-EAFB%20Utilidor%20Design%20Guide_20170817.pdf?ver=2017-08-18-133752-647
[38] University of Washington. "Utility Tunnels and Trenches" Retrieved from: facilities.uw.edu/files/media/fsdg-02-u-utility-tunnels-trenches.pdf
[39] Matthews, Terri (2019). Toward "Smart" Cities: Case Study of Three Cities' Implementation of Utilidor Infrastructure and Relation to "Smarter" City Efficiencies. CE-GY 7843 Urban Infrastructure Systems Management.
[40] ibid
[41] Rogers C.D.F. and Hunt D.V.L. (2006). Sustainable Utility Infrastructure via Multi-Utility Tunnels. School of Engineering, University of Birmingham, Birmingham, UK.

Part II. Utilidor Life Cycle Cost Analysis

Methodology

Assessing the whole lifetime cost of an infrastructure project includes accounting for the cost of acquiring it (including design, construction costs, and equipment), the costs of operating it and the costs of maintaining it throughout its useful life. This is the lifetime cost of infrastructure and allows for comparing the costs of projects in different time periods.[42] The Federal Highway Administration (FHWA) primer on LCCA identifies five steps that are necessary to complete an assessment of the true life cycle cost of an infrastructure project: 1. Establish design alternatives; 2. Determine timing of activities; 3. Estimate costs; 4. Compute life cycle costs; 5. Analyze results.[43]

Much of the LCCBA literature concludes that "repair and/or failure of infrastructures will usually result in user costs being greater than the repair or replacement costs of the infrastructure."[44] Essentially, as Thost-Christensen argues, this form of analysis demonstrates that users actually bear a significant portion of the total cost of emergency repair (as opposed to maintenance). Mirzadeh argues that "a life cycle costing system should include the key variables that drive future costs in order to provide a framework for reducing the risk of under- or overestimating the future costs for maintenance and rehabilitation activities."

The first step of a LCCBA is to identify design alternatives. In the case of analyzing the life cycle costs of current maintenance practices, we use this method to assess the true costs of maintaining assets of various utilities and city agencies compared to two alternatives: the utilidor scenario (the "model") and the current practice (the "counterfactual").

The counterfactual is the baseline against which all analysis will be made for discussing the feasibility of the utilidor project. 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 maintenance. As the utilidor has an expected useful life of 100 years, all costs for the counterfactual scenario will be measured for a 100-year timespan.

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[42] Ferreira, A., & Santos, J. (2013). Life-cycle cost analysis system for pavement management at project level: sensitivity analysis to the discount rate. *International Journal of Pavement Engineering, 14*(7), 655-673.
[43] Walls, J., & Smith, M. R. (1998). *Life-cycle cost analysis in pavement design: Interim technical bulletin* (No. FHWA-SA-98-079). United States. Federal Highway Administration.
[44] Thoft-Christensen, P. (2012). Infrastructures and life-cycle cost-benefit analysis. *Structure and Infrastructure Engineering, 8*(5), 507-516.

These initial steps result in a schedule of when future maintenance and rehabilitation activities will occur, when agency funds will be expended, and when and for how long the agency will establish work zones. As seen in Figure 2 provided by the FHWA LCCBA Primer, we see the relationship among user costs, the timing of construction, and the useful life of the project.[45] This will allow us to compare the costs borne by the users of the infrastructure, such as the traveling public and residents, surrounding the project area. By installing a utilidor, the factors impacting the life cycle of the street, assets owned by utilities, and transportation systems significantly change for users, owners, and society.

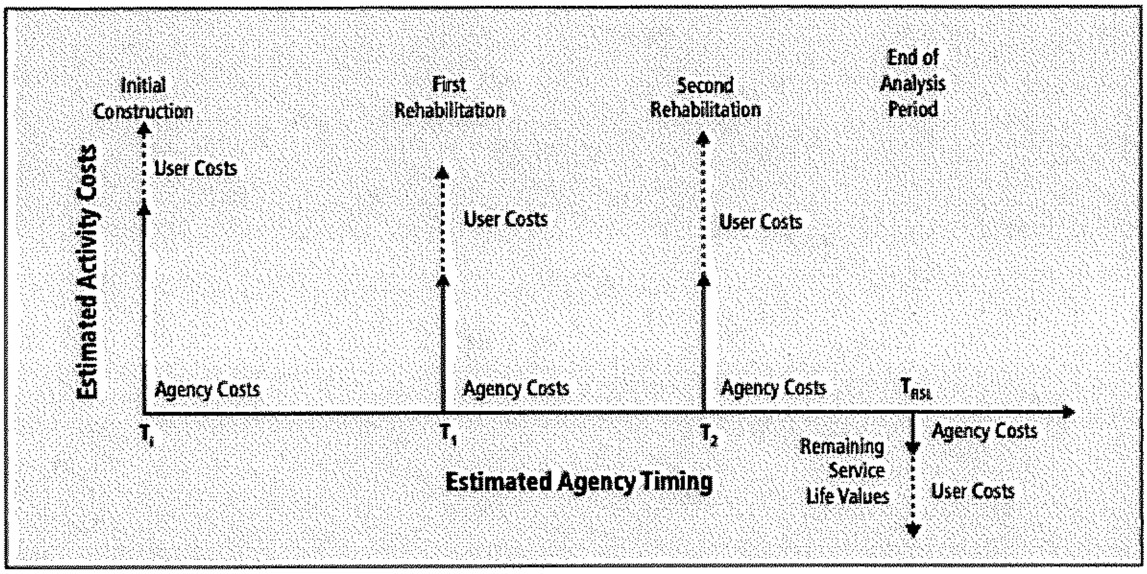


Figure 1 Expenditure Stream Diagram, with estimated activity costs, user costs, and agency timing

Standing

Before approximating how those systems are impacted in the third step, we define who has standing. Table 1 outlines the groups impacted by both design alternatives:

[45] Walls, J., & Smith, M. R. (1998). *Life-cycle cost analysis in pavement design: Interim technical bulletin* (No. FHWA-SA-98-079). United States. Federal Highway Administration. https://www.fhwa.dot.gov/infrastructure/asstmgmt/013017.pdf

Table 1 Standing Categorization

	Who is included?	Justification of standing
Government	• All government departments that are involved in the planning, budgeting, and implementation of roadway infrastructure. • All government departments involved in overseeing infrastructure underground • Government agencies that own utilities and are responsible for providing the service to the public	• Bear the direct financial costs related to utilidor installation. • Responsible for the well-being and safety of New Yorkers, which includes considering the environmental impact of construction. • Responsible for maintaining surface level infrastructure
Utilities	• Con Edison • Empire City Subway	• They maintain the infrastructure underground and would house their assets in a utilidor
Traveling Public	• Drivers • Public transit users • Pedestrians • Cyclists	• Largest user group for road space • They bear the user costs of O&M plans • Trenching causes damage to pavement condition • Time spent driving and the value of the space allocated to particular uses, such as walking and driving • Difference in congestion • Impacted by the traffic caused by recurrent roadway
Residents	• People who live in the immediate area	• Residents are impacted by temporary utility disruptions. • Direct customers of utility services

Businesses	• Disruptions caused by utility failure	• Operational costs related to delays caused by traffic are borne by the traveling public.

As the table shows, five main groups are impacted by the costs and benefits of the plan. However, we avoid double counting benefits by evaluating the costs to businesses in terms of the services utilities provide for them as customers, rather than the cost of operations. We concluded that any cost incurred by businesses in the project area relating to delivery delays or employee commute times is captured through road use categories measured in the traveling public section. For example, businesses are impacted by congestion, and the utility maintenance increases traffic in work zones. We count the preferences of the first four groups for various reasons, but each allows us to approximate the user, maintenance, agency, and rehabilitation costs created in both scenarios.

We calculate the cost of congestion in terms of lost productivity, so it wasn't necessary to double count the cost that businesses accrue due to traffic congestion. By not distinguishing between trip purpose, residents and commuters and other road users are all included in the analysis. Lack of data on various constituent groups (whether someone is a resident or a person commuting to work at a given time) confirmed our decision to evaluate 'standing' by these use types. Further, our data confirmed a redistribution of costs and benefits to businesses outside of the project area. The costs that are borne by businesses in the immediate vicinity caused by traffic, would actually be a net benefit to businesses beyond that area. In other words, there is a reasonable expectation that a business in the project area is equally substitutable for customers. For that reason, we count those impacts to the traveling public, and not business.

The first category is the government and authorities of NYC, as they determine road usage and bear the costs of altering how roads are maintained. The stakeholders of the NYC government and authorities own the roadway, water infrastructure, public bus service, and are responsible for repaving and reconstructing the street. They are also responsible for the social and economic wellbeing of New Yorkers and have a stake in increasing any indirect social benefits that may come from the project. A key question that this analysis will address is if the utilidor reduces the rehabilitation cost of the roadways borne by the City.

New York City Department of Design and Construction (DDC) completes periodic road reconstruction capital projects, and New York City Department of Transportation (DOT) resurfaces about 1,300 miles of roadway per year.[46] These agencies adjust the use of the roadway by carrying out its maintenance obligations, and DOT establishes a 5-year embargo for street opening permits, which impacts the scheduling of planned maintenance by another key stakeholder, private utilities. In theory, our

[46] Mayor's Office of Operations. "Mayor's Management Report." Last modified, 2019. https://www1.nyc.gov/assets/operations/downloads/pdf/mmr2019/dot.pdf

stakeholders confirmed with us, this is meant to encourage increased coordination. However, given the frequency of recurrent road work that occurs after major capital rehabilitations (demonstrated shortly in our case study), that coordination is clearly lacking.

As mentioned, the second key stakeholder group is the private utilities that maintain subsurface infrastructure. They are also responsible for the residual street rehabilitation after trenching activities to facilitate maintenance. One key question this analysis seeks to answer is whether a utilidor could reduce the cost of maintenance borne by utilities. The other key question this analysis seeks to answer is whether the reduction of street cuts reduces risk to other utilities and reduces the labor time required for conducting the street cuts.

The residents in the surrounding project area are considered stakeholders for two reasons. The first is that they are consumers of the utilities' services. They are impacted by unanticipated interruptions to service due to degrading infrastructure causing utility failure. They also bear user costs when maintenance is taking place, due to traffic conditions, and quality of life concerns such as construction noise and air quality.

The traveling public has standing in this analysis as well. This includes pedestrians, private vehicles, and public transportation users. They are directly impacted by DOT street maintenance, emergency repairs reducing available street space, and regular utility maintenance making the roadway unusable.

Defining Predicted Benefits

In order to evaluate the factors which determine the costs borne by these stakeholders, we defined the costs in the next step. There are many benefits associated with implementation of the utilidor. The overarching theme surrounding these benefits is increased efficiency in the subsurface area and on the street. However, as each stakeholder has differing characteristics and needs, they each experience this increased efficiency in different ways. Each associated benefit for the various stakeholders was assessed in order to analyze the overall feasibility of the project. Table 2 details each of these benefits.

Table 2 Predicted Benefits

Stakeholder	Benefits
NYC Government	• Better planning and utilization of public spaces
Utilities	• Better planning and utilization of facilities

Traveling Public	• Fewer disruptions • Reduced travel time • Lower vehicle maintenance costs
Residents	• Increased Quality of Life Indicators • Long-term service reliability
Environment	• Less water loss • Lower carbon emissions • Less construction waste

NYC Government

While each of the government entities that we studied are related to different aspects of the utilidor project, the target agencies we examined - DOT, Department of Environmental Protection (DEP), New York City Department of Information Technology and Telecommunications (DOITT) and the Metropolitan Transportation Authority (MTA) - are all expected to enjoy better planning and utilization of public spaces and subsurface spaces. For the DOT, it is expected that street maintenance costs will decrease as a result of fewer street cuts made in the project area. DEP is expected to see benefits related to fewer water main breaks. DOITT will likely see benefits in the form of less damage to telecommunications infrastructure. Finally, the MTA is expected to lose more revenue in the counterfactual scenario due to disruptions from traffic. In the model scenario, the MTA is expected to lose less revenue because traffic disruption will decrease.

Utilities

There are many utilities that will be impacted by the implementation of the utilidor. DEP, which controls NYC's water lines, was discussed above as it is a government agency. The remaining utilities, which encompasses electric, steam, gas, and telecommunications, are all run privately and will be discussed together. In the case of NYC, this applies to ConEdison (ConEd) and Empire City Subway (ECS). As ConEd runs Manhattan's gas, steam, and electric infrastructure, they will experience most of the direct impacts of the utilidor firsthand. In terms of benefits, they are expected to see decreased maintenance costs and fewer accidents, which also leads to reduced headline risk. ECS is also expected to benefit from decreased maintenance costs.

Traveling Public

As this group is composed of individuals who pass through and commute through the project area, they will experience some of the indirect impacts of the utilidor. In terms of main benefits, they are expected to enjoy decreased commute times due to less congestion on the roads. This would apply to drivers, as well as cyclists, pedestrians, and public transit passengers.

Residents

Residents who live in the project area are also expected to feel some of the indirect benefits of the utilidor. For example, they are projected to see benefits across various quality of life indicators, including decreased noise pollution, vehicle pollution, and construction pollution. They also feel impacts in the form of utility disruptions when maintenance or accidents occur.

Environment

The environment as a whole will also feel many of the expected benefits of the utilidor, which will be felt by all stakeholder groups. These benefits include reduced levels of carbon emissions from vehicles and roadwork, as well as decreased waste from construction.

The following section will introduce our results. We will explain the assumptions underpinning each of the categories we measure.

Part III. Results

Cost Estimation

Our estimations lead us to conclude that organizing utilities in a transitable utilidor will allow for maintenance costs to dramatically decrease. In doing so, DOT will increase the lifecycle of the street, thus reducing costs. Further, as we outline below, the project will produce a wide array of positive externalities for the environment, the traveling public, and residents as a result of reduced construction.

As discussed above, to categorize the impacts of the utilidor project, five key stakeholder groups were identified, each of which faces unique impacts from this project. All of these impacts must be measured in order to gain a full view of the project's overall feasibility. Below we define the assumptions that went into calculating each cost category.

In order to approximate costs borne by the City, we consider the impact in the project area on Beekman Street. Each City agency that is a stakeholder in this project has significant maintenance costs, revenue, and administrative impacts associated with the need to conduct street cuts in order to perform maintenance. Most immediately impacted by the current practice is the New York City Department of Transportation. One of our foundational assumptions is the expected number of street openings per year. This number, even in the years after a full capital reconstruction, varies significantly. We have been advised by the Utilidor Working Group that about ⅓ of street opening permits issued lead to a street cut.[47] We calculated this by taking the average of the past 5 years of street opening permits issued on the project area. Year to year, this increased at a rate of 2.77 percent.[48] In Manhattan overall, the rate of increase in street opening permits was about 1.5%.

[47] Matthews, T. Personal Communication. 2020.

[48] New York City Department of Transportation, Street Opening Permits Open Data. (2020) Retrieved 9 March 2020, from NYC Open Data: https://data.cityofnewyork.us/

Table 3 Cost and Benefit categorization

	Classification	Categorization
NYC Agencies	**Department of Transportation (DOT)**	• Maintenance cost of streets
	Department of Environmental Protection (DEP)	• Water facilities maintenance cost • Cost of accidents to workers in project area
	Department of Information Technology & Telecommunications (DOITT)	• Damage to telecom infrastructure
	Metropolitan Transportation Authority (MTA)	• Disruption to Bus Network
Utilities	**Con Edison**	• Property tax • Maintenance cost • Costs of accidents to workers • Manhole accidents compensations • Cost of major accidents • Headline risk
	Empire City Subway	• Property tax • Maintenance cost • Cost of accidents to workers
Traveling Public	**Drivers**	• Travel time value • Vehicle operation costs
	Other public	• Cyclists: value of speed delay time • Pedestrians: value of speed delay time • Public transportation passengers: value of speed delay time
Residents		• Quality of life: noise • Quality of life: pollution

	• Quality of life: public space • Utilities disruption costs
Environment	• Cost of carbon emission from traffic • Cost of carbon emission from road repair work • Waste • Water

1. NYC Agencies

(a) Department of Transportation (DOT)

Most immediately impacted by the current practice of utility maintenance is the New York City Department of Transportation (DOT). One of the most important variables determining the cost of street maintenance in our model is street cuts per year. We model this by using the amount of street opening permits issued[49] DOT experiences a net benefit in terms of reducing the lifecycle cost of maintaining the streets. In the current practice, Beekman is repaved every 13 years, but in the model, it's repaved every 14 years.

Cost of Maintenance to Streets: The City of New York maintains 6,000 miles of roadway by milling and paving, filling in potholes, and responding to emergency road maintenance needs. There is a significant body of literature documenting the impact of roadcuts on the lifecycle of streets that confirm our hypothesis that reducing the frequency of roadcuts can extend the life cycle of streets.

Chow and Troyan (1999) find that roadcuts have the biggest impact on newer or recently rehabilitated roads. Riccio models the level of roadway repaving necessary simply to maintain current road conditions.[50] When the City of New York paves fewer lane miles, there tends to be an increase in potholes filled in subsequent years. In recent years, NYC has paved more lane miles and filled more potholes, all while the number of street opening permits in Manhattan increased. For our analysis, we assume that DOT repaves streets to maintain the current condition of the roadway, considering the fact that DOT's street inspection reports remain relatively stable.[51] Any increase in street cuts inevitably results in more poorly implemented repairs called "failed street cuts." "Failed street cuts"

[49] New York City Department of Transportation, Street Opening Permits Open Data. (2020) Retrieved 9 March 2020, from NYC Open Data: https://data.cityofnewyork.us/

[50] Riccio, L. "Pothole Analytics". (2015) Retrieved from: https://www.informs.org/ORMS-Today/Public-Articles/June-Volume-41-Number-3/POTHOLE-ANALYTICS

[51] Mayor's Office of Operations. "Mayor's Management Report." Last modified , 2019. https://www1.nyc.gov/assets/operations/downloads/pdf/mmr2019/dot.pdf

occur after a utility cuts open the street and inadequately rehabilitates the road.[52] This is a key indicator in DOT's Mayor's Management Report, and although DOT confirmed that utilities are responsible for fixing these street cut issues, we use this metric as a proxy for the degrading roadway.

These are directly tied to an increase in settlements the city pays out related to damaged roads and "unmet maintenance need." Under the current practice, DOT must repave the project area every 14 years. By constructing the utilidor, and reducing the need to conduct street cuts, it would have to repave the street less often.

Table 4 NYC Maintenance Cost Comparison

Scenario	**Counterfactual**	**Utilidor Project**
NPV of NYC Maintenance Expenditures	$1,010,359,977.45	$499,465.56

(b) Department of Environmental Protection (DEP)

Water Facilities Maintenance Costs: As a stakeholder in this project, DEP saves a significant amount in averted costs that are evident in the current practice. Even in just the project area, DEP passively loses a significant amount of water each year. DEP pipes break, causing significant damage to neighbors, disruption on the street, and possibly to other utilities. For this cost, we estimate the number of labor hours to conduct repairs in the area. DEP's asset maintenance needs are increasing, a clear pattern shown in the Mayor's Management Report and confirmed by the American Water Works Association.[53][54] This is a product of aging infrastructure, as well as an imperfect, though reliable system for detecting leaks and responding to maintenance needs. [55]

This expected increase in water main breaks will create a longer response time for the agency to make the area safe. DEP responds to hundreds of water main breaks and street cave-ins per year. Responding to these complaints takes time, including shutting off service in the area, to make the area safe. Street cave-ins can occur when the earth settles due to leaky pipes; this increases costs for DOT as well as DEP, which must repair the pipes. In other words, the degradation of the roadway can occur at the surface and below the surface of the street.

Cost of Accidents to Workers: Excavation is a construction operation that has high risk for workplace injury. It is for that reason that we used labor response time to approximate costs to DEP. We modeled DEP costs in terms of labor time, as such incidents are expected to grow across the city. As the demand for emergency maintenance increases, we account for the likely direct increase of workplace injuries

[52] ibid
[53] Wood, A., & Lence, B. J. (2006). Assessment of water main break data for asset management. *Journal-American Water Works Association*, *98*(7), 76-86.
[54] Mayor's Office of Operations. "Mayor's Management Report." Last modified , 2019. https://www1.nyc.gov/assets/operations/downloads/pdf/mmr2019/dot.pdf
[55] Folkman, S. (2018). Water main break rates in the USA and Canada: A comprehensive study.

and fatalities, requiring workers compensation or court settlements. We calculated the workplace injury probability per 100,000 full time equivalent employee and estimated the number of accidents per year.

Risk of Accidents to Other Utilities: Here, we utilized data from the Common Ground Alliance assessing the risk to other utilities caused by excavation.

Table 5 Accidental Damage to Utilities from Excavation Comparion

Scenario	Counterfactual	Utilidor Project
NPV of Accidental Damage to Utilities from Excavation	$63,429,580.87	N/A

(c) Depatment of Information and Technology & Telecommunications (DoITT)

Damage to Infrastructure: The New York City Department of Information Technology & Telecommunications (DoITT) is chiefly concerned with infrastructure that provides for the delivery of efficient and effective IT services. This agency supports the following objectives that are directly impacted by this project:

- Enhances and Improves Services to offer more advanced and timely technology implementations and streamline processes.
- Provides Robust Infrastructure to protect the City's technology, telecommunications, and information assets and maintain service operations.
- Optimizes Citywide Technology Administration to improve IT procurement options and vendor accountability and save the City cost and time.[56]

A utilidor would help advance each of these objectives, however, methodologically, we could not monetize the dollar value that these benefits would bring to the city in these contexts (this will be discussed further in the appendix.). Further, it was impossible to systematically attribute the utilidor as the cause of those objectives.

However, we were able to estimate the increased capacity to deliver more reliable infrastructure. According to the Common Ground Alliance, telecommunications infrastructure is the most likely to be damaged by unintended street cut accidents.[57] By reducing the likelihood of damaged utility lines,

[56] NYC Department of Technology and Telecommunications (2020) "Who We Are"https://www1.nyc.gov/site/doitt/about/who-we-are.page
[57] Alliance, Common Ground. "Damage Information Reporting Tool."

DoITT gains benefits equal to the aggregate willingness to pay for uninterrupted service, suggested by Hayes.[58]

Table 6 Damage to Utilities Comparison

Scenario	**Counterfactual**	**Utilidor Project**
NPV of Damage to Utilities	$63,429,580.87	N/A

(d) Metropolitan Transportation Authority (MTA)

MTA is a stakeholder in this plan as it owns property that shares underground space with utilities. MTA's operations are indirectly impacted by the utilidor project as well as the current practice of operating utilities. For instance, as recently as January, 2020 an MTA subway station was flooded as a result of a water main break.[59] The probability of utility failure impacting other infrastructure is already captured as costs to the traveling public as well as costs to other agencies.

Construction of a utilidor would cause significant traffic disruption during the period of construction. On the other hand, ordinary street cuts cause traffic disruption which have contributed to the slowing down of bus service. We start by approximating the increased traffic that increasing street cuts cause every year. The average bus speed has been decreasing in Manhattan for years, accompanied by a stark decrease in ridership. The cost to MTA is calculated by the predicted loss in ridership correlating with declining bus speeds[60]. The difference in ridership multiplied by $2.75, the cost of a bus ride, is the cost to MTA.

Table 7 Bus Network Disruption Comparison

Scenario	**Counterfactual**	**Utilidor Project**
NPV of Bus Network Disruption	$20,010.46	$13,528.63

[58] Hayes, R. (2011). Valuing broadband benefits: A selective report on issues and options. *Available at SSRN 1856378.*
[59] NBC News. (2020) "UWS Water Main Break Delays Traffic, Train Service; 2nd in a Week" Retrieved from: https://www.nbcnewyork.com/news/local/uws-water-main-break-delays-traffic-disrupts-train-service/2262034/
[60] New York City Mayor's Office. "For Hire Transportation Study." (2016) Retrieved from: https://www1.nyc.gov/assets/operations/downloads/pdf/For-Hire-Vehicle-Transportation-Study.pdf

2. Private Utilities

a) Con Edison

Property Tax: Con Edison, under current practice, pays the user fee for the street as a form of property tax.[61] To calculate how much Con Edison is paying to use Beekman street, we divided the total property tax amount into the total miles of all roads in New York City and measured with the length of Beekman street. We used an 8% annual increase in property taxes based on historical data. In the model scenario, we assumed that the City would give 50% tax break to tax projections, as Con Edison has to pay the utilidor usage fee separately.

Table 8 Con Edison Property Tax Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Property Tax from Con Edison	$119,307,391.86	$59,653,695.93

Maintenance Cost: According to the dashboard of Common Ground Alliance[62] 35.67% of the root cause of underground damages is by electric, natural gas. Considering the complexity of underground facilities in New York City, we adjusted the percentage of root cause of underground damages that Con Edison is responsible for to 46.27%. We assumed the average of 20 square feet for maintenance work, and the costs relevant to street cut, repair, and repaving as $600 per square foot based on RSMeans data. As no street cut is expected with a utilidor, and as operation and maintenance costs are captured with operation and maintenance costs of a utilidor, the NPV of maintenance cost is significantly reduced with a utilidor, as seen in the table below.

Table 9 Con Edison Maintenance Cost Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Maintenance Cost	$489,877,971.41	$1,856,583.19

Costs of accidents to workers: Same as DEP measurement of the costs of accidents to workers.

Manhole accidents compensation: Between 2009 and 2018, nearly 4,000 FDNY dispatches for manhole explosions were logged. Including smoke and fire episodes, there were more than 45,000

[61] As of the financial year 2019-2020, Con Edison is charged $1.9 billion for the City of New York's property taxes. The increase of property taxes continues every year - in the fiscal year 2015, it was $1.2billion and in 2016, it was $1.4billion.
[62] Common Ground Alliance. "Damage Information Reporting Tool."

emergency manhole incidents.[63] Manhole accidents are one of the most frequent small accidents of which Con Edison must bear the costs. Over 2009-2019, manhole accidents caused 66 injuries, and the team estimated injury compensation and legal fees for settlements. With the utilidor system, we expect that the manhole accidents will reduce significantly. We used one tenth of the current accident frequency as the assumption with the utilidor system.

Table 10 Manhole Accidents Compensation Compensation

Scenario	Counterfactual	Utilidor Project
NPV of Manhole Accidents Compensation	$3,578.53	$789.84

Cost of major accidents: Here, we counted high-profile incidents that accompany street explosions that caused more than one casualty or damaged buildings or vehicles that are not manhole explosion accidents. From 2007 to 2019, there were four Con Edison incidents that fit into the defined high-profile cases, namely: 2007 New York City steam explosion, 2014 East Harlem gas explosion, 2015 East village gas explosion, and 2019 Bronx gas explosion. (Appendix 3) Considering the severity of the cases, the team decided to assume that 2.5 incidents happen over 13 years, on average (0.19 incidents/year). We captured the compensation to nearby businesses, costs for recovery works, and legal fees for settlements. In the utilidor scenario, we assumed the frequency of major accidents will be reduced to 1% of current frequency.

Table 11 Cost of Major Accidents Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Cost of major accidents	$1,076.47	$31.87

Headline risk: Headline risk measured the public relations risks that the major accidents caused. Although we expect that the incident would be likely to cause the increase in lobbying and PR costs, due to the lack of data available, we decided not to measure. Instead, we measured the impact of major accidents to Con Edison's Stock prices. Utilities are considered the classic defensive investment: generally slow-growing, but high-yielding and inexpensive relative to earnings, utilities are the traditional dividend value stock.[64] Hence, the stock price does not tumble often, and is historically stable. However, by looking into year-long development of Con Edison's stock prices in 2007 and 2014, it is found that it experienced around 5% drop during the 2-3 weeks after the incident, which led to

[63] Le Dem, G & Sandoval, G. "It's Manhole Explosion Season" (202). The City https://thecity.nyc/2020/02/its-manhole-explosion-season-on-new-york-city-streets.html
[64] JT McGee. "Reason why Wall Street Now Hates Utility Stocks" Retrieved from: https://thecollegeinvestor.com/4496/street-hates-utility-stocks/

the lowest price traded in both 2007 and 2014. Eight out of the lowest 10 closing prices happened during the post-2-3-week period of the incident in both years. The team decided that it is reasonable to assume that the price change after 2-3 weeks of the incident is relevant to the incident, as the utility's key response to the incident would likely occur within the 2-3 weeks and the price recovers the pre-incident level in 2-3 weeks.[65] Hence, we decided to measure the impact of the headline risk with the difference between the stock price traded on the date of the incident and the lowest price during the 2-3-week time frame multiplied by the volumes traded on the day of the lowest price. We decided to use the average of the 2007 and 2014 cases considering half residential, half commercial characteristic of Beekman street.

Table 12 Headline Risk Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Headline Risk	$6,694.27	$198.18

(b) Empire City Subway

Property Tax: Empire City Subway (ECS) is a private company that is responsible for providing conduit infrastructure for providers in all areas of Manhattan and the Bronx. Verizon, Time Warner Cable, and Cablevisions have the most extensive conduit infrastructure in other boroughs of New York City (Brooklyn, Queens, and Staten Island).[66] As Beekman Street is in Manhattan, the cable conduits are provided and maintained by Empire City Subway, and as there is no information available how much the company pays for its facilities underground, we assumed 1/10 of Con Edison's property tax for Empire City Subway.

Table 13 Empire City Subway Property Tax Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Property Tax	$11,930,739.19	$5,965,369.59

Maintenance Cost: According to the dashboard of Common Ground Alliance, 46.20% of the root cause of underground damages is by telecommunications. We assumed the average of 20 square

[65] For the 2007 case, the closing price of July 18 was $45.73 (volume: 2568900 shares) and on July 31, the price dropped to $43.68 (Volume: 3567500 shares). For the 2014 case, the closing price on March 12 was $54.18 (volume: 6746800 shares), and on March 20, the price dropped to $52.23 (volume: 2723400).

[66] NYC Special Initiative for Rebuilding and Resilliency. (2020). "Chapter 9. Telecommunications" Retrieved from: https://www1.nyc.gov/assets/sirr/downloads/pdf/Ch_9_Telecommunications_FINAL_singles.pdf

feet per maintenance work, and the costs relevant to street cut, repair, and repaving as $600 per square foot based on RSMeans data.

Table 14 Empire City Subway Maintenance Cost Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Maintenance Cost	$489,179,144.06	$1,853,934.71

Costs of accidents to workers: Same as DEP measurement of the costs of accidents to workers.

3. Traveling Public

Different types of street users are impacted by roadwork in the project area. We identified four categories: drivers, cyclists, pedestrians, and public transportation passengers. To estimate the cost those impacts would have on them, we calculated the amount of time they lose when the block is partially or entirely closed. It is important to note that negative health consequences from pollution were not considered in this section and were addressed in the Environmental section.

(a) Drivers

Travel Time Value: To calculate this value, we estimated the delay time costs to drivers. Delay time is the additional travel time necessary to traverse the work zone or to detour around it. To get this value we calculated the average amount of time per day each driver is losing under the current construction in the area. We based our calculations in terms of the hourly value of personal travel time per occupant of the vehicle[67] and the average amount of time roadwork takes place every year. For the model, we also estimated the cost of a detour on Fulton Street, assuming the road would be entirely closed during nights and weekends for two years for utilidor construction.

Table 15 Travel Delay for Drivers Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Travel Delay for Drivers	$7,130,911,700.27	$1,334,930.69

[67] Based on estimations made by the US Department of Transportation for roadworks on highways. From: https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop12005/sec2.htm

Vehicle Operation Costs (VOC): These are the expenses incurred by road users as a result of vehicle use. Operation Costs are the running costs that vary with the degree of vehicle use and depend on fuel consumption, engine oil consumption, tire-wear, repair, and maintenance as well as mileage-related depreciation. It does not include fixed costs such as insurance, time-dependent depreciation, financing, and storage. In this case, we considered two possible scenarios: when the speed of the vehicle decreases and when the car is idling (when the driver runs the vehicle's engine when the vehicle is not in motion). We estimated 21 and 3 hours[68] per day, respectively. We also estimated the operation costs of a detour on Fulton Street, following the same assumptions.

Table 16 Vehicle Operation Cost Comparison

Scenario	Counterfactual	Utilidor Project
NPV of VOC Idling	$8,424,606,554.27	$4,272,116.38
NPV of VOC Speed Change	$1,533,173.68	$44,194,560.50

(b) Other Public

Cyclists: Cyclists are important users of roads in New York City. There was a 134% growth in daily cycling between 2007 and 2017 in the city[69]. The annual average growth rate of cycling is estimated at 9%[70] (based on the increase between 2008-2018). To get the cost of the affectation, we calculated the average amount of time per day each cyclist is losing during construction in the area by the value of personal travel time estimated for them[71] in terms of the Median Annual Income for all US[72].

Table 17 Travel Delay for Cyclists Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Travel Delay for Cyclists	$14,956,870.09	$8,604.11

Pedestrians: New York has a significant number of pedestrians every day, particularly in Downtown and Midtown, where both tourists and citizens meet. To calculate how they would be affected by the roadwork we also estimated the costs in terms of their travel delay time, the value of their personal

[68] Based on daily traffic levels of the area from historic traffic estimated by Google Maps, being on average 12:00 PM to 3:00PM the hours with higher traffic during the day.
[69] NYC DOT. "Cycling in the City". From: https://www1.nyc.gov/html/dot/html/bicyclists/cyclinginthecity.shtml
[70] NYC DOT. "Cycling in the City". From: https://www1.nyc.gov/html/dot/html/bicyclists/cyclinginthecity.shtml
[71] Victoria Transport Policy Institute. Transportation Cost and Benefit Analysis: Travel Time Costs. Pp. 23 From: https://www.vtpi.org/tca/tca0502.pdf
[72] Based on the Median Household Income in the US in 2018. From: https://www.census.gov/library/stories/2019/09/us-median-household-income-up-in-2018-from-2017.html

travel in terms of the Median Annual Income for all US,[73] and the average population per square mile in the city.

Table 18 Travel Delay for Pedestrians

Scenario	Counterfactual	Utilidor Project
NPV of Travel Delay for Pedestrians	$8,169,171.74	$8,012.27

Public Transportation User: As noted before, we assumed subway ridership is not affected by current roadwork and by the implementation of the utilidor. However, although no bus lines are running on Beekman street, we concluded that four (4) surrounding bus lines might be affected. We estimated the value of the personal time of passengers[74] riding those lines in terms of the Median Annual Income for all US and multiplied that by the reduced speed per bus.

Table 19 Travel Delay for Public Transportation User Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Travel Delay for Public Transportation User	$97,155.97	$440,017.55

4. Residents

Like the Traveling Public, Residents face some of the indirect costs of subsurface utility infrastructure maintenance practices. These are impacts that more acutely affect individuals who live in the project zone. The majority of these impacts can be categorized as Quality of Life indicators - for this study, the three quality of life indicators addressed were noise pollution, air pollution, and public space use. Beyond these indicators, the cost of utility line disruptions was also included. Each of these impacts are greatly reduced when transitioning from the counterfactual scenario to the utilidor.

Quality of life: Noise Pollution

Noise pollution has been widely studied as having a social cost on those impacted by it. It refers to the level of sound that disturbs human life - thus not all noise is examined, just excess noise. This cost is

[73] Victoria Transport Policy Institute. Transportation Cost and Benefit Analysis: Travel Time Costs. Pp 23 From: https://www.vtpi.org/tca/tca0502.pdf
[74] Victoria Transport Policy Institute. Transportation Cost and Benefit Analysis: Travel Time Costs. Pp. 23. From: https://www.vtpi.org/tca/tca0502.pdf

materialized in the form of costs to health, productivity, and general wellbeing. In terms of direct health impacts of noise, it can result in hearing loss, negative cardiovascular effects, hypertension or high blood pressure, stress, and tinnitus.[75] It was assessed for this project due to the large amount of ongoing construction work in the project area, which, in turn, causes a large amount of noise. It also includes vehicle-related noise as current construction practices exacerbate traffic congestion.

Implementing the utilidor would reduce noise pollution as the amount of construction performed in the project area would decrease once the utilidor is put in place. Quantifying this cost involves making a number of assumptions as there is not a set calculation to monetizing noise pollution. In order to get a sense of the magnitude of the problem, construction and vehicle-related noise complaints were extracted from NYC 311's dataset. The data used spans from 2010 to 2019. In order to extract a baseline number of annual noise complaints, the average number of complaints over the period was used: 666.19.[76] The same data showed an average annual increase in complaints of 11.56%.[77]

For simplification purposes, this was kept constant over the entire period. To estimate the overall annual cost of noise pollution, a cost of $338 per complaint was used.[78] As construction is estimated to be nullified after the utilidor implementation, noise pollution costs are reduced to 0 once the construction period is over. Table 19 below shows the difference in costs for the counterfactual scenario versus the utilidor scenario.

Table 20 Noise Pollution Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Noise Pollution	$3,703,890,107.80	$520,668.32

Quality of life: Air Pollution

Air Pollution was also included in the cost modelling for residents as both construction and traffic congestion lead to higher levels of ambient pollution. Construction results in increased levels of particulate matter - for purposes of this report PM10 (Particulate Matter up to 10 micrometers in size) was used to measure the impact of construction on air pollution. Vehicle use also leads to air pollution - for this report, CO_2 and NO_x were used to measure its impact.

To quantify the impact of construction on pollution, an annual amount of construction miles for the project area was estimated at 331, with an average annual increase of 6.03%. Estimates from the EPA

[75] Abdallah, Thomas. (2017). Environmental Impacts. In *Sustainable Mass Transit: Challenges and Opportunities in Urban Public Transportation* (pp. 45-59). Amsterdam, Netherlands: Elsevier.
[76] NYC 311. (2020) Retrieved 9 April 2020, from NYC Open Data: https://data.cityofnewyork.us/
[77] NYC 311. (2020) Retrieved 9 April 2020, from NYC Open Data: https://data.cityofnewyork.us/
[78] Bureau Veritas. (2012). Estimating the Cost of Complaints about Noise Nuisance (Rep. No. 4660523). London: DEFRA.

were used to quantify the resulting PM10 impacts from construction. This suggests that each mile of construction emits 140 grams of PM10.[79] Finally, to monetize overall costs, a social cost of PM10 was used at the value of $1700 per short ton.[80]

To quantify the impact of vehicles on air pollution, both CO2 and NOx were studied. To set a baseline amount of vehicle miles, the average delay time (in hours) was combined with the average vehicle speed (in mph), resulting in the amount of 329,395 miles; an annual increase of 6.77% was applied across the project timeline. From the Bureau of Transportation Statistics, we derived the vehicle emission rates for both NOx and CO2.[81] Combined with the social cost of NOx and the social cost of carbon, respectively, resulted in the monetization of NOx and CO2 emissions. As seen below, the NPV was significantly improved from the counterfactual scenario to the utilidor scenario.

Table 21 Air Pollution Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Quality of Life – Air Pollution	$9,299,287.53	$24,969.76

Quality of life: public space

An important aspect to discuss when analyzing large infrastructure changes is how the use of public space is impacted by the project's implementation. The project zone contains one park, which is City Hall Park, as shown in Appendix 2. The utilidor construction would directly cross through the park, as shown in Appendix 1. This impact was only considered in the utilidor scenario as it is assumed that current general construction does not hinder the use of the park.

While by definition public spaces are free to access, for the purposes of Cost Benefit analysis, economists have come up with monetary estimates to show the value of visiting a public space. This allows for more realistic assessments of the value of public spaces. This report uses estimates published by the Trust for Public Land which set the average value per visit for general park use at $2.45.[82][83] Combined with estimates for annual park visitations, we have been able to generate annual cost projections of the value of this lost space. As this cost is only considered in the utilidor scenario, it sees significant increases from the counterfactual scenario to the utilidor scenario.

[79] EPA, "Emission Factor Documentation for AP-42, Section 13.2.1: Paved Roads," January 2011 (will format later)
[80] National Resource Council. (2010). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use.* Washington, DC: The National Academies Press.
[81] Bureau of Transportation Statistics [BTS] (2018). National Transportation Statistics. *US Department of Transportation.*
[82] Harnick, Peter and Ben Welle (2009). Measuring the Economic Value of a City Park System. *The Trust for Public Land.*
[83] The original estimate given was $1.91 (2006 USD), which the authors of the report have translated into $2.45 (2020 USD).

Table 22 Public Space Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Quality of Life - Public Space	N/A	$47,980,800.00

Utility disruption costs

Finally, residents experience utility disruption costs. In the counterfactual scenario, these occur when the utilities experience failures that cause disruption of service to residents. In the utilidor scenario, they only occur during the construction period, as the probability of utility failures are considered to be negligible once the infrastructure is implemented. This cost was calculated separately for ConEd, DEP, and ECS as they each have their own characteristics.

To quantify the disruption costs, the probability of disruptions or accidents for each utility was used to derive an estimate of the overall number of disruptions. The National Association of Regulatory Utility Commissioners (NARUC) published that the average cost to customers per disruption is around $99.[84] This value was used to calculate annual disruption costs. As seen in Table __ below, the NPV was significantly improved from the counterfactual scenario to the utilidor scenario.

Table 23 Utility Disruption Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Utility Disruptions	$231,240,089.14	$38.56

5. Environment

Cost of carbon emission from traffic

The frequent road work makes the drivers detour. Here we measured the cost of carbon emission from extra miles of driving caused by detour for road construction. The social cost of carbon is based on the EPA's prediction.

[84] Burlingame, Mark and Patty Walton (2013). Cost-Benefit Analysis of Various Reliability Improvement Projects from the End Users' Perspective. *The National Association of Regulatory Utility Commissioners.*

Cost of carbon emission from road repair work

Road repair work requires materials, equipment, project lighting, and mobilization. An analysis based on one case study of a road project in New Jersey suggested that the road construction emits 2.94 tons of carbon per square feet. We calculated the cost of carbon emission from road repair work assuming the average size of road repair work is 20 square feet.

Waste

As for how much waste the road construction generates in New York City, we used demolition and disposal costs per square feet to estimate the costs of waste from road repair works. The data for demolition and disposal costs are from RSMeans.

Water

Due to antiquated water infrastructure, New York City lost 45,221.991 MG between July 2017 and June 2018.[85] Water losses are grouped into two types, apparent and real losses. Apparent losses are due to water theft and billing errors, and real losses are physical losses for leakage. As only actual losses have environmental impact, we counted only real losses to estimate environmental costs. Under the utilidor model, with smart infrastructure systems that detect water leakages, we assumed the water losses will be only 10% of the counterfactual model.

Table 24 Environmental Costs Comparison

Scenario	Counterfactual	Utilidor Project
NPV of Carbon Emission from Traffic	$12,048,430.60	$82,448.01
NPV of Carbon Emission from Road work	$828,692,239.21	$210,567.38
NPV of Cost of Waste	$37,213,046.95	$334,407.15
NPV of Water losses	$1,497,214,708.00	$176,404,505.20

[85] New York City Department of Environmental Protection. (2019) "Water Demand Management Report". Retrieved from: https://www1.nyc.gov/assets/dep/downloads/pdf/water/drinking-water/water-conservation-report2019.pdf

6. Utilidor Cost Estimation

(1) Overview

In this section, we will discuss the categories that lead us to arrive at our cost estimate of the utilidor. The utilidor will run underneath the roadway and will accommodate the telecommunications, electrical, water, steam, and gas utilities. In our appendix section, you will find further discussion on the caveats and assumptions that guided our decision making in crafting this cost estimate. Because of the lack of design, the estimation is based on several assumptions.

The direct cost associated with the utilidor project can be broken down into six elements:

1: Construction (prefabricated outside of New York City)
2: Transportation (carrying the utilidor to Beekman street)
3: Relocation of utilities
4: Installation (excavating the street and put the utilidor underground)
5: Resurfacing and backfilling
6: Operation and Maintenance

The costs are estimated in this paper for each element assuming that all of them will be completed in two years. In addition, it is assumed that the City of New York will need to pay the interest payment on 63-20 debt. Therefore, debt service cost is also included in the utilidor cost estimation.

(2) Construction Cost

The construction cost is estimated by the sum of costs of 10 subcategories as below.

1: Access point door (both for personnel and equipment)
2: Space from surface to access point - for personnel entry
3: Space from surface to access point – for equipment entry
4: Installation of pipes and conduits
5: Smart infrastructure equipment
6: Hangers (shelves) to support utilities
7: Ventilation
8: Main Structure
9: Fill material
10: Waterproofing

(3) Result

The NPV of direct costs is shown in Table 24.

Table 25 NPV of Direct Cost per Category

Category	NPV of cost
1. Construction Cost	$3,926,370
2. Transportation Cost	$40,345
3. Relocating Utility Cost	$18,793,267
4. Installation Cost	$41,178
5. Resurfacing and Backfilling Cost	$1,751,968
6. Operation & Management Cost	$38,871,068
7. Debt Service Cost	$5,902,296
Total	$69,326,493

Assumptions for each cost estimation are listed in the appendix. Most costs are estimated using RSMeans.

LCCBA Results

Table 26 NPV Comparison per Impact Standing

Impact Standing	NPV of Utilidor (A)	NPV of counterfactual (B)	A - B
NYC Governments	-$514,214.97	-$1,116,767,357.52	$1,116,253,142.55
Utilities	-$69,331,197.03	-$1,110,308,335.19	$1,040,977,138.16
Traveling Public	-$64,783,853.82	-$15,580,274,626.03	$15,515,490,772.21
Residents	-$48,526,476.63	-$3,944,429,484.47	$3,895,903,007.84
Environment	-$177,031,927.74	-$2,375,168,424.76	$2,198,136,497.02
Direct Cost	-$69,326,493.20	-	-$69,326,493.20
Sum	-$429,514,163	-$24,126,948,228	$23,697,434,065

The result of our LCCBA shows that the cost of current practice for the next 100 years is estimated to be $24,126,948,228 (NPV), while with utilidor, it is significantly reduced to $429,514,163 (NPV). This is only 1.78% of the cost with counterfactual. In all categories, we see almost 90% or more reduction in costs with the utilidor compared to current practice, given the outstanding decrease in street cuts. As we assume there will be no street cuts relevant to utility repair purposes after the utilidor is installed, the costs with the implementation of the utilidor in all standing groups become significantly lower.

Although the costs we estimated here are based on the efficient utilization of assets of NYC governments and private utilities, they do not include the broader positive impacts they would have in terms of management for such organizations. We believe the new data available from this modern infrastructure will possibly change operation strategies and even the structures of the organizations, which will result in even higher internal efficiency.

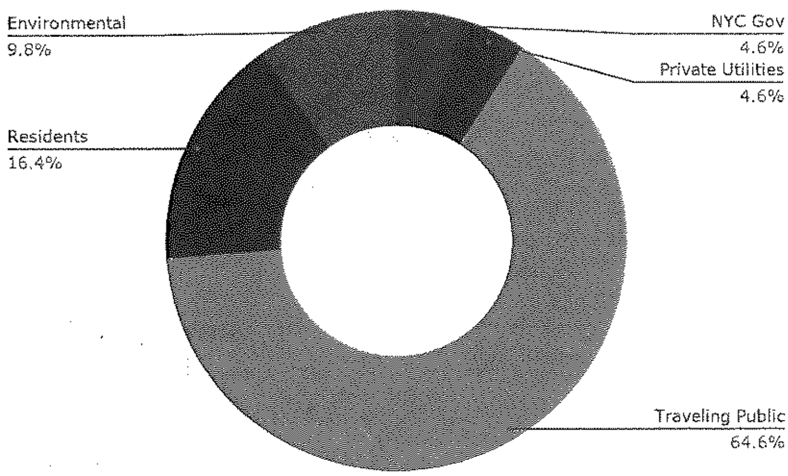


Figure 2 Counterfactual Scenario by Impact Category

In the counterfactual scenario, the traveling public bears most of the costs associated with the current practice. Their costs are directly related with the number of street cuts in the project area. After the utilidor is implemented, costs are reduced to 18%; however, most of them increase acutely during the period of the utilidor construction. The environmental costs are the highest in the utilidor scenario, mostly due to inevitable water loss and waste produced during the construction period. After efficient reallocation of subsurface space and utilization of the street, costs are significantly reduced overall. Finally, as has been discussed, street cuts correlate with many of the cost categories, accounting for almost 40% of all costs in the counterfactual.

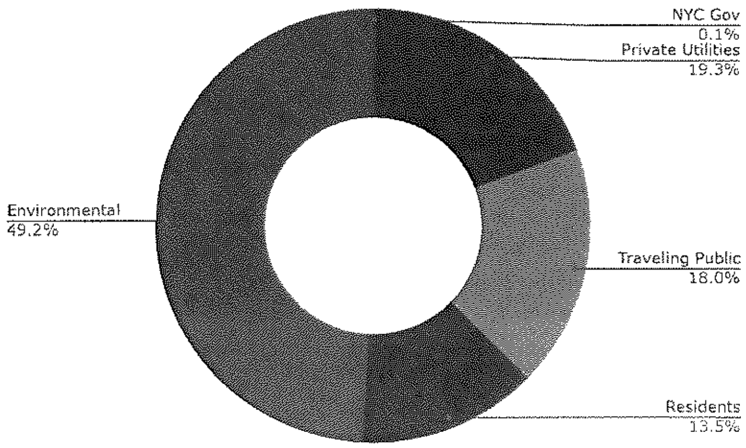


Figure 3 Model Scenario by Standing Group

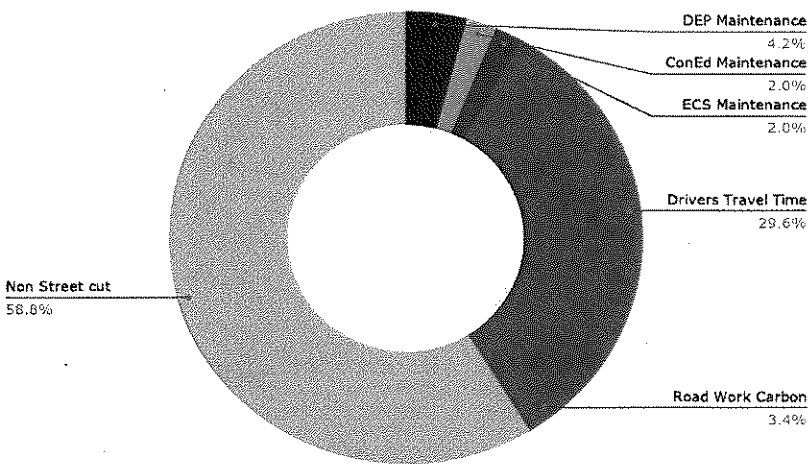


Figure 4 Percentage of street-cut related costs in counterfactual scenario

Sensitivity Analysis

As we explained above, the costs for the counterfactual and the model scenarios are estimated based on many assumptions. Though these estimation show that installing a utilidor would be economically better than continuing current utility maintenance practices, there may be some concern that our assumptions may no longer apply in the future or that they have varied. Thus, sensitivity analysis was conducted to examine how robust the economic benefits over the current practice are, by simulating their net present values under different which may have a large impact on overall estimation.

The four scenarios we tested are: the construction cost of the utilidor, up to 600% of the current estimate; the maintenance cost, allowing for up to 20% of construction cost from 10% of the cost.; the variation of the key determinant of many of our costs: street cuts; and, finally, variation in the e discount rate from 1-10%.

(1) Construction Cost of the Utilidor

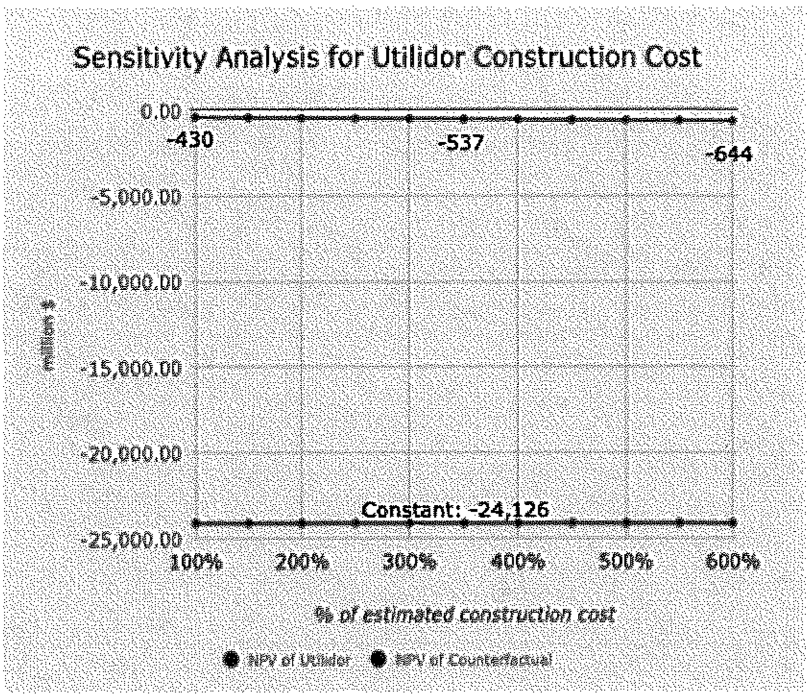


Figure 5 Sensitivity Analysis - Construction

Because of the lack of design, it is essential to account for possible variations to our cost estimate. Additionally, because of the lack of detailed information, as well as the unprecedented nature of the project for lower Manhattan, the accuracy in our estimate is not guaranteed. We relied on industry accepted data and interviews, but considering the magnitude of these costs, the NPV of model scenario should be examined by allowing variation in the costs. The graph below shows that, even if the true construction cost turned out to be 5 times higher than the estimation, net present value of the utilidor project is still higher than counterfactual.

(2) Operation and Maintenance Cost of the Utilidor

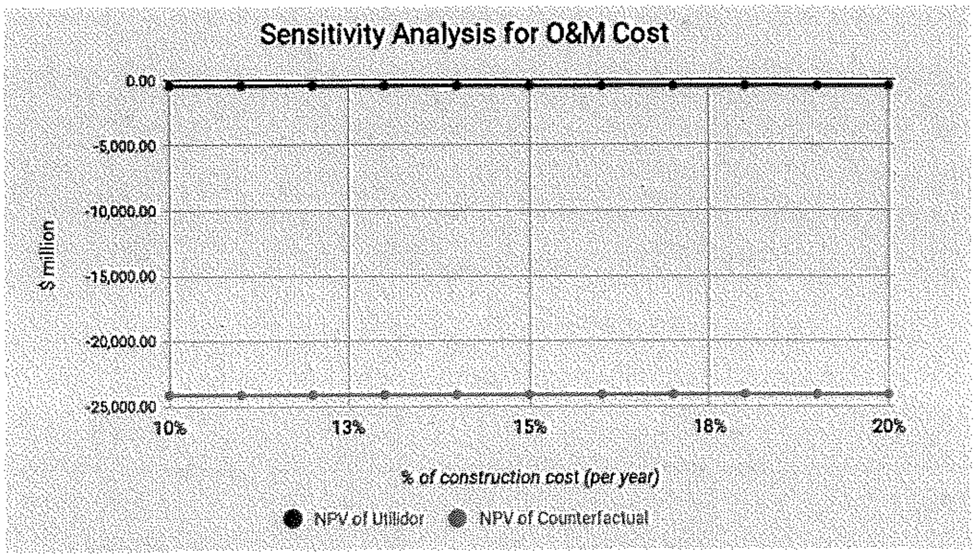


Figure 6 Sensitivity Analysis - Operation and Maintenance of Utilidor

Annual operation and maintenance cost for the utilidor is estimated at 10% of its construction cost, which is itself a conservative estimate.[86] The table and graph below shows that even if the percentage of operation and maintenance cost to construction gets as high as 20%, the net present value of the utilidor project is far higher than that of counterfactual.

(3) Street Cuts

[86] We believe this is conservative based on DEP's current headcount and based on the conversations we have had with stakeholders.

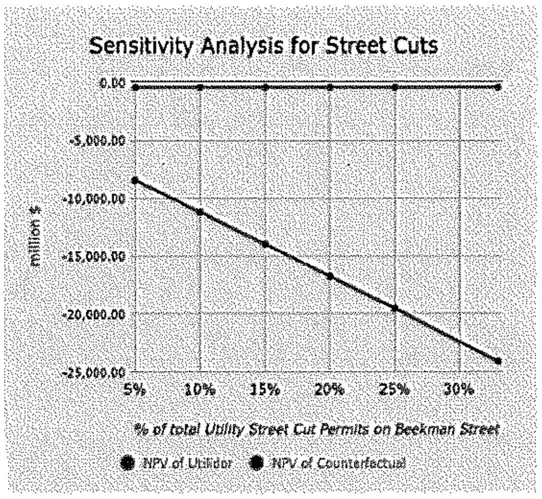


Figure 7 Sensitivity Analysis - Street Cuts

The estimation of counterfactual cost, street cuts are a key driver of costs of many categories, including maintenance costs for utilities, unmet maintenance needs for DOT, accidental damage to utilities, and environmental costs. Year to year, the number of street opening permits issued varied significantly, but we took the average rate of growth over a period of five years to inform our assumption. The actual number of street cuts are assumed to be 1/3 of the total number of utility street permits on Beekman Street. In this section, net present value of counterfactual is examined by allowing the percentage to vary down to 5%. As shown in the graph below, even in the 5% case, NPV of utilidor is higher than that of counterfactual.

(4) Discount Rate

	NPV of Utilidor	NPV of Counterfactual
1%	-2,044,309,524	-304,605,984,986
2%	-1,072,037,042	-127,148,224,411
3%	-634,948,150	-54,497,912,230
4%	-429,514,163	-24,126,948,228
5%	-327,731,026	-11,127,959,514
6%	-274,116,019	-5,410,946,773
7%	-243,871,926	-2,814,584,925
8%	-225,528,977	-1,589,219,588
9%	-213,575,026	-983,530,330
10%	-205,247,122	-667,278,408

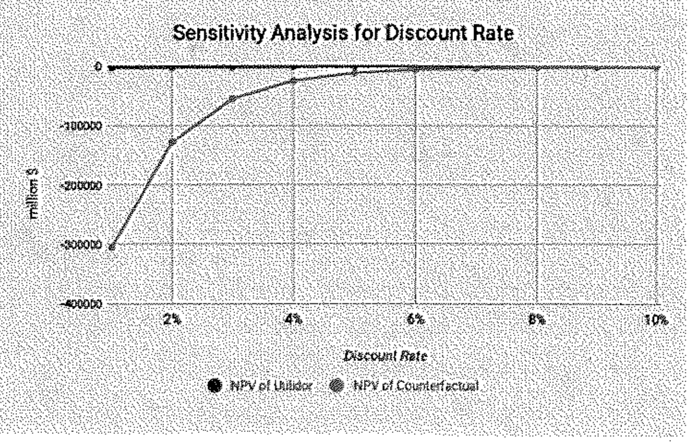


Figure 8 Sensitivity Analysis - Discount Rate

A Discount Rate is used to convert each year's estimated costs into present value. In this section, NPV of the utilidor project and counterfactual are compared by allowing the discount rate to vary from 1% to 10%. In every scenario, Utilidor project's net present value is higher than counterfactual.

In each model we tested our inputs, and we found a lower NPV than the utilidor project. We confirmed our analysis that this project is economically worthwhile. This result suggests that the economic superiority of this utilidor project is robust.

property tax that utilities would pay in the counterfactual if there's no utilidor. The net present value of total user fees, 114 million, is also a lot smaller than utilities' total cost avoidance, 1,040 million. Thus utilities will be most likely willing to pay these fees to be able to use the utilidor.

Conclusion

Conclusion and Policy Recommendation

Currently, underground infrastructure in New York City (NYC) is operated and maintained without coordination among stakeholders. As utility companies and the DEP need to cut open roads to repair and maintain their own utility lines, their recurrent roadwork impacts NYC with unnecessary traffic congestion, attrition of road surface, pollution and lower quality of life. It also limits structuring coordinated data to see the whole picture of NYC underground infrastructure.

However, coordination of stakeholders may improve the situation by creating a utilidor to house certain utility assets. This infrastructure enables utility owners to repair and maintain their utility lines without cutting open the street. Because of this, the negative impacts of current practice on NYC are expected to be significantly mitigated. While it requires significant upfront construction cost, it is expected that the comprehensive smart infrastructure equipment installed will enable more efficient utility maintenance.

In this context, this paper aims to quantify the economic benefit of utilidor infrastructure to NYC by conducting life cycle cost benefit analysis (LCCBA) assuming that Utilidor will be installed where the previous Beekman project was conducted. The first step of LCCBA is identifying stakeholders: NYC government, private utilities, traveling public, residents, and environmental impact. The benefit of this project is measured by the difference in cost to each stakeholder, comparing the current practice of maintaining utility infrastructure to the cost of implementing the utilidor.

On the other hand, the cost of the utilidor is roughly estimated by breaking it down into construction cost, transportation cost, relocating utilities cost, installation cost, resurfacing and backfilling cost, operation and management cost, and debt service cost. Our estimation shows 23,766 million dollars in benefit, while only 69 million dollars in cost. This project still holds under sensitivity analysis on several key factors. Therefore, our analysis suggests that the benefits of installing a Utilidor warrant the significant upfront cost it would require.

Utilidor infrastructure in NYC should be feasible as well as beneficial. Even if the utilidor makes economic sense in the long term, it cannot be introduced unless the initial cost is financed. Since it seems to be difficult to assume that the City of New York can finance the cost by issuing government bonds, project finance is examined in this report as well. We examine the feasibility of a two-phase financing system where a 63-20 non-profit organization issues bonds for the initial construction and installation of a utilidor, then establishes a Smart City Infrastructure Agency through the state legislature to transit to revenue credit.

It may take years for the city to go through state legislation, get all stakeholders involved, update franchises agreements and set up the new agency. Utilizing 63-20 during the initial stage will allow the city to be better prepared to tackle these challenges. The new revenue agency, once established, will need to collect at least 5.9 million annually. Given the property tax utilities need to pay in counterfactual and utilities' cost avoidance in LCCBA results, this finance model can be regarded as feasible.

In this way, our analysis suggests that introducing utilidor infrastructure to NYC is worth considering seriously. Also, considering that the number of street cuts has a significant impact on NYC, policies allowing the street cuts to decrease other than Utilidor may also be beneficial.

Limitations

Simplified Financial Model

Regarding our revenue credit finance model, in order to assess the feasibility and utilities willingness to pay the minimum fees, our calculation shows a situation where the least revenue is collected to make accumulated revenue 0 at year 100, the end of the useful life of the utilidor. In real practice, user fees might be adjusted to make a positive revenue out of utilidor according to the city's decision.

With the exception of bond issuance and utilidor maintenance, the model didn't incorporate other factors that will potentially increase the utilities cost and other costs that might occur during the transition of two financing agencies. For implementation, user fees might also be adjusted to reflect other potential costs when a more detailed cost estimate is done.

Private Utilities' Willingness to Pay

Utilities may have different revenue incentives to engage in the project. This issue and the detailed percentage being assigned to different utilities will require further investigation.

Future Study Required for New Possibilities[100]

Considering water utilities occupy a large portion in the utilidor, it may be possible to set up a new utilidor authority under the aegis of the water authority. Because it already exists, such an arrangement would not need to be facilitated by the state legislature.

[100] Randolph Mayer, Uyen Poh, Experts Interview. April 15, 2020

There might also be the possibility of separating the private portion and the public portion (Water and Sewer) to leverage tax benefit by issuing tax-exempt bonds on the public portion. These possibilities can be taken into account for the next step's study.

Utilidor Impact on Businesses

Beekman Street is a residential area where there are few businesses subject to the impact of the utilidor installation process. Because of that, the impact of the utilidor on businesses is anticipated to be negligible. Surrounding businesses are not included as a stakeholder. Though there are some hospitals, we do not anticipate much impact on the quality of medical service, assuming that emergency power is equipped in the hospitals so that utility failure does not affect medical treatment.

However, when further studies examine feasibility of utilidor projects in other areas in New York City, its impact on businesses on the target street should be considered. Utilidor may be beneficial for businesses on the target area for a variety of reasons. The decrease in operational cost coming from delay in delivery, loss avoidance in production from workers' tardiness caused by traffic delay, and decrease in damage from utility failure. The loss in revenue should be examined carefully because, even if utility failures cause loss of revenue for businesses on the street, it might be offset by increase in revenue for nearby businesses. Overall, it would be prudent to consider businesses as a stakeholder: considering their clout as a constituency, their preferences should be counted in future analyses.

Subway Tunnel

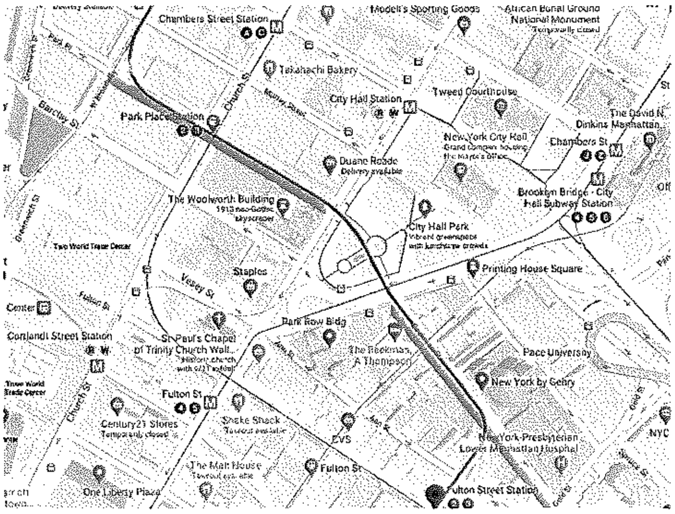
In this paper, the costs we estimated of implementing a utilidor did not include costs associated with MTA subway tunnels. It did not include the cost of potentially installing a utilidor abutting tunnels nor did it account for potential disruptions to service, which would have distorted the costs significantly. However, in an effort to expand a pilot project, more coordination will be necessary between stakeholders like the MTA and the City of New York. Our conversations with stakeholders confirmed that the feasibility of a utilidor in close proximity to a subway tunnel is more likely if the Subway is deep underground. Further, they confirmed, MTA is a stakeholder that would be unlikely to be willing to accommodate utility tunnels on its property. However, assessing these costs is worthy of further study. A huge amount of subsurface infrastructure is New York City's Subway, and any Citywide utility coordination system would inevitably involve the MTA. Further study should focus on the cost associated with potential periodic disruption to the subway.

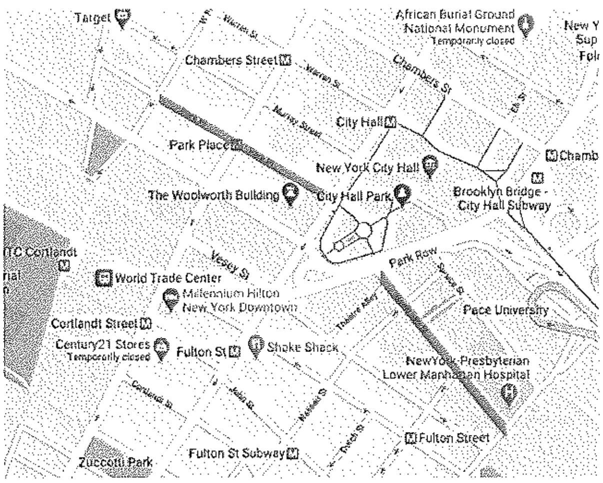
Use of Park Space

Our estimation is based on the assumption that the utilidor would run below City Hall Park and an entry point is created at the park. Given that the land use of public parks are regulated, discussion among departments in NYC is also necessary.

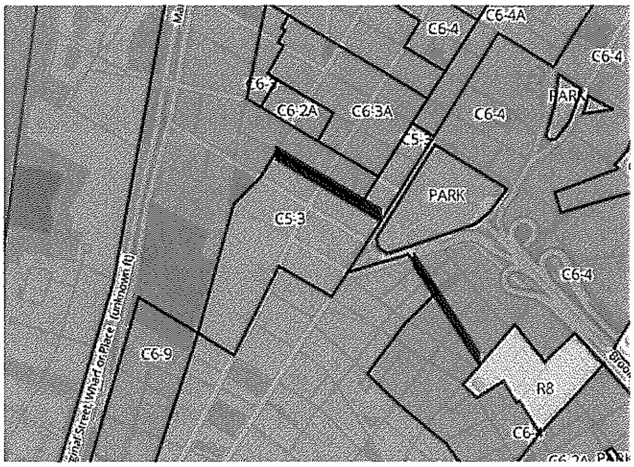
Appendix

Appendix 1: Project Area





Appendix 2:



Name	Project Description	Year	City Capital Cost	Released Permits	Land Use	Noise Complaints	Congestion (Average)		
			$ USD	#		Rank	# Vehicles	Daily Traffic*	Public Transport Lines-Routes**
Fulton Street 2 (William Street)	Relief Program for Lower Manhattan (9/11/01 WTC)	2010	37,539,614.76	1166	Commercial	1	10955		9
Fulton Phase 3 (William Street)	Reconstruction of Fulton Street - Phase III	2012	11,298,861.70	816	Commercial	2	8417		3
Beekman (Maiden)	Beekman Street & Park Place	2010	17,455,612.76	681	Commercial	4	11775		1
John Street between William and Pearl	Resurfacing South of Canal St.	2008	6,261,490.49	440	Commercial	3	4233		0
Old Slip between Water and South	Lower Manhattan Recovery	2005	1,225,892.29	281	Commercial	5	3891		1

Appendix 3

Con Edison: 4 Major Accidents during 2007-2019

2007 New York City steam explosion (2007, July 18): The escaping steam shook nearby office buildings, causing many occupants to immediately evacuate. A 51-year-old New Jersey woman, who worked a block from the site, died of a heart attack suffered while fleeing the disaster area. 45 people were injured, with two injured critically.[101] Con Edison has offered to reimburse businesses for direct costs of damage and clean-up, but not for business interruption costs, such as lost productivity and revenue.[102]

2014 East Harlem gas explosion (2014, March 12): The 2014 East Harlem gas explosion occurred at 9:31 a.m. on March 12, 2014, in the East Harlem neighborhood of Manhattan in New York City. The explosion leveled two apartment buildings located just north of 116th Street at 1644 and 1646 Park Avenue, killing eight people, injuring at least 70 others, and displacing 100 families. City officials initially pointed to a gas leak as the cause of the blast. In June 2015, the National Transportation Safety Board (NTSB) blamed the explosion on failures by Consolidated Edison and the city[103] On February 16, 2017, Con Ed agreed to pay $153.3 million to settle charges stemming from the 2014 deadly East Harlem gas explosion. The settlement, approved on Thursday by the state's Public Service Commission, marks the highest payout for a gas safety incident in New York State history.[104][105]

2015 East Village gas explosion (2015, March 26): A gas explosion occurred in the afternoon of March 26, 2015, in a building located at 121 Second Avenue, in the East Village neighborhood of Manhattan, New York City. The explosion was caused by an illegal tap into a gas main. The explosion caused two deaths, injured at least nineteen people, four critically, and the resulting fire completely destroyed three adjacent buildings at 119, 121, and 123 Second Avenue between East 7th Street and St. Marks Place.[106]

2019 Bronx gas explosion (2018, September 26): A ruptured gas line caused a massive sinkhole to erupt on a Bronx street at 2:50 pm on September 26, 2018. No one was injured but nearby cars were damaged.[107]

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[101] https://en.wikipedia.org/wiki/2007_New_York_City_steam_explosion#cite_note-Belson-8
[102] https://www.nysun.com/new-york/steam-pipe-blast-stalls-a-con-edison-lobbyist/59007/
[103] https://en.wikipedia.org/wiki/2014_East_Harlem_gas_explosion
[104] https://nypost.com/2017/02/16/con-ed-agrees-to-150m-settlement-after-deadly-explosion/
[105] https://images.law.com/contrib/content/uploads/documents/389/92170/city-v.-con-ed-complaint.pdf
[106] https://en.wikipedia.org/wiki/2015_East_Village_gas_explosion
[107] https://www.ny1.com/nyc/all-boroughs/news/2019/09/26/con-ed--massive-sinkhole-in-the-bronx-due-to-ruptured-gas-line

Appendix 4: Utilidor Assumption and Caveats

Unless specified otherwise, assume all costs found in RS Means.

1. Utilidor Construction Cost
   I. Access point door for utilidor.

We specified to AECOM that we would need 3 doors big enough to accommodate both personnel and equipment. In our interview, they confirmed that this would be a sound assumption and suggested that the door should be 5x7 feet.

II. Space from surface to access point for personnel entry

We assume that manholes can be utilized for personnel entry as well.

III. Space for equipment entry

It is assumed that manholes are too small to carry equipment for repair and maintenance. Therefore, a larger entry path should be secured. In this paper, the large entry is assumed to be built in City Hall Park, though the use of underground space in the park should require some steps to be taken among the government.

This entry route should always be accessible for utility companies and the government. Therefore, by installing precast concrete walls vertically from surface to Utilidor entry point, the space is secured.

IV. Installation of pipes and conduits
   - Sewage and drainage pipes are not installed into Utilidor to avert risk of flooding. This was requested by Con Ed and acknowledged by the Utilidor Working Group.
   - Telecom fiber lines does not have to be replaced because it is relatively new infrastructure
   - Because electrical, gas, water main and steam pipes are old, they will be replaced. By replacing water pipes in particular, we assume a lower break rate for the entire period of the utilidor.
   - Assumed size and length: water main = 24 inches diameter and 1821 feet length, electrical wire = 2 inches diameter and 5000 feet length, gas pipe = 8 inches diameter and 1821 feet length, and steam pipe = 16 inches diameter and 1821 feet length

V. Smart infrastructure equipment (and security system)
   - Intrusion detection system should be installed at every entry point
   - Video surveillance system should be equipped by every 50 feet for security

- Fire detection sensors, fuel-gas detection sensors and humidity detection system should be equipped by every 50 feet to detect accidents with pipes.[108]
- Crack detection sensors for main structure, gas pipe, water pepe and steam pipe, and power cable default detection system should be equipped by every 50 feet to effectively and efficiently monitor utility lines' status to make more efficient maintenance and repair feasible[109]
- Unit cost of Crack detection sensors for gas pipe, water pepe and steam pipe, and power cable default detection system is assumed to be the same as Crack detection sensors for main structure

VI. Hangers (shelves) to support utilities

- We calculated the length in feet of the utilities that would be accommodated. We assume that the utilidor will need hangers running the length of the utilidor down each side.

VII. Ventilation

- The Utilidor should be equipped with ventilators every 50 feet

VIII. Main frame

- Precast box culvert
- Main structure should be waterproof

IX. Fill material

- Assuming one truck of fill material is necessary
- Price of fill material can be negligible
- Calculating transportation cost by assuming fill material will be transported from Long Island City
- Unit transportation cost: 1.962 dollars per mile (average marginal cost per mile in Northeast region)[110]

2. Transportation Cost

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[108] Unit material cost of humidity detection system: honeywell Lyric Wi-Fi Water Leak and Freeze detector https://www.techhive.com/article/3138905/best-water-leak-detectors-for-smart-homes.html

[109] Unit material cost of crack detection sensors for main structure: concrete crack data logger, WiFi https://www.certifiedmtp.com/concrete-crack-data-logger-wifi/

[110] https://truckingresearch.org/wp-content/uploads/2019/11/ATRI-Operational-Costs-of-Trucking-2019-1.pdf

- Transportation cost is estimated assuming that Utilidor main structure will be fabricated in Kingston, NY and then delivered to Beekman street by trucks. This is calculated by transportation unit cost[111] multiplied by distance.
- Maximum length of truck is 35 feet in NYC. [112] Based on this regulation, one truck is assumed to deliver 30 feet utilidor for one travel.

3. Relocating Utility Cost

- This cost is estimated at Beekman street case study cost (in 2010) multiplied by escalation cost. For from 2010 to 2019, Producer Price Index is used as the escalation rate.[113]

4. Installation Cost

- Installation cost is estimated by the amount of days installation will take multiplied by the crew, who are assumed to be the same as the prefabrication of box culvert. Utilidor is assumed to be installed in 10 foot increments, therefore, it is assumed to take 61 days. This a constraint necessary to fit the crane on the street and given the weight of the utilidor.

5. Resurfacing and backfilling Cost

Resurfacing and backfilling cost is broken into two subcategories: backfill cost of soil, and backfill cost of concrete and asphalt. Assumptions for each category are as below.

a. Backfill cost of soil

- Utilidor is assumed to be installed at 15 feet depth
- In terms of excavating up to the ground, backfilling and resurfacing, it is assumed that 10 feet wide is enough considering 5 feet width of utilidor
- Under Beekman street and Park Place, assuming 4 inches depth of asphalt and 6 inches depth of concrete under asphalt, 14.167 feet (15 feet - 4 inches - 6 inches) depth of soil is necessary for backfilling.[114][115]
- Under City Park, all of the 15 feet depth should be backfilled by soil.

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[111] https://truckingresearch.org/wp-content/uploads/2019/11/ATRI-Operational-Costs-of-Trucking-2019-1.pdf
[112] https://www1.nyc.gov/html/dot/html/motorist/sizewt.shtml
[113] U.S. Bureau of Labor Statistics
https://www.bls.gov/regions/new-york-new-jersey/data/xg-tables/ro2xgppihistind.htm
[114] Minimum thickness of asphalt is 3 inches, according to NYC DOT design manual.
http://www.nyc.gov/html/dot/downloads/pdf/nycdot-streetdesignmanual-interior-03-materials.pdf
Also,according to Asphalt paving design guide by Asphalt Paving Association of Iowa, 4 inches is enough for residential street https://www.apai.net/Files/content/DesignGuide/Chapter_4B.pdf
[115] According to NYTimes, standard concrete thickness is 6-8 inches
https://www.nytimes.com/interactive/2016/08/18/nyregion/new-york-101-streets-repair-and-maintenance.html?mtrref=www.google.com&assetType=REGIWALL
Also, according to FHWA, 4-6 inches is the base thickness
https://www.fhwa.dot.gov/pavement/concrete/pubs/hif16005.pdf

- In the space for pathway from surface to access point door for equipment entry (at City Park space), no backfilling or resurfacing is required.

b. Backfill cost of concrete and asphalt

- Unit cost of asphalt: $ 51.1333 (average cost in FY 2015-2017 according to Mayor's report)[116]
- Unit cost of concrete is referred to "material cost of Mortar, Portlan cement and lime, 1:1:6 mix, 750 psi, type N" in RSMeans, considering that target strength of cement-treated base should be somewhere between 300 and 800 psi[117]
- The utilidor is assumed to be installed at 15 feet depth
- In terms of excavating up to the ground, refilling and resurfacing, it is assumed that 10 feet wide is enough considering 5 feet width of utilidor
- Assuming 4 inches depth of asphalt and 6 inches depth of concrete under asphalt
- Equipment cost and labor cost is assumed to be the same as soil backfill cost

6. Additional Mark-Up Costs (common for costs above)

Because it is required to ask the construction company to execute each step, additional mark-up cost is necessary. The additional costs are design contingency (15%), general conditions (15%), overhead and profit (20%), permits cost (2.5%), bonds and issuance (instruments to guarantee the owner the work is completed; 1.5%), and escalation adjustment.

Escalation adjustment is the process in which each cost will be increased according to how long the period (period A) is, from the beginning of Utilidor project to the midpoint of each operation. For example, in terms of step 2, it is assumed that the transportation process initiated 6month later from the beginning of the project and it takes 18 months. Therefore, period A is 15 months. In this case, assuming that inflation cost is 4%, escalation cost is 5.12%. All of the costs in step 1 to 4 is adjusted by this process.

7. Operation and Maintenance Cost

It is assumed that operation and maintenance cost per year is 10% of construction cost multiplied by 4% inflation.

In sum, net present value of the direct cost is estimated as below, assuming 4% of discount rate.

Category	NPV of Cost($)

[116] https://www1.nyc.gov/assets/operations/downloads/pdf/pmmr2018/2018_pmmr.pdf
[117]https://www.fhwa.dot.gov/pavement/concrete/pubs/hif16005.pdf#search=%27tech+brief+bases+and+subbases+for+concrete+pavement+FHWA%27

1. Construction Cost	-3,926,370
2. Transportation Cost	-$40,345
3. Relocating Utility Cost	-$18,793,267
4. Installation Cost	-$41,178
5. Resurfacing and Backfilling Cost	-$1,751,968
6. Operation and Maintenance Cost	-$38,871,067
Total	-$63,424,197

8. Debt Service Cost

Interest payment of $1,378,848 from 2022 to 2026.

Appendix 3:

63-20							
Project year	1	2	3	4	5	6	
Year	2021	2022	2023	2024	2025	2026	Total
Initial cost (construction)	$25,535,254.44						
Maintenance & operation cost		$424,676.23	$441,663.28	$459,329.81	$477,703.01	$496,811.13	$2,300,183.46
NPV of Maintenance & operation cost (at 2021 base)		$408,342.53	$408,342.53	$408,342.53	$408,342.53	$408,342.53	$2,041,712.66
Bond Issuance (63-20 bond) amount ($)	$27,576,967.09						
Bond term	10						
Interest rate	5%						
Interest Payment		$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	
Total interest							$6,894,241.77
Principal Payment		0	0	0	0	0	
Total Principal							0
Total Payment		$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$6,894,241.77

(Table of 63-20 financing model)

Appendix 4:

Revenue Credit								
Year		2027	2028	2029	2030	2031	2032	2033
	6320 bond interest payment	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	Total revenue bond issuance need	
	6320 bond principal payment	0	0	0	0	$27,576,967.09	$34,471,208.87	
Total revenue bond issuance	$34,471,208.87							
Interest rate	4%							
Interest payment		$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.3
Bond term	15							
Principal payment		0	0	0	0	0	0	0
Maintenance & operation cost		$516,683.57	$537,350.91	$558,844.95	$581,198.75	$604,446.70	$628,624.57	$653,769.55
Total cost		$1,895,531.93	$1,916,199.27	$1,937,693.30	$1,960,047.10	$1,983,295.05	$2,007,472.92	$2,032,617.9
Total capital cost	$557,819,804.42							
User fees per year needed		$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.2
Net profit/loss		$4,038,721.31	$4,018,053.97	$3,996,559.93	$3,974,206.14	$3,950,958.19	$3,926,780.32	$3,901,635.3
Accumulated profit/loss		$4,038,721.31	$8,056,775.28	$12,053,335.22	$16,027,541.35	$19,978,499.54	$23,905,279.86	$27,806,915.:

(Table of revenue credit financing model 2027-2033)

The rest of the model for 2034-2120 is easily accessible in excel sheet

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FINAL PRESENTATION DECK

PROGRESS BRIEFING

PROGRESS BRIEFING | LIFE CYCLE COST BENEFIT ANALYSIS | PROJECT FINANCE | CONCLUSION |APPENDIX

| Interviews

AECOM

Joe Fell (Cost Estimator)
- General Methodology
- Cost Estimation of Utilidor Construction

Stantec

Vivienne Edwards (Civil Project Engineer)
- On underground infrastructure construction design

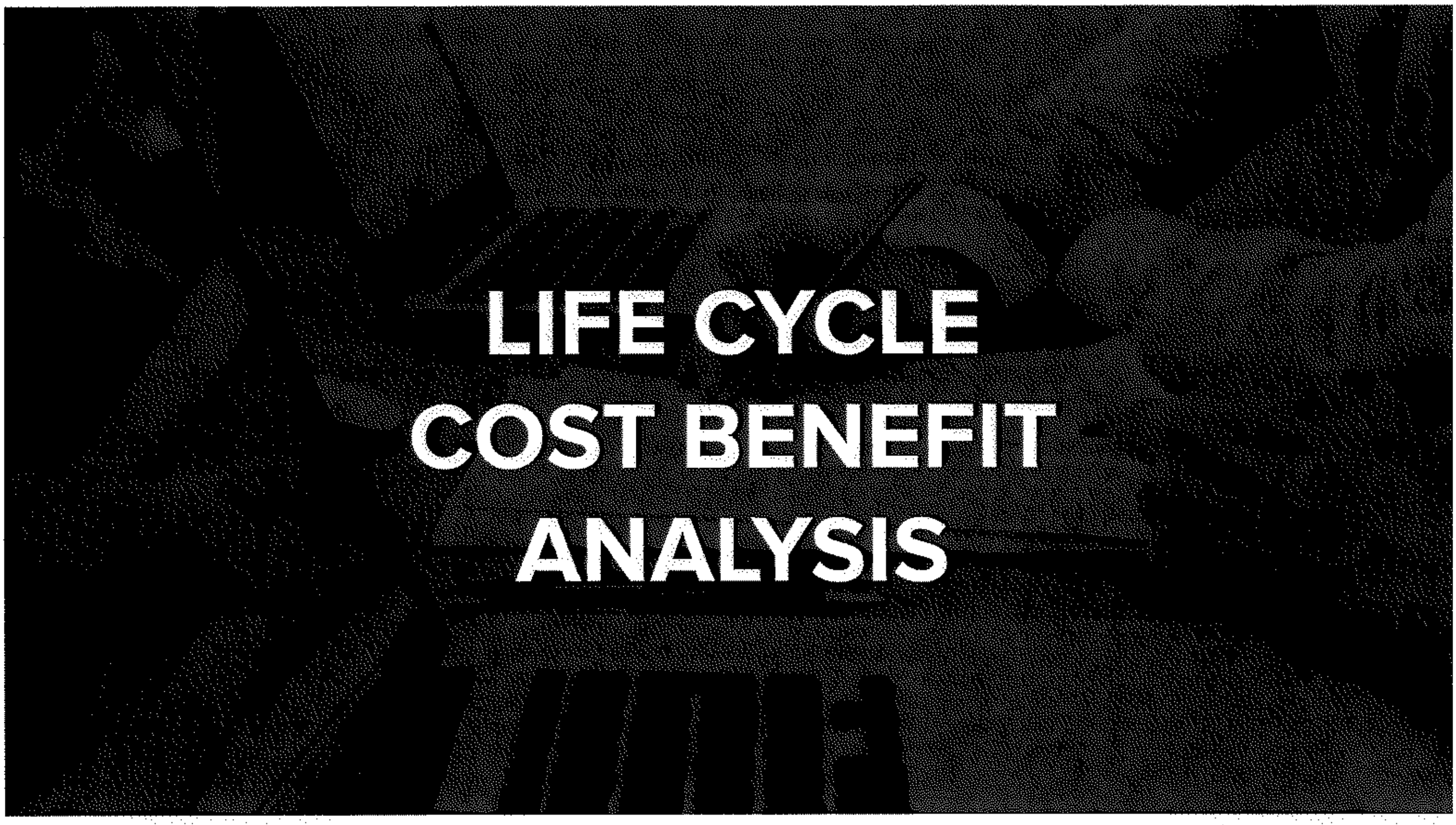
NORTON ROSE FULBRIGHT

Randolph Mayer, Uyen Poh
- Revenue credit legal constraints

NIXON PEABODY

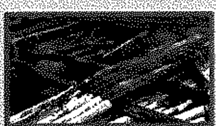
Mitchell Rapaport
- 63-20 legal process


Wendy Dolf (GIS specialist), Alan Leidner (Geospatial Information Expert)
- General information on New York City's underground
- Data availability and Needs



| Methodology

COUNTERFACTUAL | **MODEL**



Current Practice

Projecting costs under status quo scenario for the expected service life of utilidor

- **Inefficiencies caused by the current practice** were captured as **costs under Counterfactual.**
- **100-year** Period

Project Construction

Calculating costs during utilidor construction and installation

- **Direct costs** associated with the construction of the utilidor and installation of utility service lines.
- **2 year** of Construction Period

Utilidor

Projecting costs and benefits with utilidor system for the expected service life of utilidor

- **Costs of O&M** of the utilidor. **Efficiency gains and increase of quality of life** were captured as cost-reductions.
- **98-year** Period

| Major Assumptions

Major cost determinants to the City
- Street cuts: ⅓ of all permits (2.77% annual increase)
- Change in labor time required for maintenance
- Excavation risk

Growth Rate
- Annual Inflation: 4%
- Annual population Growth: 0.32%

Property Tax and Utilidor User Fee for Private Utilities
- Assumed 50% discount in Model scenario

Project Area
- Beekman street
- Total Project Length: 0.345 miles

| Impact categories

NYC Government & Authorities	Private Utilities	Traveling Public	Residents	Environmental
DOT 1) Maintenance Cost of Streets **DEP** 1) Maintenance Cost 2) Cost of Accidents to Workers 3) Revenue Loss due to Unidentified Leakages **DOITT** 1) Damage to Telecom Infrastructure **MTA** 1) Disruption to Bus Network	**Con Edison** 1) Property Tax 2) Maintenance Cost 3) Cost of Accidents to Workers 4) Manhole Accidents Compensations 5) Cost of Major Accidents 6) Headline Risk Cost **Empire City Subway** 1) Property Tax 2) Maintenance Cost 3) Cost of Major Accidents	**Drivers** 1) Travel Time Value 2) Vehicle Operation Cost **Other Users** Value of Speed Delay Time 1) Cyclists 2) Pedestrians 3) Public Transportation Passengers	1) Quality of Life: Noise 2) Quality of Life: Pollution 3) Quality of Life: Public Space 4) Utilities Disruption Costs	1) Cost of Carbon Emission from Traffic 2) Cost of Carbon Emission from Road Repair Work 3) Cost of Waste Management 4) Real Water Losses

| Utilidor Cost

1. Utilidor Construction	• Construction per unit cost data from RSMeans • Aggregate of several costs: 1) Main structure 2) Installation of pipes and conduits including support system 3) Access point doors and entryway 4) Ventilation 5) Smart infrastructures 6) Waterproofing
2. Transporting Utilidor	• Assuming that Utilidor is prefabricated in Kingston, New York
3. Relocating Utilities	• Estimated at Beekman case study project's cost X escalation
4. Installing Utilidor	• Assuming installation takes 61 days (30 feet per day)
5. Resurfacing and Backfilling	• Assuming 4 inches depth asphalt, 6 inches depth concrete, and 15 feet under roadway surface
6. Operation and Management	• Assuming that O&M costs per year is 10% of construction cost
7. Debt Service	• Interest payment on 63-20

| Result

B/C Ratio: 342.8 (Benefit/Cost)

(in $mn)

Impact Category	(A) NPV of Counterfactual	(B) NPV of Utilidor	Benefit (B-A)
NYC government	**-1,117**	**-1**	**1,116**
Utilities	**-1,110**	**-69**	**1,041**
Traveling Public	**-15,580**	**-65**	**15,515**
Residents	**-3,945**	**-49**	**3,896**
Environment	**-2,375**	**-177**	**2,198**
Total	**-24,126**	**-360**	**23,766**

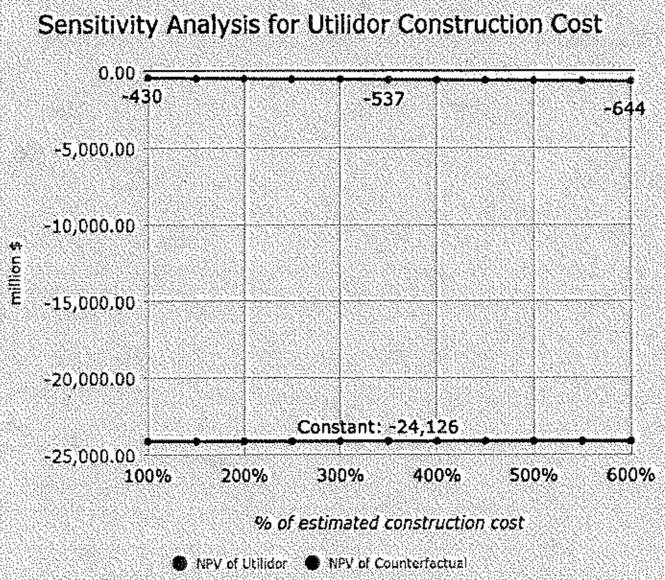
Utilidor Cost	(A) NPV of Counterfactual	(B) NPV of Utilidor	Cost (B-A)
Total	**-**	**-69**	**-69**

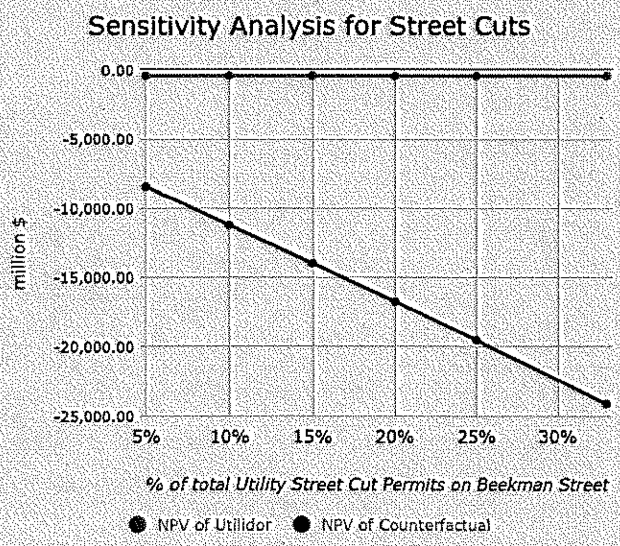
| Sensitivity Analysis

1. **Utilidor construction cost:** 100-600% of current estimate (base: 100%)
2. **Utilidor maintenance cost:** 10-20 % of construction cost (base: 10%)
3. **Actual street cuts:** 5% - 33% of total number of street cut permits (base: 33%)
4. **Discount rate:** 1-10% (base 4%)

**In all four scenarios,
Utilidor project is cost-benefit justifiable**

| Sensitivity Analysis





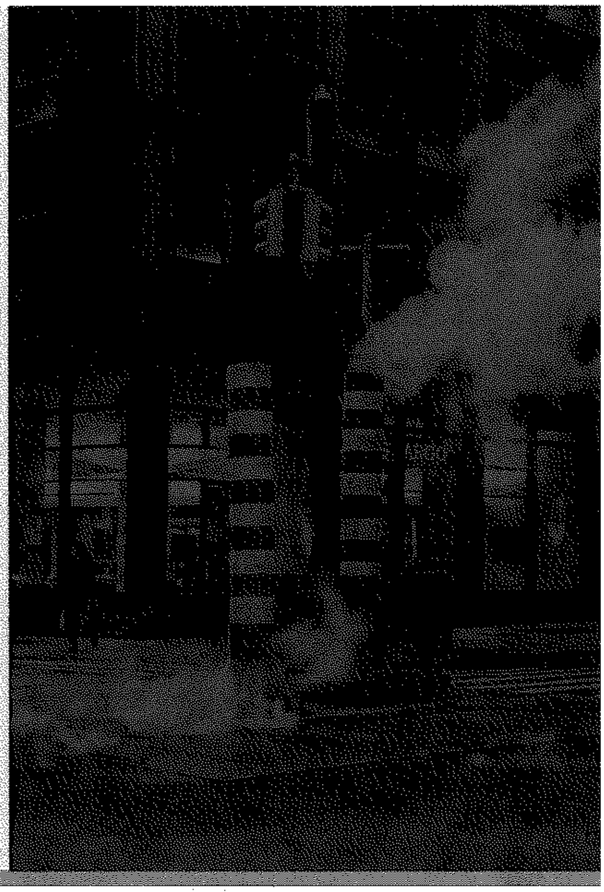
| Implications and Limitations

Policy Implications

- Economically beneficial to NYC
- Other solutions exist that could result in similar benefits

Limitations

- Subway
- Surrounding businesses
- Underground space under public parks
- Traffic costs



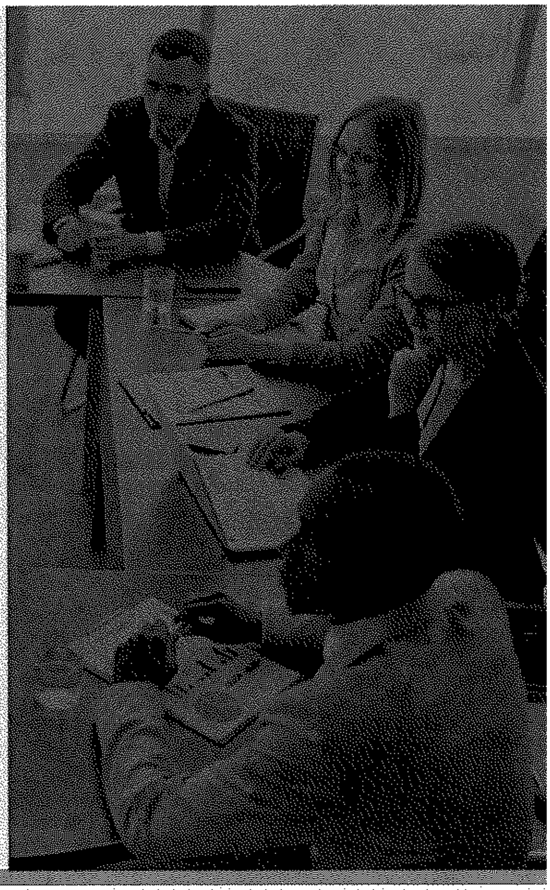
Process Mapping: 63-20

A. **Establishment of Non-For-Profit under 63-20**
   - The duration of which cannot exceed 30 years

B. **Set up a board of directors**

C. **Issue bonds on behalf of the NYC**
   - Public Use: Tax-exempt general obligation bonds
   - Private Use: Taxable private activity bonds

D. **Make decisions on**
   - Debt service payment methods
   - Possible alternation of franchises and agreements in terms of using utilidor collaboratively



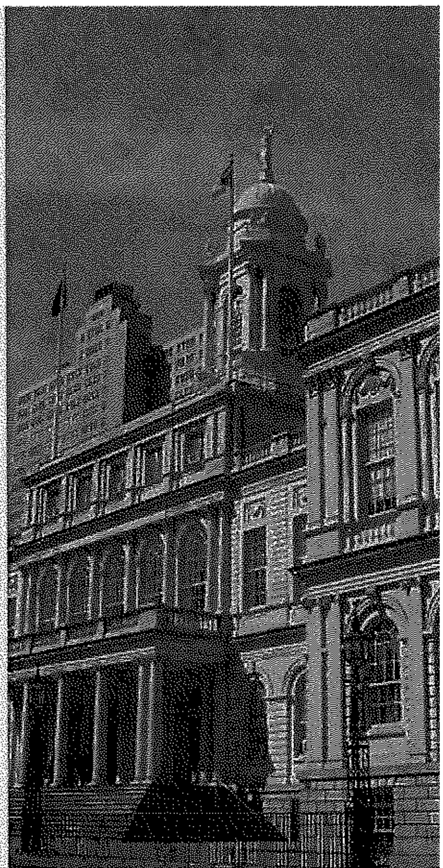
Process Mapping: Revenue credit

A. **State legislation for a creation of Smart City Infrastructure Agency (SCIA)**

B. **Amendment of utility franchises agreements before the establishment of SCIA**

C. **The legislation will authorize the transfers including:**
   - 63-20's liability
   - 63-20 financed utilidor assets
   - Financing agreements with utilidor users

D. **Authorization to hire staff and manage the utilidor assets and SCIA financed assets**



| 63-20 Financing Model

- Bond term: 10 years / Interest rate: 5%
- Annual coupon will be paid every year/ Bond face value will be paid at maturity
- The recurring annual interest expense would be paid from property taxes collected from utilities under existing franchise agreements

Project Year	1	2	3	4	5	6	
Actual Year	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**Total**
Initial cost (construction)	**$25,535,254.44**						
O&M Cost (2022-2026)		$424,676.23	$441,663.28	$459,329.81	$477,703.01	$496,811.13	
NPV of O&M Cost (2021 base)		$408,342.53	$408,342.53	$408,342.53	$408,342.53	$408,342.53	**$2,041,712.66**
Bond Issuance (63-20)	**$27,576,967.09**						
Coupon Payment (5%)		$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	**$6,894,241.77**

| Revenue Credit Financing Model

Revenue Bond Sizing

Project Year	7	8	9	10	11	12	13
Actual Year	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
6320 bond interest payment	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35		
6320 bond principal payment	0	0	0	0	$27,576,967.09		

Revenue Bond Issuance: $34,471,208.87

- Bond term: 15 years / Interest rate: 4%
- The useful life of Utilidor is 100 year (2121)
- SCIA collects user fees on a fixed rate every year

Annual Revenue Source Sizing

Total cost (Coupon + O&M Cost)	$1,895,531.93	$1,916,199.27	$1,937,693.30	$1,960,047.10	$1,983,295.05	$2,007,472.92	$2,032,617.90

SUM of 2027 (Year 7) ~ 2121 (Year 100)

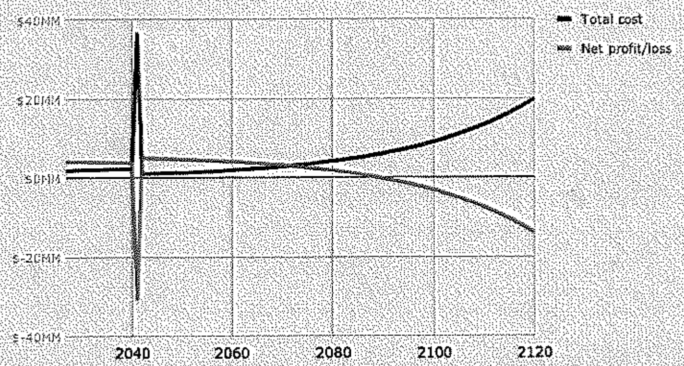
Total Capital Cost: $557,819,804.42

Divide Total Capital Cost by the rest of Utilidor Service Life

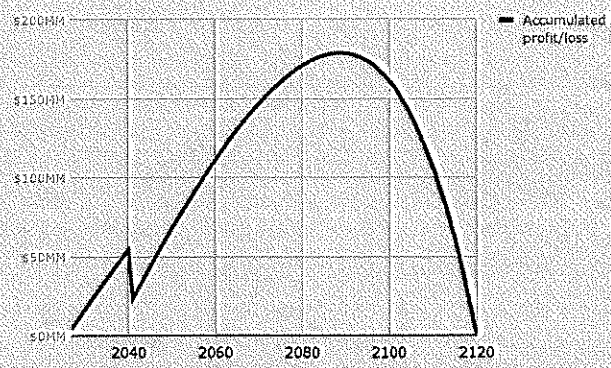
User fee needed per annum	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24

| Profit and Loss

Total cost & Net P/L Per Year



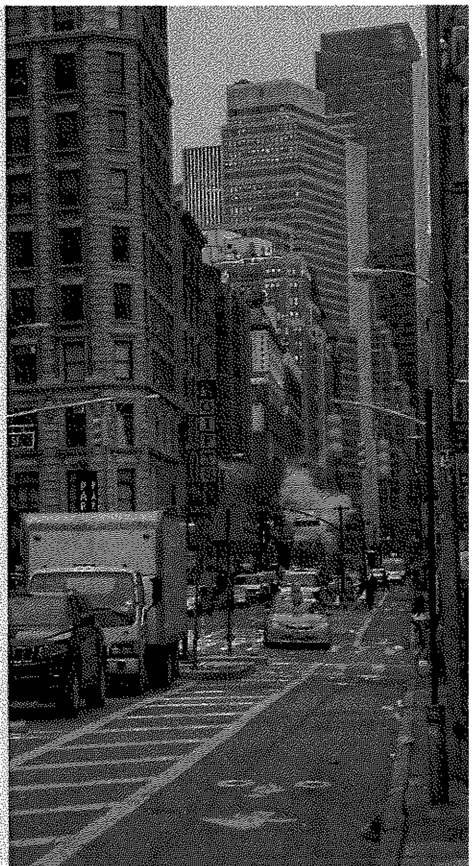
Accumulated P/L

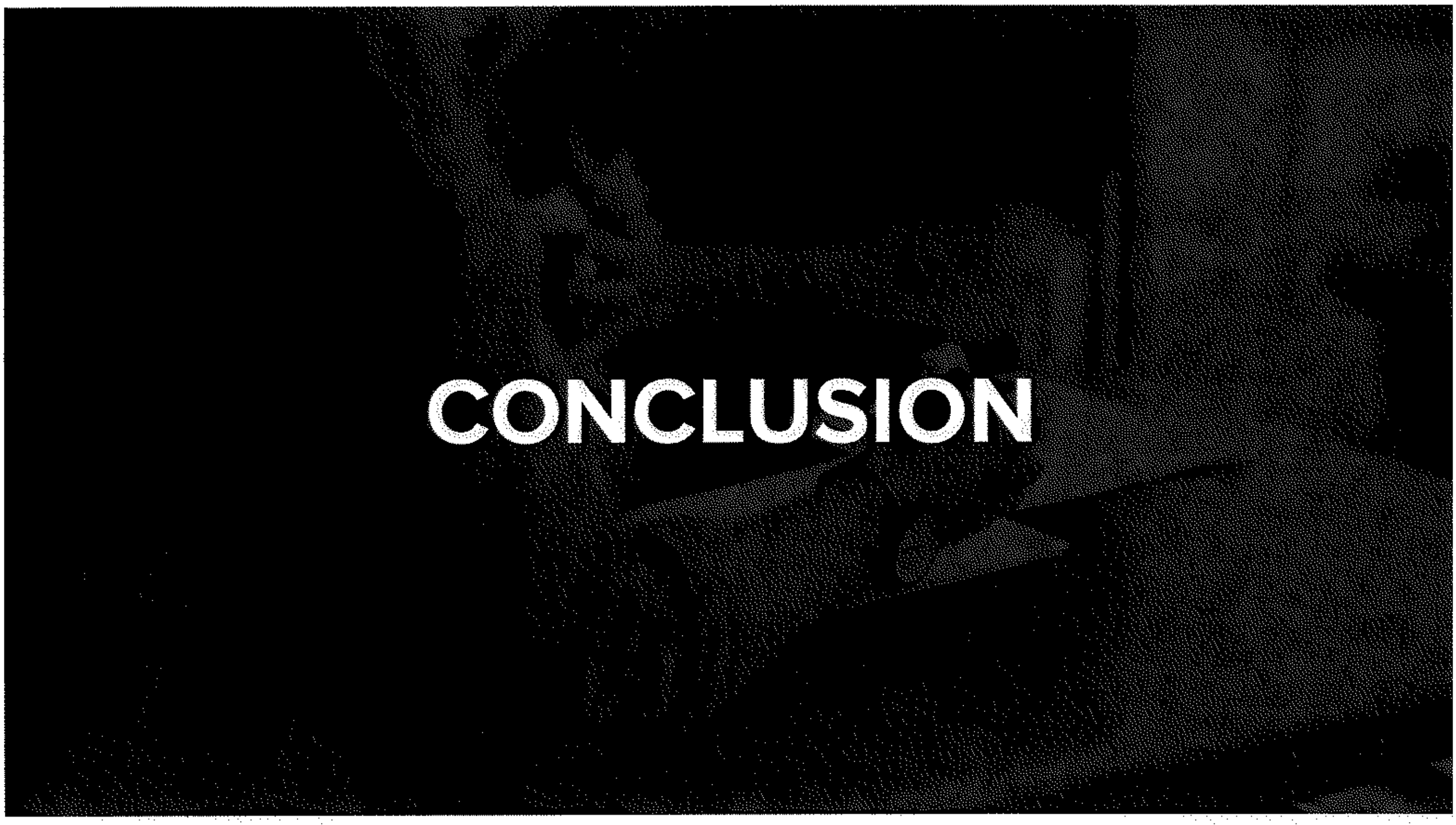


Heavy maintenance cost in later stage of utilidor's life cycle

| Feasibility and Limitations

- SCIA needs to collect at least **$6 mn** annually
- User fee is **87%** of the projected property tax in counterfactual
- NPV(Total user fees): **$114 mn**
  < NPV(Utilities' total cost avoidance): **$ 1,040 mn**
- Utilities may have different revenue incentives to engage in project





| Summary

CBA

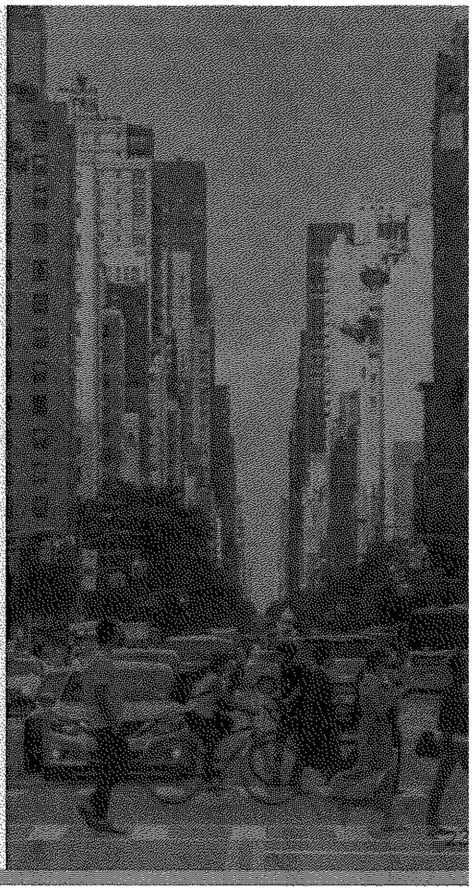
- Utilidor has a net benefit of $23.7 bn and **B/C Ratio of 342.8**
- Much of the benefits attributable to fewer street cuts
- Positive CBA results still hold up under sensitivity analyses

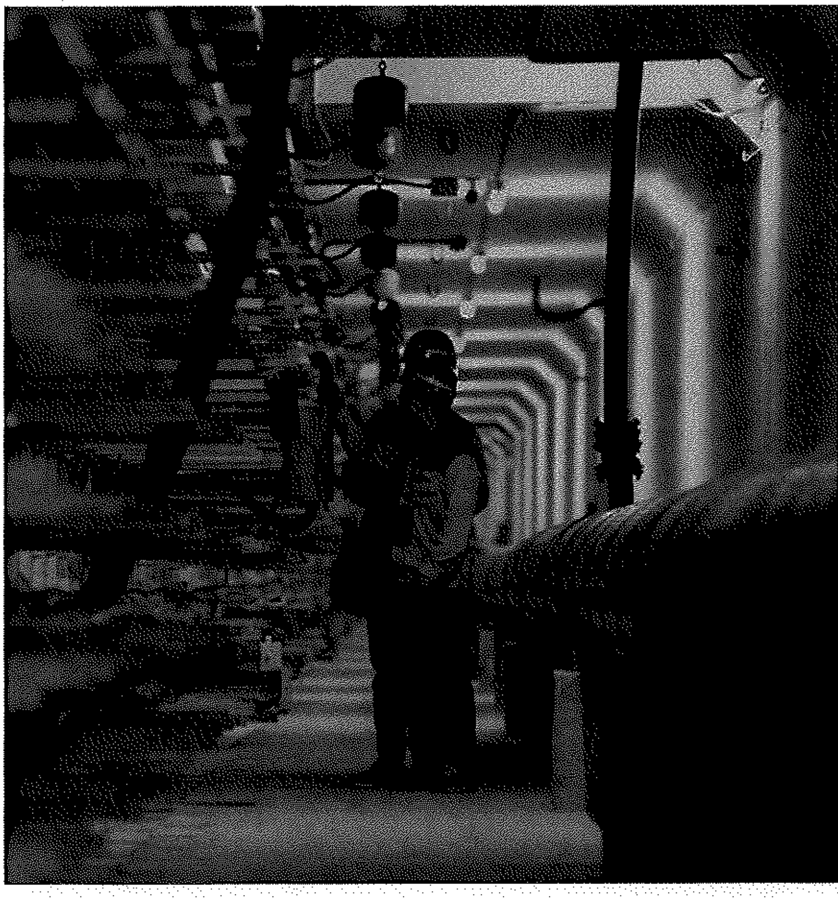
Project Finance

- Two phase financing
- **$5.9 million** of user fee annually
- **87.1%** of the utilities' property tax projection in counterfactual
- Total user fees smaller than utilities' total cost avoidance

| Next Steps

- Further analysis needed for utilidor feasibility in other areas
- Further study needed on utilities' willingness to pay and the exact proportion being assigned to each utility
- Analyze possibility of using water authority as a starting point for utilidor entity



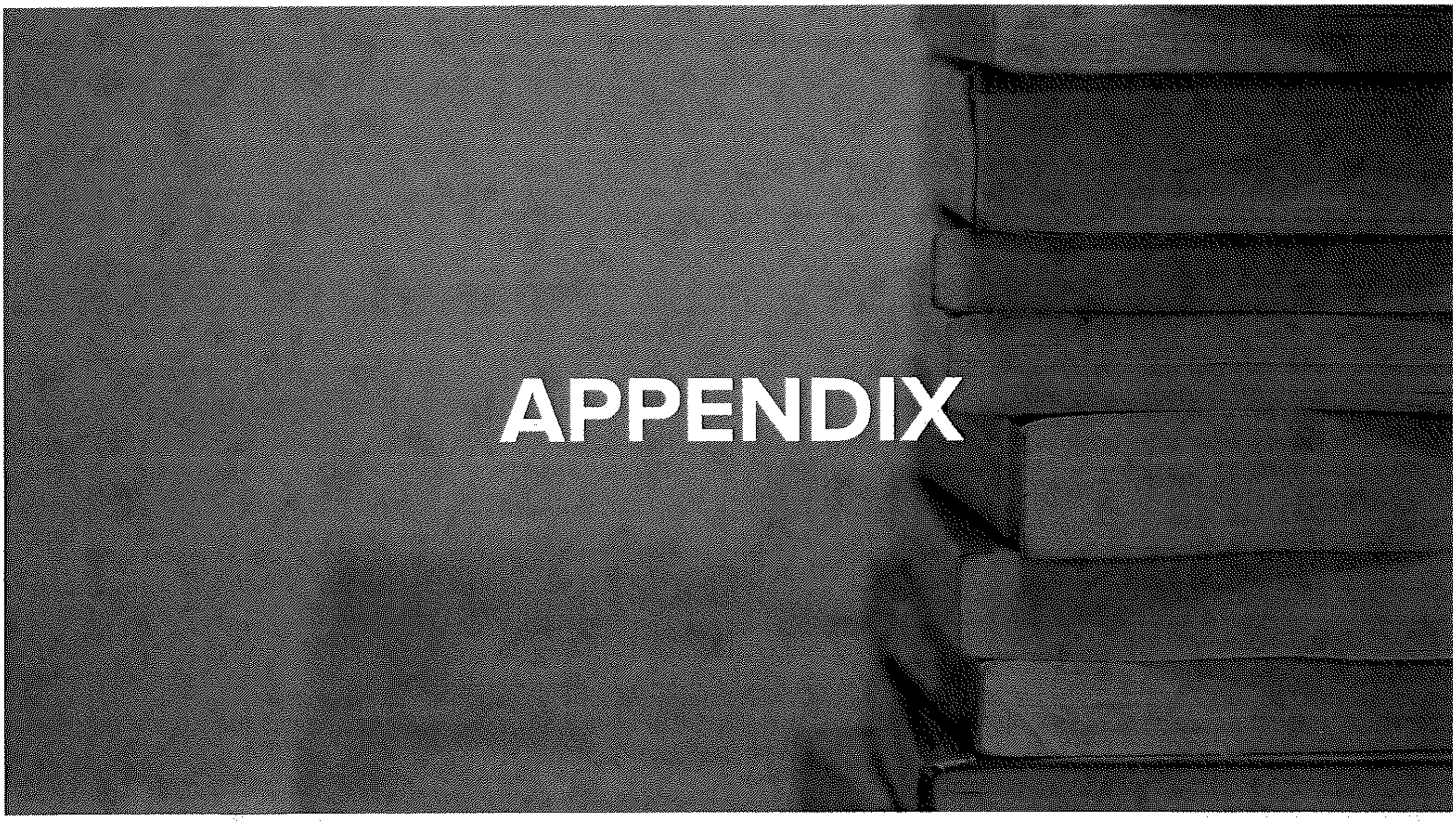


Road to Smart City

NYC Underground Utilidor Project

Presented by:
Mei Butler, Yuya Ikeda, Haeun Kim, Sam Kraus, Jennifer Lee, Daniela G. Santoyo, Yufei Zhang, Xuanrui Zhou

Advising Professor: Thomas P. Quaranta



STAKEHOLDER ANALYSIS

| Stakeholder Identification

NYC Government and Authorities
Department of Transportation (DOT)
Department of Design and Construction (DDC)
Department of Environmental Protection (DEP)
Department of Information Technology & Telecommunication (DOITT)
Metropolitan Transportation Authority (MTA)

Private Utilities
Con Edison
Verizon & Telecommunications

Businesses
Businesses located in the areas surrounding the project

Traveling Public
Commuters or other travelers who access the project area

Residents
Local residents of impacted areas in the project

EXPENDITURE ESTIMATION

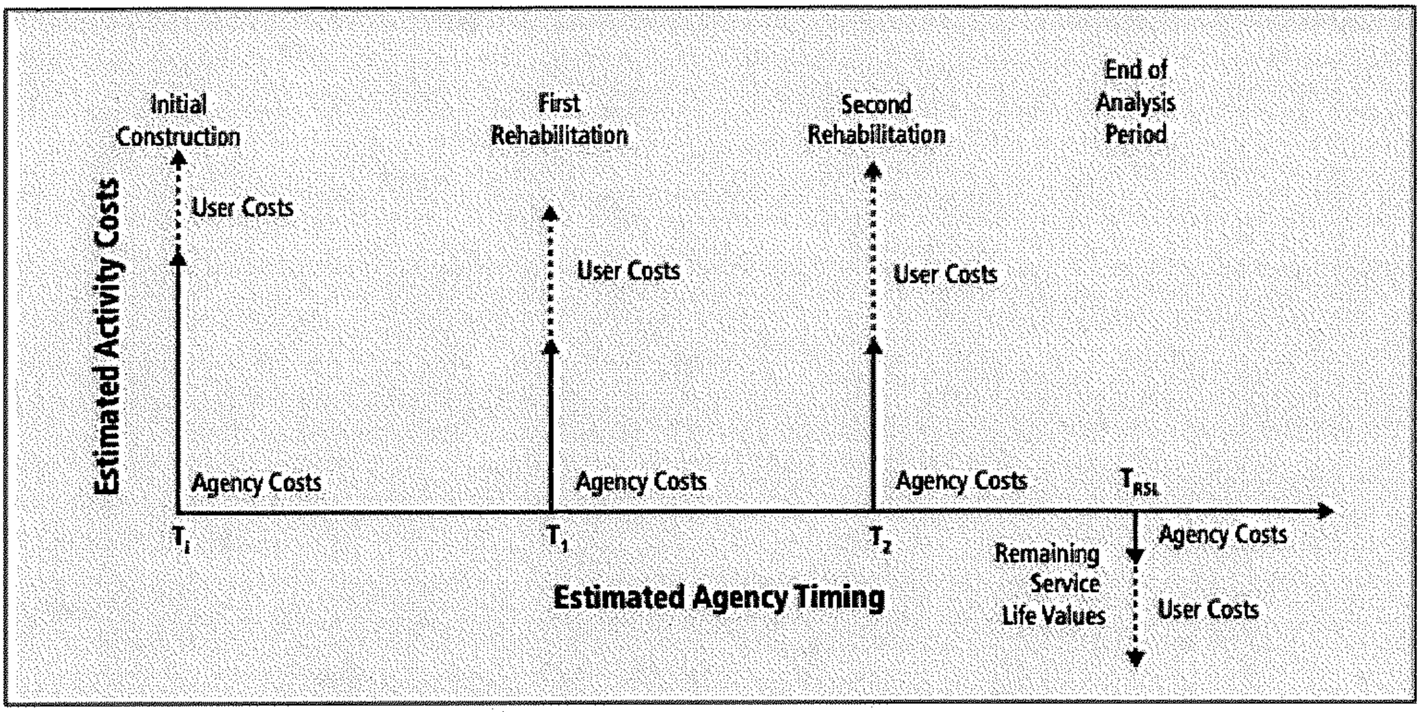


FIGURE 2. EXPENDITURE STREAM DIAGRAM, SHOWING ACTIVITIES, COSTS, AND TIMING

LIFE CYCLE COST BENEFIT ANALYSIS RESULT

| Result

B/C Ratio: 377.2 (Benefit/Cost)

(in $mn)

Impact Category	(A) NPV of Counterfactual	(B) NPV of Utilidor	Benefit (B-A)	Main factors causing difference
NYC government	**-1,117**	**-1**	**1,116**	Maintenance cost
Utilities	**-1,110**	**-69**	**1,041**	Maintenance cost and Property Tax
Traveling Public	**-15,580**	**-65**	**15,515**	No disruptions on the street after utilidor construction: no traffic, idling and vehicle operation costs associated with roadwork
Residents	**-3,945**	**-49**	**3,896**	Reduced traffic & less construction
Environment	**-2,375**	**-177**	**2,198**	Lower carbon emission and waste generation
SUM	**-24,126**	**-360**	**23,766**	**Estimated Benefit expressed as Reduced Cost**

Utilidor Cost	(A) NPV of Counterfactual	(B) NPV of Utilidor	Cost (B-A)	Main factors causing difference
SUM	-	**-63**	**-63**	**Estimated Cost of Utilidor**

| Breakdown of CBA Result: NYC government

(in $mn)

Impact Category	Cost	(A) NPV of Counterfactual	(B) NPV of Utilidor	Benefit (B-A)
DOT	**Maintenance Cost**	**-0**	**-0**	**0**
DEP	**Maintenance Cost**	**-1,010**	**-0**	**1,010**
	Cost of Accidents to Workers	**-0**	**-0**	**0**
	Revenue Loss From Unidentified Leakages	**-0**	**-0**	**0**
	DEP Total	**-1,010**	**-0**	**1,010**
DOITT	**Damage to infrastructure**	**-63**	**-**	**63**
MTA	**Disruption to Bus Network**	**-0**	**-0**	**0.0**
NYC government Total		**-1,117**	**-1**	**1,116**

| Breakdown of CBA Result: Private Utilities

(in $mn)

Impact Category	Cost	(A) NPV of Counterfactual	(B) NPV of Utilidor	Benefit (B-A)
Con Edison	Property Tax	-119	-60	60
	Maintenance Cost	-490	-2	488
	Cost of Accidents	-0	-0	0
	Con Edison Total	-609	-62	548
Empire City Subway	Property Tax	-12	-6	6
	Maintenance Cost	-489	-2	487
	Cost of Accidents	-0	-0	0
	Empire City Subway Total	-501	-8	-493
Private Utilities Total		-1110	-69	1,041

| Breakdown of CBA Result: Traveling Public

(in $mn)

Impact Category	Cost	(A) NPV of Counterfactual	(B) NPV of Utilidor	Benefit (B-A)
Drivers	Travel Time Value	-7,131	-1	7130
	Idling Vehicle Operation Cost	-8,425	-4	8420
	Speed Change Vehicle Operation Cost	-2	-44	-42
	Drivers Total	-15,557	-63	15493
Other Users	Cyclists	-15	-0	15
	Pedestrians	-8	-0	8
	Public Transportation Passangers	-0	-0	0
	Other Users Total	-23	-0	-23
Traveling Public Total		-15,580	-65	-15,515

| Breakdown of CBA Result: Residents

(in $mn)

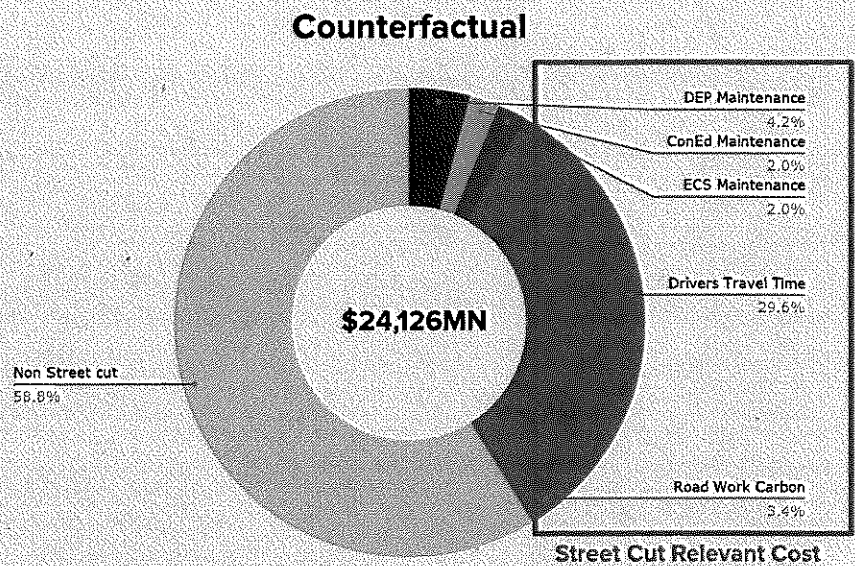
Impact Category	Cost	(A) NPV of Counterfactual	(B) NPV of Utilidor	Benefit (B-A)
Residents	Quality of Life - Noise	-3,704	-1	3,703
	Quality of Life - Pollution	-9	-0	9
	Quality of Life - Public Space	-	-48	-48
	Utility Disruption Cost	-231	-0	231
Residents Total		**-3,944**	**-49**	**3,895**

| Breakdown of CBA Result: Environmental Cost

(in $mn)

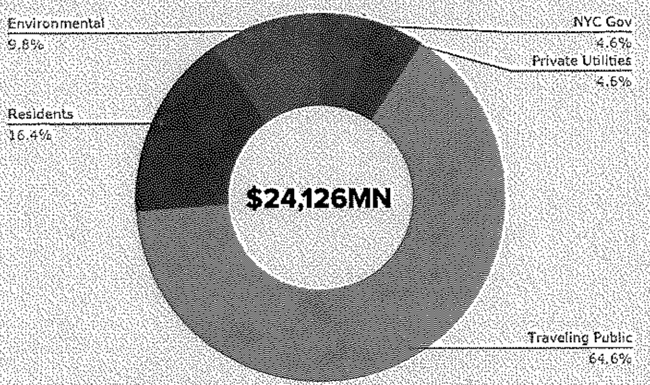
Impact Category	Cost	(A) NPV of Counterfactual	(B) NPV of Utilidor	Benefit (B-A)
Environmental Cost	Carbon Emission from Traffic	-12	-0	12
	Carbon Emission from Road Repair	-829	-0	828
	Waste	-37	-0	37
	Water	-1,497	-176	1,321
Environmental Cost Total		**-2,375**	**-177**	**2,198**

| CBA Analytics: Street Cut Relevant Costs

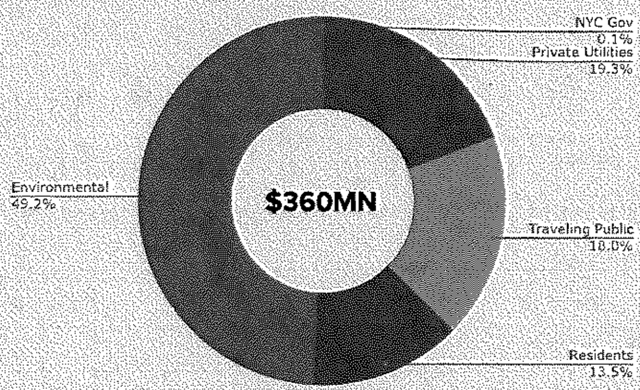


41.24% of total NPV of Counterfactual
is dependent on **the number of Street Cuts**

| CBA Analytics: Change in Composition



Counterfactual



After Utilidor

Traveling Public takes 64.6% of total cost

This implies the economic inefficiency of current utilization of roads and underground

Environmental Cost becomes the largest

For inevitable water loss (10% of current leakage) even after smart infrastructure

NYC GOVERNMENT CBA CALCULATION

Costs: DOT

1) Maintenance	
Miles repaved per year X The miles of all roads in New York City = **Maintenance of Beekman Street** X The Length of Beekman Street = **Portion of Paving for Beekman Street** + **Settlements from Potholes in Beekman Street**	**Maintenance Costs:** • DOT paves a relatively constant number of miles of street per year, fills in potholes, and pays settlements for unmet maintenance needs • As street cuts increase, we expect 'unmet maintenance needs to grow. **Milling & Paving vs. Potholes** • Maintenance costs vary depending on approach

Costs: DEP

1) Maintenance & Water Loss

Miles repaved per year
X The miles of all roads in New York City
= **Maintenance of Beekman Street**
X The Length of Beekman Street
= **Portion of Paving for Beekman Street**
+Settlements from Potholes in Beekman Street

Apparent water loss:
Water loss in the project area
X Cost of water loss
Cost on Beekman Street

2) Risk to Workers

Excavation construction risk
Time to respond to water main breaks or leakage
X Full time equivelent workforce
= **Number of workplace accidents**
X Workers comp for death or accident
= **Anticipated Compensation from accidents**

Costs: DoITT

1) Monetizing Agency Objectives

- **Enhances and Improves Services to offer more advanced and timely technology implementations and streamline processes.**
- **Provides Robust Infrastructure to protect the City's technology, telecommunications, and information assets and maintain service operations.**
- **Optimizes Citywide Technology Administration to improve IT procurement options and vendor accountability and save the City cost and time.**

Challenges of monetization:
- A utilidor would help advance each of these objectives, but not at the scale of the pilot.
- Methodologically, we could not monetize the dollar value that these benefits would bring to the city
- However, by reducing the likelihood of damaged utility lines, DoITT gains benefits equal to the aggregate willingness to pay for uninterrupted service, suggested by Hayes.

Probability of Damage due to other utility work
X Cost of Damaged Telecom Infrastructure
X Customers in Service Area

- **Cost of Accidental Damage to Telecom Infrastructure**
- **Common Ground Alliance -- Damage Information Reporting Tool: Telecom is most likely to be damaged**

Costs: MTA

1) Maintenance	
Loss or ridership x Bus speed decrease index X fare cost **= Revenue lost from declining ridership in adjacent bus lines due to increased traffic**	**MTA:** • Natural stakeholder as they own subsurface infrastructure. • MTA's operations are indirectly impacted by the utilidor project as well as the current practice of operating utilities: o For example: as recently as January, an MTA subway station was flooded as a result of a water main break. o The probability of utility failure impacting other infrastructure is already captured as costs to the traveling public as well as costs to other agencies.

PRIVATE UTILITIES CBA CALCULATION

Private Utilities: Con Edison

1) Property Tax	
Total property tax to City of New York X The miles of all roads in New York City = **Property Tax per Mile** X The Length of Beekman Street = **Portion of Property Tax for Beekman Street**	**Property Tax:** • How Con Edison is paying to the City for using City's underground currently • Assumed 50% cut in Property Tax for Con Edison in Utilidor model for Con Edison pays Revenue Credit to the City for using Utilidor

2) Maintenance Cost	
Con Edison Street Cuts in Beekman Street per year X Average size of a Road Work (Square foot) X Demolish, Repair and Repayment Cost (per Square foot) = **Con Edison Maintenance Cost for Beekman Street**	**Con Edison Street Cuts:** • 46.27% of total Street Cuts (Modified data from Common Ground Alliance) **Average size of Road Work:** • Assumed 20 square foot **Demolish, Repair and Repayment Cost:** • Data based on RS means

Private Utilities: Con Edison

3) Cost of Accidents to Workers	
Used the DEP's Costs of Accidents to Workers estimate	

4) Manhole Accidents Compensations	
Manhole Injuries per year X Injury Compensations = **Total Injury Compensations per year** + Legal Fees for Settlement per year = **Total Costs for Manhole Accidents Compensations** X For Beekman street = **Manhole Accidents Costs for Beekman Street**	**Manhole Injuries per year:** • 6.6 cases • Assumed 1% occurance of current frequency with Utilidor **Legal Fees for Settlement:** • Assumed 1 lawyer (Con Edison has its legal team)

Private Utilities: Con Edison

5) Cost of Major Accidents	
Compensation to Businesses around + Costs for Recovery Works + Legal Fees for Settlements **= Total Cost for a Major Accident** X Number of Major Accident per year **= Total Cost for a Major Accident per year** X For Beekman Street **= Annual Major Accidents Costs for Beekman Street**	**Compensation to Businesses around:** • $5000 daily sales, 10 businesses, for 2 days **Cost for Recovery Works:** • Reinstallment of Infrastructure, Compensation to other facilities, etc. • Assumed $500,000 **Number of Major Accidents:** • 2.5 incidents over 13 years = 0.19 per year

6) Headline Risk	
Number of Major Accident per year X The Change in Company Value After a Major Incident **= Total Headline Risk Costs** X For Beekman Street = **Headline Risk Costs for Beekman Street**	**Change in Company Value:** • Yahoo Finance Historical Data • Impact to Stock Price lasts 2-3 weeks • Change in Stock Price * Traded Volume

Private Utilities: Empire City Subway

1) Property Tax	
Total property tax to City of New York X The miles of all roads in New York City **= Property Tax per Mile** X The Length of Beekman Street **= Portion of Property Tax for Beekman Street**	**Property Tax:** • Assumed 1/10 of Con Edison/s Property Tax • How the Utility is paying to the City for using City's underground currently • Assumed 50% cut in Property Tax

2) Maintenance Cost	
Empire City Subway Street Cuts in Beekman Street per year X Average size of a Road Work (Square foot) X Demolish, Repair and Repayment Cost (per Square foot) **= Maintenance Cost for Beekman Street**	**Empire City Subway Street Cuts:** • 46.20% of total Street Cuts (Modified data from Common Ground Alliance) **Average size of Road Work:** • Assumed 20 square foot **Demolish, Repair and Repayment Cost:** • Data based on RS means

3) Cost of Accidents to Workers	
Used the DEP's Costs of Accidents to Workers estimate	

TRAVELING PUBLIC CBA CALCULATION

Costs: Traveling Public

1) Drivers - Travel Time Value

Reduced Speed Delay Per Car X Average # of vehicles in all project area daily = **Delay Time for All Vehicles** X Hourly Value of Personal Time X Average vehicle occupancy (1.67) = **Value of Delay Time for All Drivers** X Number of Workdays of Roadwork = **Total Annual Cost of Delay Time for All Vehicles**	**Vehicles:** • 11775 vehicles in total (Beekman) Average increase of 0.03%. **Average Travel Speed WITH disruption:** • 22% less than the usual speed (7.1mph) • Average annual decrease of 3.42% **Value of personal time:** • 50% of Median Annual Household Income ($61,937) / 2080 hours. **Workdays:** • Number of permits x Labor Hours required per permit (Average growth of 2.77%).

Costs: Traveling Public

2) Drivers - Travel Time Value - Detour (Model)	
Reduced Speed Delay Per Car in Detour Area (Fulton) X Average # of vehicles in all project area and detour area daily **= Delay Time for All Vehicles in Detour Area** X Hourly Value of Personal Time X Average vehicle occupancy (1.67) **= Value of Delay Time for All Drivers** X Number of Workdays Detour is needed **= Total Annual Cost of Delay Time in Detour Area for All Vehicles**	**Detour:** • Road closed 2 years - All weekends & nights (7 hours per day). • 18497 vehicles in total (Beekman and Fulton) Area of 2583.71 ft (Fulton Street) **Average Travel Speed WITH disruption:** • 57% less than the usual speed (7.1mph)

Costs: Traveling Public

3) Drivers - Vehicle Operation Costs	
Queuing/Idling Number of Vehicles / Queuing/Idling speed **= Total Queuing/Idling time** X Idling VOC cost **= Idling Cost in Project per vehicle** X Total Queuing/Idling Number of Vehicles X Number of Workdays of Roadwork **= Total Annual value of queuing/idling VOC for ALL vehicles**	**Queuing/Idling time:** • ~3 hours of heavy traffic in project area (11775 vehicles/24 * 3) **Speed:** • 1.4% of Average Speed (7.1mph). • Cost Estimation per hour: $0.94 (From NCHRP Report 133)
Delayed (Speed Change) Number of Vehicles X Total Additional Cost **= Total VO Cost of Delay time for All Vehicles** X Number of Workdays of Roadwork /1000 **= Total Annual value of speed change VOC for ALL vehicles**	**Delayed (Speed Change) time:** • ~21 hours of delay in project area (11775 vehicles/24 * 21) **Total Additional Cost** • Average cost per 10 mph - Average cost per 5mph = $8.30

Costs: Traveling Public

4) Cyclists - Travel Time Value

Reduced Speed Delay Per Bike X Average # of daily bike rides in all project area daily **= Delay Time for All Bikes** X Hourly Value of Personal Time for Cyclists **= Value of Delay Time for All Cyclists** X Number of Workdays of Roadwork **= Total Annual Cost of Delay Time for All Cyclists**	**Bikes:** • 21560 bike rides in total in the area. (490,000 in the city - 22% in Manhattan - 4.4 in the project area). • Average increase of 9% every ten years. **Average Travel Speed WITH disruption:** • 11% less than the usual speed (9.23 mph 30 % faster than cars) **Value of personal time:** • 25% of Median Annual Household Income ($61,937) / 2080 hours.

Costs: Traveling Public

5) Pedestrians - Travel Time Value

Reduced Speed Delay Time Per Pedestrian X Average travel speed with disruption **= Average number of extra miles per day** X Average Cost of Travel Mile per Pedestrian X Population per Square Mile **= Total Annual Cost of Delay Time for All Pedestrians**	**Average Travel Speed WITH disruption:** • 11% less than the usual speed (3 mph). No increase. **Time Value:** • Estimated Average Cost from VTI Report ($1.56 per mile).

6) Public Transportation Passengers - Travel Time Value

Reduced Speed Delay Per Bus X Average Ridership Change **= Delay Time for All Passengers affected** X Hourly Value of Personal Time for PT passengers **= Value of Delay Time for All PT Passengers** X Number of Workdays of Roadwork **= Total Annual Cost of Delay Time for All Passengers**	**Buses:** • Ridership change from lines M9,M22,M103 Ridership Change: 15560 **Average Travel Speed WITH disruption:** • 5.79mph (Usual speed 7.4 mph) **Value of personal time:** • 35% of Median Annual Household Income ($61,937) / 2080 hours.

RESIDENTS
CBA CALCULATION

Residents

1) Quality of Life - Noise Pollution

Construction-Related Noise Complaints in Zip Code
X Project Area Proportion of Zip Code
= **Number of Annual Noise Complaints**
X Cost per Noise Complaint
= **Total Annual Cost of Noise Complaints**

Noise Complaints:
- Assumed 11% constant increase in noise complaints (Average from 10-year data)
- Cost per complaint set as $338

2) Quality of Life - Air Pollution

Vehicle Pollution:
Annual Vehicle Miles on Road
X Pollutant Emission Rate
X Social Cost of Pollutant
= **Annual Cost of Vehicle Pollution**

Construction Pollution:
Annual Miles of Construction
X Pollutant Emission Rate
X Social Cost of Pollutant
= **Annual Cost of Construction Pollution**

Vehicle Pollution:
- Assumed NOx and CO as main pollutants
- Social Cost of NOx = $14,000 / metric tonne
- Social Cost of Carbon = $123/ metric tonne

Construction Pollution:
- Assumed PM-10 as main pollutant
- Social Cost of PM-10 = $1,700 / short ton

Residents

3) Quality of Life - Loss of Public Space	
Annual Visits X Cost per Visit **= Annual Cost of Public Space Use**	• City Hall Park assumed to be the main public space in the project zone • Cost per visit valued at $2.45

4) Utility Disruptions	
Utility cuts per year X Cost per utility disruptions **= Annual Cost of Utility Disruptions**	**Annual Utility Cuts:** • ConEd, DEP, and ECS each considered separately • Assumed cost per utility disruption to be $99

ENVIRONMENTAL CBA CALCULATION

Environmental

1) Cost of Carbon Emission from Traffic

Extra Miles of Driving for Road Work per Year X The Average Passenger Vehicle Carbon Emission per Mile **= Carbon Emission from Extra Miles of Driving** X Social Cost of Carbon **= Cost of Carbon Emission from Traffic**	**Social Cost of Carbon:** • $42 per ton in 2020 • 1.5% annual increase based on EPA projection • 4% inflation

2) Cost of Carbon Emission from Road Repair Work

Carbon Emission from Road Construction X Average Size of Road Repair Work X Number of Road Repair Work per year **= Carbon Emission from Road Construction** X Social Cost of Carbon **= Cost of Carbon Emission from Road Repair Work**	**Carbon Emission from Road Construction:** • Data from New Jersey Highway Case Study **Average Size of Road Repair Work:** • Assumed 20 square foot

Environmental

3) Cost of Waste Management

Average Size of Road Repair Work (Square foot) X Number of Street Cut X Demolition Costs ($ / square foot) **= Demolition Costs per year** **+ Disposal Costs per year ($ / road wor)** **= Cost of Waste Management**	**Demolition Costs:** • Used as a proxy to handling wastes **Disposal Costs per year:** • Assumed $600 per street cut which is average Construction and Demolition Waste Cost in New York based on research

4) Real Water Losses

= Annual Cost of Real Losses	**Real Losses:** Water wasted due to unidentified leakages **Annual Cost of Real Losses:** • Data from Water Demand Management Plan by NYC DEP • 4% annual inflation

UTILIDOR COST

| Utilidor Cost

Category	NPV of Cost (million $)
1. Construction Cost	**-4**
2. Transportation Cost	**-0**
3. Relocating Utility Cost	**-19**
4. Installation Cost	**-0**
5. Resurfacing and Backfilling Cost	**-2**
6. Operation and Management Cost	**-39**
7. Debt Service Cost	**-6**
Total	**-69**

Utilidor Cost - Construction Cost

1) Access Point Door	
Unit Cost of entrance doors (per each access point) X Number of Access Point **= Access Point Door Cost**	**Unit Cost** • Unit cost is provided by RSMeans **Number of Access Point** • Assuming 3 access points

2) Space from Surface to access point - for personnel entry	
0	• Assuming we can utilize existing manhole for two of the three entry, for human entry

Utilidor Cost - Construction Cost

3) Space from Surface to access point - for equipment entry	
Unit Cost of precast wall panel (per square foot) X Area of one wall **= Cost for of one wall** X The number of wall **= Cost of creating vertical space from surface to entry point**	**Assumption** • Assuming by setting 4 walls vertically from surface to entry point, we can create vertical passway for equipment • Assuming this entry point will be created in City Park **Unit Cost** • Unit cost is provided by RSMeans

Utilidor Cost - Construction Cost

4) Installation of pipes and conduits

Unit Cost of utility line (per linear foot)
X Length of utility line
= Replacement of Utilities cost

Assumption
- Assuming renewed water main pipe (24 inches diameter, 1821 feet length), electrical wire (2 inches diameter, 5000 feet length), gas pipe (8 inches diameter, 1821 feet length) and steam pipe (16 inches diameter, 1821 feet length) should be equipped in Utilidor when it is prefabricated
- Water main and sewer pipe will not be equipped in the Utilidor

Unit Cost
- Unit cost is provided by RSMeans

Utilidor Cost - Construction Cost

5) Smart Infrastructures

Unit Cost of each system
X Number of system
= Cost for of Smart Infrastructures

Assumption
- Assuming intrusion detection system, video surveillance system, fire detection sensors, fuel-gas detection sensors, humidity detection system, crack detection system for Utilidor frame and each pipe, and power cable default detection system should be equipped
- Unit cost of intrusion detection system, video surveillance system, fire detection sensors, fuel-gas detection sensors is provided by RSMeans
- Retail unit price of smart water leak sensor and concrete crack detection sensor is used as unit cost of humidity detection system and crack detection system for Utilidor frame and each pipe. For these costs, labor cost is assumed to be the same as that of video surveillance system.
- Assuming that power cable defalt detection system cost is the same as crack detection system
- Except for intrusion detection system, all equipment is assumed to be equipped every 50 feet. Intrusion system is assumed to be equipped with each entry point.

Utilidor Cost - Construction Cost

6) Hangers (shelves) to support utilities	
Unit Cost of hangers X The number of hangers **= Hangers cost**	**Unit Cost** • Unit cost is provided by RSMeans

7) Ventilation	
Unit Cost of ventilator X The number of hangers **= Ventilation cost**	**Assumption** • Assuming ventilators should to be equipped every 50 feet **Unit Cost** • Unit cost is provided by RSMeans

Utilidor Cost - Construction Cost

8) Main Structure	
Unit Cost of hangers (per linear foot) X Length of Utilidor **= Main structure cost**	**Unit Cost** • Unit cost provided by RSMeans ("Box culvert, precast, base price, 8' long, 6' x 7'" under "Sewage/Drainage collection, concrete pipe section) **Length** • 6 feet height, 5 feet width, 1821 feet length

9) Fill Material Cost	
Transportation unit cost (per mile) X Transporting distance **= Fill material cost**	**Assumption** • Assuming fill is transported from Long Island city • Assuming one truck of fill material is necessary **Unit Cost** • Assuming fill material cost is negligible • Unit transportation cost: 1.962 dollars per mile (average marginal cost per mile in Northeast region)

Utilidor Cost - Construction Cost

10) Waterproof	
Unit Cost of waterproof (per cubic yard) X Volume of Utilidor **= Waterproof cost**	**Unit Cost** • Unit cost provided by RSMeans

Utilidor Cost - Transportation Cost and Relocating Utility Cost

Transportation Cost - delivering Utilidor from the place it will be prefabricated to Beekman Street	
Transportation unit cost (per mile) X Aggregate transporting distance **= Transportation cost**	**Assumption** • Assuming Utilidor is prefabricated in Kingston, NY • Assuming one truck can carry 30 feet Utilidor per one driving (under NYC regulation, maximum length of truck is 35 feet. Assuming that 5 feet is necessary for driver seat) **Unit Cost** • Unit transportation cost: 1.962 dollars per mile (average marginal cost per mile in Northeast region)

Relocating Utility Cost - to avoid Utility disruption when installation	
Project cost in Beekman case study in 2010 X Escalation **= Relocating Utility cost**	**Escalation** • From 2010 to 2019: measured by Producer Price Index in New York - New Jersey • In 2020 and 2021: assuming 4% increase per year

Utilidor Cost - Installation Cost

1) Equipment Cost	
Unit cost (per linear foot) X Length **= Equipment cost**	**Unit cost** • No exact cost is found in RSMeans • Assuming unit equipment cost is the same that of main frame cost

2) Labor Cost	
Unit daily labor cost X Working days **= Labor Cost**	**Unit Cost** • No exact cost is found in RSMeans • Assuming unit daily labor cost for equipment operator (crane), which is the unit labor cost for main framework, can be used as unit cost in this estimation **Assumption for working days** • Assuming 30 feet installation is possible per day

Utilidor Cost - Resurfacing and Backfilling Cost

1) Backfill of Soil	
Unit cost (per cubic yard) X (Required volume under City Park and Required volume under street) **= Backfilling soil cost**	**Unit cost** • Unit cost is provided in RSMeans **Assumption for required volume** • Excavating up to 10 feet width (considering 5 feet width of Utilidor) • Under City Park: 15 feet depth • Under street: 15 feet - 4 inches (asphalt) - 6 inches (concrete) • In equipment entry point area, no backfilling is required

2-1) Backfill of Asphalt and Concrete- Asphalt Material Cost	
Asphalt cost (per ton) X Required volume **= Backfilling concrete cost**	**Unit Cost** • Unit cost: average unit cost in FY 2015-2017 found in Mayor's report **Assumption for required volume** • Excavating up to 10 feet width (considering 5 feet width of Utilidor) • 4 Inches depth of asphalt

Utilidor Cost - Resurfacing and Backfilling Cost

2-2) Backfill of Asphalt and Concrete - Concrete Base Material Cost	
Unit concrete cost (per cubic yard) X Required volume **= Backfilling concrete cost**	**Unit Cost** • Unit cost: target strength of cement-treated base should be somewhere between 300 and 800 psit • Based on this assumption, concrete cost is picked from material cost of Mortar, Portian cement and lime, 1:1:6 mix. 750 psi, type N in RSMeans **Assumption for required volume** • Excavating up to 10 feet width (considering 5 feet width of Utilidor) • 6 inches depth

2-3) Backfill of Asphalt and Concrete - Equipment and labor cost	
Unit equipment and labor cost (per cubic yard) X Required volume **= Equipment and labor cost**	**Unit Cost** • Assuming unit costs are the same as backfilling soil cost **Assumption for required volume** • Excavating up to 10 feet width (considering 5 feet width of Utilidor) • 4 inches depth of asphalt and 6 inches depth of concrete

Utilidor Cost - Additional Mark-up

Assumed Additional Mark-up Costs	
Total Cost X Design Contingency (+15%) X General Conditions (+15%) X Overhead and Profit (+20%) X Permits (+1.5%) X Bonds and Issuance (+1.5%) X Escalation (+4% per year, adjusted according to the months to mid-point of construction) **= Total Additional Mark-up Cost**	

UTILIDOR COST ESTIMATION ASSUMPTIONS

Construction Cost Assumptions

- Unless specified otherwise, assume all costs found in RS Means
- **Access point door for utilidor**
  - We specified to AECOM that we would need 3 doors big enough to accommodate both personnel and equipment. In our interview, they confirmed that this would be a sound assumption and suggested that the door should be 5x7 feet
- **Space from surface to access point for personnel entry**
  - We assume that manholes can be utilized for personnel entry as well
- **Space for equipment entry**
  - It is assumed that manholes are too small to carry equipment for repair and maintenance Therefore, larger entry path should be secured. In this paper, the large entry is assumed to be built in City Park.
  - This entry route should always be accessible for utility companies and the government Therefore, by installing precast concrete walls vertically from surface to Utilidor entry point to secure the space

Construction Cost Assumptions

- **Installation of pipes and conduits including support system**
  - Sewage and drainage pipes are not installed into Utilidor to avert risk of flooding. This was requested by Con Ed and acknowledged by the Utilidor Working Group.
  - Telecom fiber lines does not have to be replaced because it is relatively new infrastructure
  - Because electrical, gas, water main and steam pipes are old, they will be replaced. By replacing water pipes in particular, we assume a lower break rate for the entire period of the utilidor.
- **Smart infrastructure equipment (and security system)**
  - Intrusion detection system should be installed at every entry point
  - Video surveillance system should be equipped by every 50 feet for security
  - Fire detection sensors, fuel-gas detection sensors and humidity detection system should be equipped by every 50 feet to detect accidents with pipes
  - Crack detection sensors for Utilidor mainframe, gas pipe, water pepe and steam pipe, and power cable default detection system should be equipped by every 50 feet to effectively and efficiently monitor utility lines' status to make more efficient maintenance and repair feasible

Construction Cost Assumptions

- **Hangers (shelves) to support utilities**
  - We calculated the length in feet of the utilities that would be accommodated. We assume that the utilidor will need hangers running the length of the utilidor down each side
- **Ventilation**
  - The Utilidor should be equipped with ventilators every 50 feet
- **Backfill cost of soil**
  - Utilidor is assumed to be installed at 15 feet depth
  - In terms of excavating, backfilling and resurfacing, it is assumed that 10 feet wide is enough considering 5 feet width of Utilidor
  - Under Beekman street and Park Place, assuming 4 inches depth of asphalt and 6 inches depth of concrete under asphalt.
  - Under City Park, all of the 15 feet depth should be backfilled by soil.
- **Backfill cost of concrete and asphalt**
  - Utilidor is assumed to be installed at 15 feet depth
  - In terms of excavating, backfilling and resurfacing, it is assumed that 10 feet wide is enough considering 5 feet width of Utilidor
  - Assuming 4 inches depth of asphalt and 6 inches depth of concrete under asphalt

Construction Cost Assumptions

- **Contingency Cost Estimation**
  (Applied to Utilidor Construction / Transporting Utilidor/ Relocating Utility / Installation / Resurfacing and Backfilling)

  Because it is required to ask the construction company to execute, additional cost is necessary for every cost listed above. The additional costs are design contingency (15%), general conditions (15%), overhead and profit (20%), permits cost (2.5%), bonds and issuance (contingency cost; 1.5%), and escalation adjustment.

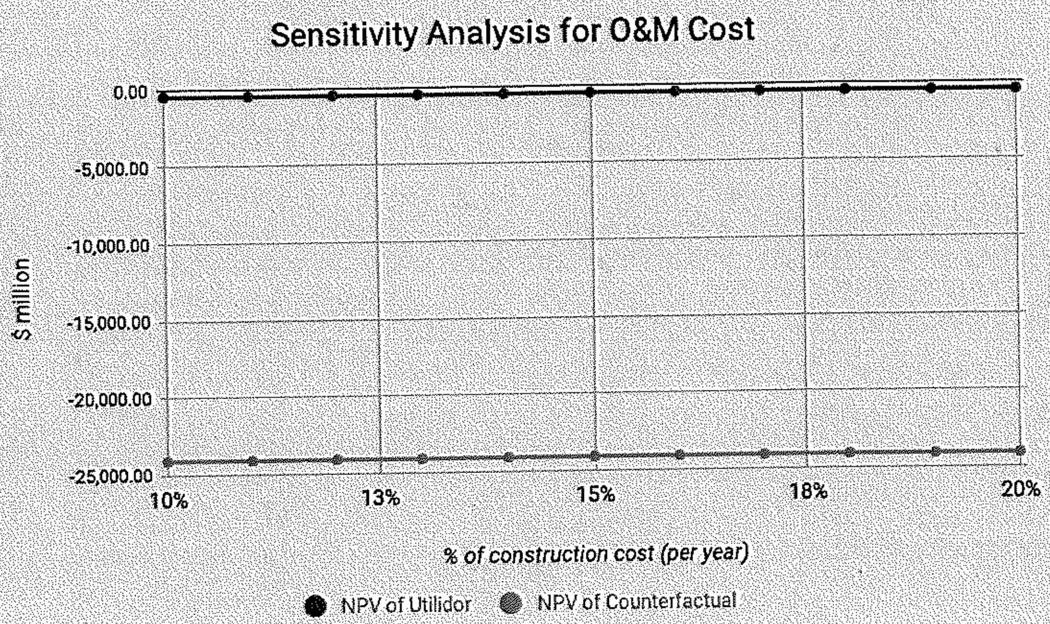
  Escalation adjustment is the process in which each cost will be increased according to how long the period (period A) is, from the beginning of Utilidor project to the midpoint of each operation. For example, in terms of transporting Utilidor to NYC, it is assumed that the transportation process initiated 6 month later from the beginning of the project and it takes 18 months. Therefore, period A is 15 months. In this case, assuming that inflation cost is 4%, escalation cost is 5.12%. All of the costs is adjusted by this process.

- **Operation and Maintenance Cost**

  It is assumed that operation and maintenance cost per year is 10% of total construction cost.

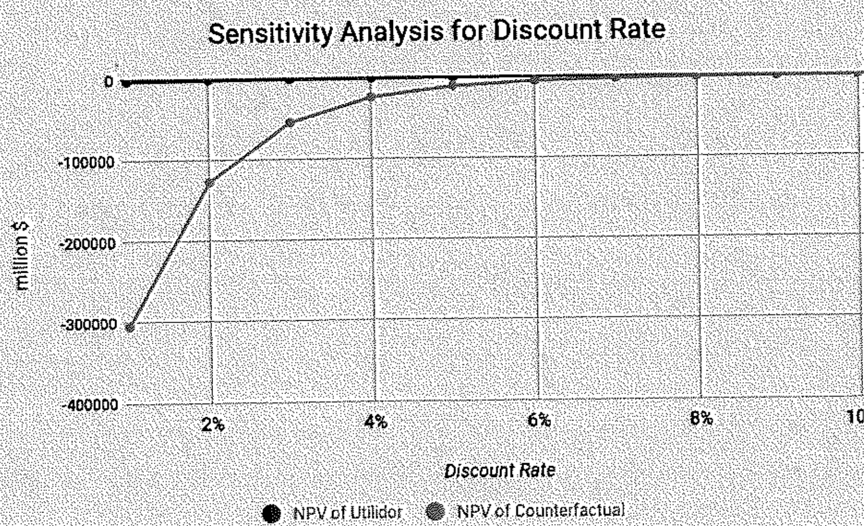
SENSITIVITY ANALYSES

Sensitivity Analysis for Utilidor O&M Cost



Sensitivity Analysis for Discount Rate

	NPV of Utilidor	NPV of Counterfactual
1%	-2,044,309,524	-304,605,984,986
2%	-1,072,037,042	-127,148,224,411
3%	-634,948,150	-54,497,912,230
4%	-429,514,163	-24,126,948,228
5%	-327,731,026	-11,127,959,514
6%	-274,116,019	-5,410,946,773
7%	-243,871,926	-2,814,584,925
8%	-225,528,977	-1,589,219,588
9%	-213,575,026	-983,530,330
10%	-205,247,122	-667,278,408



FINANCING MODEL DETAIL

| Revenue Credit Financing Model

- Bond term: 15 years / Interest rate: 4%
- The useful life of Utilidor is 100 year (2121)
- SCIA collects user fees on a fixed rate every year

Project Year **Actual Year**	7 **2027**	8 **2028**	9 **2029**	10 **2030**	11 **2031**	12 **2032**	13 **2033**
6320 bond interest payment	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35		
6320 bond principal payment	0	0	0	0	$27,576,967.09		

Revenue Bond Issuance: $34,471,208.87

Bond Coupon payment	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35	$1,378,848.35
Maintenance & operation cost	$516,683.57	$537,350.91	$558,844.95	$581,198.75	$604,446.70	$628,624.57	$653,769.55
Total cost	$1,895,531.93	$1,916,199.27	$1,937,693.30	$1,960,047.10	$1,983,295.05	$2,007,472.92	$2,032,617.90

Total Capital Cost: $557,819,804.42 SUM of 2027 (Year 7) ~ 2121 (Year 100)

Divide Total Capital Cost by the rest of Utilidor Service Life **User fee needed per annum**	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24	$5,934,253.24

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