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Transitioning into Lifecycle Cost Analysis

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TABLE OF CONTENTS

Executive Summary	4
Lifecycle Cost Analysis.....	4
Assessment of Externalities	5
Looking Ahead.....	6
Introduction	7
Background of NYCDOT’s Sustainability Agenda.....	7
Purpose	8
Overview of Lifecycle Cost Analysis	8
Lifecycle Cost Analysis.....	8
Design, Material and Construction Costs.....	9
Maintenance Costs.....	9
Rehabilitation Costs	10
User Costs	10
Serviceable Life and Salvage Values.....	11
Analysis Period	11
Discount Rate	12
Sensitivity Analysis	13
Application of Lifecycle Cost Analysis to DOT Projects	13
Lifecycle Costing Calculation	14
Initial Cost	15
Maintenance Cost	16
Discount Rate	16
Analysis Period and Material Lifespan	16
Limitations in Applying Lifecycle Cost Analysis to DOT Projects.....	19
Projects Actual Cost	19
Maintenance Cost	19
Material Lifespan and Serviceable Life.....	20
External Benefits of Sustainable Streetscape Projects.....	21
Identified Benefits of Sustainable Streetscape Projects.....	21
Benefits Matrix Database.....	22
Conclusion.....	30
Looking Ahead.....	30
Appendix A DOT Material/Treatment Comparison	32
Appendix B DOT Material/Treatment Benchmark Costs	34
Appendix C DOT Material/Treatment Lifespan & Maintenance.....	35
Appendix D Benefits Matrix Database	36
Appendix E LCCA Template West Houston	38

Appendix F Full Report on Chicago..... 39
Appendix G Full Report on London 48

EXECUTIVE SUMMARY

The New York City Department of Transportation (NYCDOT) has taken great strides toward utilizing more sustainable materials in the design and construction of NYC streets and public places. Through rigorous evaluation, design elements are valued in terms of durability, quality, and cost for potential use in upcoming street projects. Various mechanisms are in place to evaluate projects for these conditions, but these systems generally do not consider the full lifecycle costs of materials or positive externalities due to design. Without considering these two issues, it is not possible to have a comprehensive understanding of which elements perform best, are most cost-effective in the long-term, and provide the most benefits to the tax-paying public. Therefore, NYCDOT wishes to consider use of a more holistic way of costing materials, taking into account full costs over the lifespan of a material, as well as assessing positive externalities not represented in the cost.

Working with NYCDOT, the Capstone team set out to answer the following questions:

1. Is the use of upgraded materials in streetscape projects more cost effective in the long-term than their standard counterpart?
2. Do the upgraded materials add additional external benefits not captured in the lifecycle cost analysis?

The Capstone team conducted quantitative and qualitative research that examined the comprehensive costs and benefits of various design elements used in NYC streetscape projects. Taking into consideration the full lifecycle costs and external benefits of each element enables better judgment-making about which products and designs are most cost-effective for the taxpayer in the long-term. This helps NYCDOT better understand how various materials perform in relation to comparable materials (e.g. granite versus concrete), and if the products and designs have positive externalities not currently recognized in the planning process by financial analysis. In addition, to supplement the lifecycle cost analysis and to account for external benefits not recognized in the cost of a project, the Capstone team created a template for lifecycle costing analysis and a supplementary benefits matrix database.

Lifecycle Cost Analysis

The research begins by exploring lifecycle costing in general terms and investigates the necessary data needed to conduct a lifecycle cost analysis. Lifecycle cost analysis (LCCA) allows departments of transportation to evaluate the costs of owning and operating a project over the project's entire lifetime, including design, construction, maintenance, rehabilitation and salvage costs. This enables agencies to make more informed decisions by revealing potential projects with the lowest long-term cost, and making investment decisions based on costs over the lifespan of a project as opposed to one-time, upfront project costs. Ultimately, this type of analysis ensures taxpayer dollars are spent wisely.

The team applied LCCA to four recent NYCDOT projects with the goal of determining which project designs prove the most cost effective in the long-term. The analysis compared upgraded materials and designs for each of the four NYCDOT projects, to their standard counterparts.

Data on design, construction, maintenance, and rehabilitation costs and salvage values is required to conduct LCCA. Much of this data is difficult to gather, as municipal agencies are not organized to collect such data with this use in mind. Some figures are reported in aggregate and other figures are not available. This proved a significant barrier for conducting LCCA on NYCDOT projects.

Specifically, NYCDOT did not have data on maintenance costs and material lifespan for the specific materials used in the analysis. NYCDOT does not establish a maintenance plan for streetscape projects in the planning phase so this data was not available. One difficulty in determining the lifespan of materials, especially in NYC, is the system whereby roadways are cut and compromised by utility companies. Beneath NYC streets lies an intricate web of utility lines, including electrical lines, water mains, and communication cables; access to these utilities necessitates cutting into the street surface. Non-emergency utility work is done through a permit process, and the repair of the roadway is the responsibility of the utility operator. Unfortunately, this repair work significantly compromises the lifespan of the roadway, making it difficult for NYCDOT to predict roadway lifespan with a high degree of certainty.

Due to these limitations, the research team conducted LCCA with estimated data, providing a template by which a full LCCA can be conducted once accurate data is available. Though the findings do not provide results by which the research question can be answered, the findings are significant, providing NYCDOT with a clearer picture as to the data required to conduct LCCA.

Assessment of Externalities

The second part of the research focuses on the external benefits of materials and projects not captured in LCCA. Sustainable streetscape projects have many benefits—such as increasing safety for all commuters or reducing urban heat island effect—that are not currently captured by LCCA. Although some recent research has focused on quantifying these benefits, this type of analysis is in its infancy. This new research underscores the importance of acknowledging that these benefits have value.

The analysis evaluates the overall impact of streetscape projects through the lens of the following four benefits: safety, mobility/accessibility, environmental health and sustainability, and economic vitality. Research shows that several streetscape designs offer spillover benefits in each one of these categories. These external benefits are captured in a benefits matrix database based on research of current and past NYCDOT projects, street projects undertaken in other innovative cities, and a formal literature review. The benefit database also attempts to capture material and maintenance costs, and lifespan of these street designs. Additionally, the analysis is supplemented by an interactive scorecard that assigns a relative numerical value to each element based on how beneficial it is within the given categories of analysis. The benefits matrix database and the interactive scorecard provide a framework for a comparative analysis that will allow NYCDOT to consider benefits of elements beyond basic costing and LCCA.

The design elements that rank the highest on the scorecard, when combining the benefit categories, are Class I bike paths, curb extensions with vegetation, and planted medians. Class I bike paths are bike paths that are separated from the car traffic either by a barrier or by moving the parking lane. Class I bike paths score higher than Class II bike paths (Class II are bike paths not separated from vehicle traffic) because adding barriers increases safety and mobility. Planting greenery can improve environmental health and economic vitality. Adding vegetation to curb extensions and medians (design elements that provide safety and mobility benefits) increases stormwater absorption, decreases pollution, reduces urban heat island effect and provides aesthetic benefits that improve economic vitality. The deliberate selection of certain materials can also improve safety and environmental health. Asphaltic concrete roadways, porous asphalt, and porous concrete all scored high. Porous materials reduce stormwater runoff and asphalt provides environmental benefits as it is made from recycled asphalt. These design elements and materials add the most benefit for the public in terms of safety, mobility/accessibility, environmental health and sustainability, and economic vitality.

Looking Ahead

The data required to conduct LCCA, specifically lifespan and maintenance costs and schedules, are not currently collected by New York City agencies. Although an analysis can be conducted using estimates for missing data for informative or experimental purposes, using actual costs will provide a true understanding of the cost differentials between standard and upgraded materials and designs in the long-term.

For NYCDOT to effectively conduct LCCA in the future it is recommended that:

1. Data be collected through a centralized and categorized system;
2. A maintenance plan be incorporated into the planning process of projects;
3. Street construction permit processes are reassessed;
4. Data be reported in line item format, not in aggregate; and
5. Inter-agency cooperation is increased.

INTRODUCTION

Background of NYCDOT's Sustainability Agenda

On Earth Day 2007 Mayor Bloomberg announced PlaNYC¹, a plan to create a greener, greater New York City by the year 2030. The plan seeks to address the needs of a growing population, an aging infrastructure, the decreasing quality of our air, water and land; and the effects of global climate change. The mandate to deliver on the goals of PlaNYC falls on many city agencies including the New York City Department of Transportation (NYCDOT). NYCDOT's mission "is to provide for the safe, efficient, and environmentally responsible movement of people and goods in the City of New York and to maintain and enhance the transportation infrastructure crucial to the economic vitality and quality of life of our primary customers, City residents²." Included in PlaNYC are several transportation initiatives that fall under NYCDOT's mission including bus rapid transit, improved pedestrian paths and bike lanes. In 2008 DOT released Sustainable Streets 2008 and Beyond³ a strategic plan outlining the steps NYCDOT would take to ensure the success of the objectives outlined by PlaNYC, not the least of which was to transform NYC "streets and squares into more people-friendly places⁴."

Additionally in 2008, NYCDOT released World Class Streets: Remaking New York City's Public Realm. This report contains findings from a Ghel Architects public life survey that quantifies how New Yorkers use the streets⁵. The survey found pedestrian traffic in New York far exceeds that of other world-class cities such as London, Sydney and Copenhagen yet many of the sidewalks are overcrowded much of the day creating problems for safety, commerce and accessibility. The report outlines projects that would move NYC to the forefront of public space design. Some of the projects included in the World Class Streets report are: Plaza Program, World Class Boulevards, Complete Streets Projects and Design Standards; New Streetscape Materials; and Weekend Pedestrian and Cycling Streets⁶ among others. The Street Design Manual, released in 2009 by NYCDOT, is a comprehensive guide detailing the policies, street designs, and materials NYCDOT will use to implement these plans.

Under the leadership of Janette Sadik-Khan, NYCDOT has taken significant steps, with regard to planning, design and construction, towards realizing the ambitious, forward looking agenda set forth in PlaNYC. Implementing these plans requires city agencies to recognize the long-term benefits streetscape projects can provide future generations.

Currently, NYCDOT capital projects are reviewed based on their upfront costs, with little regard given to maintenance and operations expenditures. By reviewing these costs, NYCDOT will be better poised to make decisions based on the long-term investment costs rather than upfront costs, which do not capture many of the financial benefits provided by sustainable streetscape projects.

Additionally, sustainable streetscape projects provide external benefits not currently considered in formal reviews of NYCDOT capital projects. These benefits fall into the following categories: safety, mobility/accessibility, environmental health and sustainability, and economic vitality. An analysis that incorporates the economic, environmental and social benefits of

project alternatives (both standard and sustainable projects) will help municipalities choose the best investment for the taxpayer in the long-term.

As NYC moves towards creating a greener, greater NYC, it is important that projects are evaluated based on their long-term costs and benefits. Simply looking at the upfront costs of streetscape projects does an injustice to future generations, as what appears to be the least expensive solution today, may not prove to be the least expensive solution in the long-term.

Purpose

Working with NYCDOT and New York City Department of Design and Construction (DDC), the Capstone team set out to answer the following questions:

1. Is the use of upgraded materials and designs in streetscape projects more cost effective in the long-term than their standard counterpart?
2. Do the upgraded materials and designs add additional external benefits not easily captured by economic analysis?

The first section of the report provides an overview of lifecycle cost analysis (LCCA), a tool for analyzing the economic costs of a project over its serviceable life. In the following section, LCCA is applied to four recent NYCDOT capital projects, demonstrating the potential strength of LCCA in reviewing the comprehensive costs of owning and operating a project over time, as opposed to the current practice of analyzing only upfront costs. The applied LCCA provides a template by which NYCDOT can conduct LCCA when evaluating capital projects in the future.

The next section of the report examines external benefits through the development of a benefit matrix database and a benefit scorecard. These tools evaluate the overall impact of streetscape projects through the lens of the following four benefit categories: safety, mobility/accessibility, environmental health and sustainability, and economic vitality. The findings presented by each tool are based on research of current and past NYCDOT projects, street projects undertaken in other innovative cities, and a formal literature review.

Finally, the report provides concluding thoughts, discusses the specific limitations faced when applying LCCA to NYCDOT projects, and the steps NYCDOT and other agencies could take in order to successfully conduct LCCA in the future.

OVERVIEW OF LIFECYCLE COST ANALYSIS

Lifecycle Cost Analysis

With an increasing focus on sustainability, it is important to evaluate capital projects in a more holistic way, assessing the economic, environmental and social benefits of project alternatives. LCCA is a step in that direction. While LCCA does not capture the environmental and social benefits of project alternatives, it does evaluate the economic benefits.

LCCA analyzes the direct costs of constructing, owning, operating and ultimately disposing of a potential capital project. In doing so, LCCA compares the overall long-term economic efficiency of alternative capital investment projects,⁷ as opposed to evaluating projects based solely on their upfront costs. To do this, LCCA examines the following costs over a specified analysis period: design, construction, maintenance, rehabilitation and user costs, serviceable life and salvage values. By analyzing the value of these costs over time, as opposed to comparing upfront expenditures taking place at one point in time (usually capital expenditures at the beginning of a project), the full costs of competing projects can be compared, thus informing investment decisions by revealing the project with the lowest long-term cost and best value. This type of analysis is important because the project with the lowest long-term cost will prove the best investment for the taxpayer.

LCCA is not a new concept. The National Highway System (NHS) Designation Act of 1995 requires that States conduct LCCA on all NHS projects costing over \$25 million⁸. In 1998 the Federal Highway Administration (FHWA) produced the Demonstration Project 115, "Life-Cycle Cost Analysis in Pavement Design," which resulted in a technical bulletin, an LCCA training program, and an LCCA software tool to be used by State Departments of Transportation when evaluating highway projects.⁹ The software tool is called RealCost, is available for free via download, and helps State Departments of Transportation conduct LCCA on various pavement options in accordance with FHWA's established best management practices. The practices established by the FHWA provide a valuable framework by which municipal departments of transportation can conduct LCCA when evaluating major infrastructure project alternatives.

As recommended by FHWA, LCCA should be conducted in the early stages of project planning. Since the main purpose of LCCA is to compare the costs of competing projects over time, the first step is to establish the alternative projects to be analyzed and collect data on the following variables: design, material, construction, maintenance, rehabilitation and user costs, serviceable life and residual values.

Design, Material and Construction Costs

Design costs are comprised of the costs associated with designing a streetscape project. These costs include planning in accordance to the city's design policy, actual project design, working with stakeholders, feasibility and road usage studies. Material costs are comprised of the costs of materials for the streetscape project. These costs are important because there is often significant variation between the quality and cost of different materials. Construction costs include the labor (construction manpower and traffic attendants) and equipment costs of completing a project.

Maintenance Costs

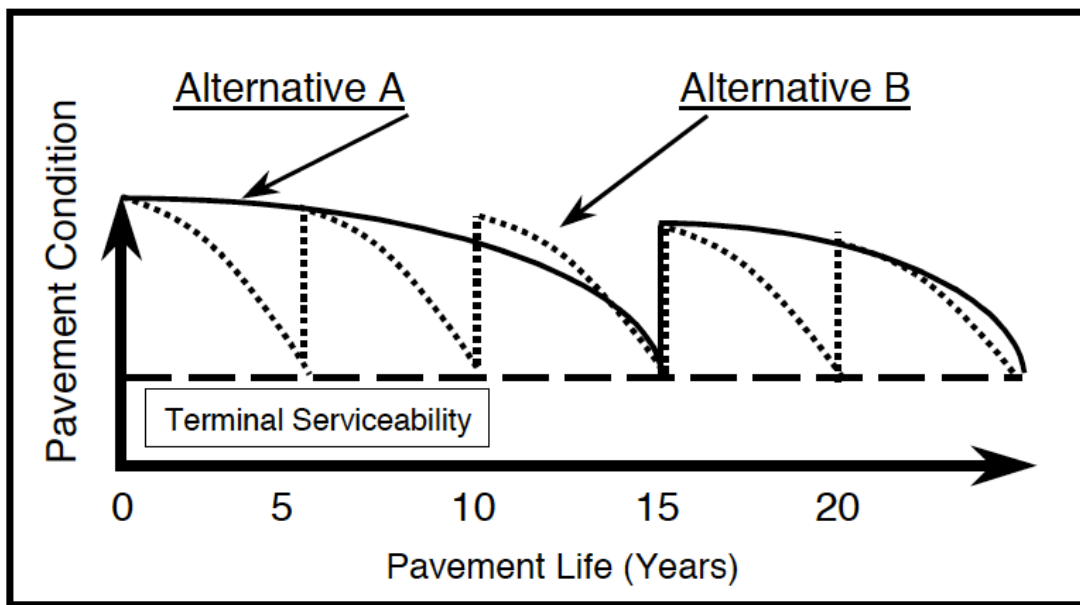
A major component of LCCA is the maintenance cost of the treatment alternatives. In order to realize the full lifespan of the material, it must be regularly maintained in accordance with manufacturer's specifications. In order to analyze whether a material used is more cost effective when compared to an alternative, a thorough upfront analysis of the maintenance

cost is essential; some materials may require more frequent and expensive maintenance than others. Without accounting for maintenance costs and timing, the analysis will merely be assessing the initial costs of the materials and therefore will not be examining the full costs through LCCA.

Rehabilitation Costs

Rehabilitation costs are those costs associated with doing a major re-build of a capital asset. For example, if a project has a lifespan of 20-years, after 10-years of use, it may require a major rehabilitation. This may consist of the replacement of the top layer of asphalt as well as major repairs to curbs. Some materials may require fewer rehabilitation activities over their lifespan. As seen in Figure 1, Alternative A has a longer time period between rehabilitation activities than Alternative B. Depending on the cost of these rehabilitation events, Alternative A may prove more cost effective in the long-term, even if its upfront costs are more than Alternative B. As such, the cost, timing and frequency of rehabilitations are an important variable when considering the full costs of a capital investment.

Figure 1



Rehabilitation Timings for Project Alternatives¹⁰

User Costs

User costs are those costs incurred by the streetscape user over the life of the project. User costs fall into two categories, those incurred during *normal roadway operation* and those incurred during *work zone operation*¹¹. An example of reduced normal operation user costs would be the reduction in crashes caused by a traffic calming project. Or, if a project uses a type of pavement that is smoother, causes less wear and tear on automobiles' tires and increases fuel economy, this cost could be incorporated into the analysis. Work zone operation user costs consist of the delay, vehicle operating (gas, wear and tear), and crash costs incurred

by users of a roadway. In an ideal scenario, both normal roadway operation and work zone operation user costs would be reliably quantifiable and taken together, would encompass user costs included in LCCA. Though currently, this type of data is not reliable and difficult to attain.

Serviceable Life and Salvage Values

Another important yet difficult to reliably quantify aspect of LCCA – especially for urban roadway projects - is the serviceable life and salvage values. Serviceable life should be calculated for materials that will have a useful life remaining at the end of the analysis period. For instance, if option A has a serviceable life of 5 years at the end of the analysis period and option B has a serviceable life of 10 years at the end of the project yet the serviceable life is not taken into account – all other variables being held constant - the analysis will inaccurately favor option A¹². In order to calculate a value for the serviceable life of a material it is necessary to know the lifespan of the given material.

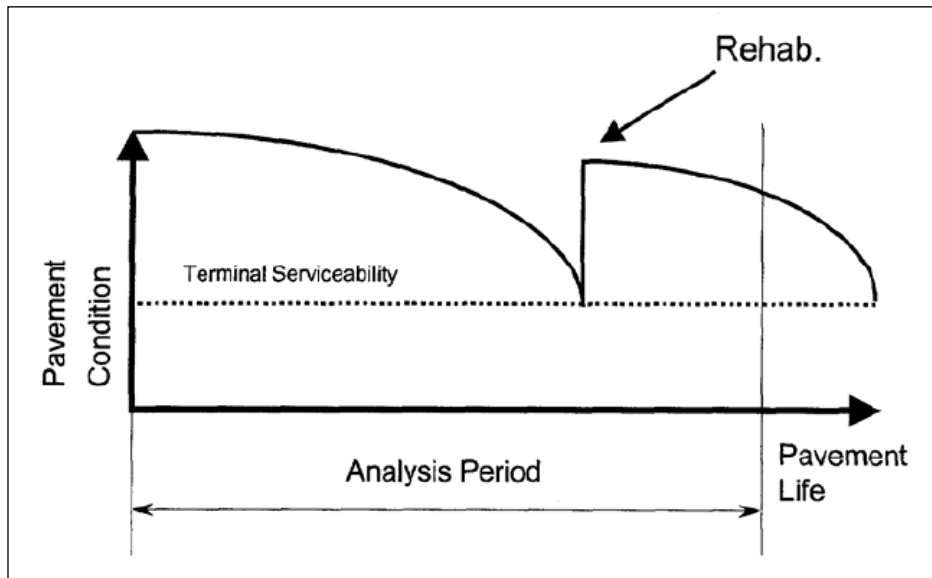
The lifespan of the roadway is dependent on where it is located. Variables such as usage, road construction, and weather play a major role in a material's lifespan. A roadway does not only suffer from normal wear and tear, but at any given time within the roadway's lifespan, the roadway may be compromised by construction. In urban areas there are several layers of public utility lines (e.g. electrical lines, water mains, communication cables, etc.) located beneath the streets. In order to repair or maintain utilities, the utility companies must gain access to these lines by cutting into the roadway. If the road is not repaired to the highest standards – generally the responsibility of the utility agency – the lifespan of the roadway can be significantly compromised. If maintenance plans are not followed or roadways are compromised due to utility cuts and repair work, the lifespan of streetscape projects can be significantly compromised. A misestimated lifespan will lead to inaccurate estimates for serviceable life when conducting LCCA.

Salvage values consist of the net value of recycling materials¹³ at the end of the project's life. The serviceable life and salvage values of roadway projects prove difficult to project as these values could change considerably over the analysis period.

Analysis Period

Once the data on the aforementioned costs are collected, the next step is establishing an analysis period. The analysis period should reflect a period long enough to capture the full costs and benefits of each infrastructure design being examined. The analysis period must be the same for all alternatives being considered, should be long enough to include a rehabilitation activity, but shorter than the expected lifespan of the project, as shown in Figure 2. FHWA recommends a period of at least 35 years¹⁴ but it is reasonable to use shorter periods depending on the project. Urban areas may benefit from examining shorter analysis periods to account for shorter lifespan due to high traffic volumes, poor maintenance plans and frequent utility cuts.

Figure 2



Analysis Period for a Pavement Design Alternative¹⁵

Discount Rate

Because LCCA examines benefits and costs over time, specifically costs incurred at different times, the discount rate is an extremely important factor. In order to compare the costs and benefits of a capital project over time it is necessary to convert the costs and benefits to a value at the same point in time. This conversion is done using discount rates. The FHWA Technical Bulletin recommends using a discount rate that reflects historical interest rate trends over a long period of time.¹⁶ Based on this, many states have recently chosen a discount rate of 4% when conducting LCCA on capital highway projects (WSDOT, 2005; Florida DOT, 2005; MoDOT, 2004)¹⁷.

The discount rate represents the foregone future rate of return on an investment (or opportunity cost) of investing in one project versus another. Assumptions about future investments must be made in order to choose a discount rate for the analysis. If a chosen discount rate is too low, the calculated future cost will be exaggerated and reflect more than what it might potentially cost; if the discount rate used is too high, it understates the cost of an investment. Using high, medium, and low discount rates is beneficial to the analysis since it provides parameters by which to compare various scenarios¹⁸.

Table 1 - Average and standard deviation values for published US OMB rates.¹⁹

Parameter	3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
Average	3.3	3.6	3.9	4.2	3.1	4.5
Standard Deviation	1.2	1.3	1.3	1.4	1.0	1.4

Table 1 lists the average US OMB rates for various time parameters over the past 28 years. For instance, if using a 30-year analysis period, the average (over the past 28 years) discount rate recommended by the US OMB was 4.5%, give or take 1.4%. Over the past few years, based on Appendix A of the US OMB Circular A-94 (a federal government publication that lists real treasury interest rates) discount rates have dipped. FHWA recommends using a real discount rate of anywhere between 3% and 5%. In addition, the US OMB suggests using a 7% discount rate, as in recent years the private sector has earned an average marginal pretax rate of return on investment of 7%.²⁰

Sensitivity Analysis

Due to the limitations of some of the assumptions involved in LCCA, specifically the analysis period and the discount rate, it is recommended that a sensitivity analysis be conducted. Sensitivity analysis is helpful for investigating questions such as: is the discount rate chosen appropriate? Or, is the analysis period too short/too long? To help provide a clearer picture on the impact these variables have on the results, LCCA is conducted for various discount rates and analysis periods and the results of each analysis are compared.

APPLICATION OF LIFECYCLE COST ANALYSIS TO DOT PROJECTS

Overview

The LCCA calculation comprises several input variables. The essential next step in the research is to gather these variables and apply the theoretical LCCA framework to specific DOT projects. In its attempt, the team was confronted with data limitations. Since much of the critical data requires deliberate planning, collection, and monitoring, a number of significant variables were missing, specifically, maintenance costs and useful material lifespan. Without these costs, a meaningful LCCA analysis could not be conducted. Instead, a template is provided for NYCDOT for future use to conduct an LCCA comparative analysis when data is available.

Process

NYCDOT provided information on three completed street design projects: Kingsbridge-Fordham, Sands Street, and West Houston Street, and one upcoming (not yet completed) street design project: East Houston Street. These specific projects were chosen because they encompassed designs with identified spillover benefits not measured by LCCA. East and West Houston were originally selected to conduct a comparative analysis on the differences in costing methods. These street projects included public space with and without vegetation, and Class II bike lanes. Kingsbridge-Fordham was chosen for its public plaza space with vegetation. Finally, Sands Street was selected for its Class I protected bike lane.

NYCDOT and Department of Design and Construction (DDC) provided all quantitative data (material cost, construction cost, and maintenance cost) used in the calculation. All data are adjusted to fit the variables used in the LCCA formula. Project costs are calculated using upgraded cost figures as well as the standard cost figures—this would be the basis of the

comparison analysis. Once the costs of the projects are calculated, the costs are then discounted to present value in order to compare the costs.

During the initial breakdown of the data, limitations became apparent. Several materials lacked specific maintenance costs and useful material lifespan needed to conduct the LCCA calculation. In order to supplement this missing data, a wide research scan was conducted. This involved reaching out to experts in the field, contacting street contractors, and scouring research articles and transportation journals. Unfortunately, the search yielded similar results of null datasets. This lack of critical data resulted in the inability to conduct a meaningful LCCA.

To contribute to NYCDOT's investment and research in LCCA, the team created an LCCA template. This template extracts data from previous projects and calculates the Net Present Value of a given street design. It then adds an annuity factor to account for different material lifespan. The template allows NYCDOT to compare the cost of using standard versus upgraded materials over a certain time horizon. The following section describes how a basic LCCA can be applied to these projects.

NYCDOT Data Methodology

Analysis Framework

After gathering data, the first step requires segmenting the data into analysis groups. Each of the four projects are broken up in to two design categories: upgraded design and standard design. The majority of the materials used in the projects are upgraded materials (with the exception of Sands Street which used predominately standard materials in the street design). As such, the total cost of these street designs are assigned to upgraded design. For comparison purposes, standard material costs were substituted in to calculate the total cost if the project used standard materials. Assumptions for standard and upgraded materials are made based on the research and information from the NYCDOT Street Design Manual. Appendix A lists the assumptions.

NYCDOT and DDC provided benchmarks for calculating the standard costs of the various materials. The price is multiplied by the quantity used in each project. Appendix B shows a summary of the benchmarks used.

Lifecycle Costing Calculation

The formula for the LCCA cost (Figure 3) adds the initial cost to the rehabilitation cost of the project, and multiplies the sum by the present value factor (PV). The present value factor takes into account the current discounted value of the investment. Meaning, the calculation takes into consideration the time value of money—that a dollar today is worth more than a dollar in the future. The resulting figure is the net present value (NPV) of the project at the given discount rate and year of expenditure. The NPV is the sum of all the present value factors. To interpret the figure, the higher the NPV, the higher the cost of the project is.

The LCCA calculation requires four main variables: initial cost, rehabilitation cost, discount rate, and year of expenditure (otherwise referred to as analysis period.)

Figure 3

$$NPV = \text{initial cost} + \sum_{k=1}^N \text{Rehab cost}_k \left[\frac{1}{(1+i)^{n_k}} \right]$$

where:

i = discount rate

n = year of expenditure

$\left[\frac{1}{(1+i)^{n_k}} \right]$ = present value (PV) factor

Source: FHWA Report, Life-Cycle Analysis²¹

Using the formula variables a guide, the data is organized within each project into three sections: construction cost, material cost, and maintenance cost. Total cost of construction, materials, and maintenance cost were calculated for both upgraded and standard designs within each project. The following shows the calculation of formula variables:

Initial Cost	=	Construction Cost + Material Cost
Rehabilitation Cost	=	Maintenance Cost
Discount Rate	=	3, 5, 7 Percent
Year of Expenditure	=	Analysis Period: 20, 30, 40 years

Based on the data provided by DOT, the formula variables were defined as follows:

Initial Cost

The initial cost of a given project is defined as all costs associated with construction. More specifically, initial costs fall under these premises:

- Preliminary engineering – Any costs associated with preliminary items such as feasibility studies, permitting, engineering design and consultation²²;
- Contract administration;
- Initial construction;
- Construction supervision;
- Administrative cost;
- Furnishing, delivery and installation cost;
- Greenery cost;

- Materials cost;
- Any additional cost associated with the project's construction

This list captures the main variables used in initial costs, but specific line items can be inserted or removed based on the project's scope. It is important to note that user costs and salvage value would also be included under initial cost; however, for the purposes of this research, these variables are not included due to the complexity of calculating these figures.

There were discrepancies found when dissecting material costs. Bid costs were provided instead of actual costs for the completed project. By nature, bid costs are not accurate, nor do they reflect true estimates in costs. This was a limiting factor as it would be difficult to completely state the cost effectiveness of the material with analysis based on estimated costs.

Maintenance Cost

Maintenance costs of a given project are defined as the combined recurring maintenance expenditures for the materials used. The maintenance cost used in the calculation is calculated by multiplying the per year maintenance cost of the material by the quantity used in the project. Once the yearly figure is calculated, it is multiplied by the number of years in the analysis period. Maintenance costs are calculated based on data provided by NYCDOT and the DDC. Appendix C provides a summary of maintenance cost data provided by NYCDOT and DDC for select materials along with their estimated lifespan. The analysis primarily focuses on sidewalk pavement, street pavement, and vegetation. Within the four NYCDOT projects chosen for analysis, these three main materials lacked sufficient maintenance cost and lifespan data, thus LCCA on these materials was not possible.

Discount Rate

NYCDOT does not currently use a standard discount rate. However, other New York City agencies, along with Federal and State agencies, use a wide range of discount rates—ranging from .75 to 7 percent²³. Based on the research, using a range of 3, 5, and 7 percent discount rate is appropriate for this analysis, as it would yield an NPV using high, medium and low discount rates, providing a conservative to risky spectrum of analysis. If the discount rate chosen is too low (a conservative approach), the expense of the project will be exaggerated causing a project to look more expensive than it actually is. Alternatively, if the discount rate chosen proves to be too high (a riskier approach), the project will appear to be less expensive than it is in reality.

Analysis Period and Material Lifespan

The analysis period refers to the time period over which the street design is analyzed. It must be sufficiently long enough to capture the long-term cost differences and maintenance expenditures of the comparison materials. For the purposes of this research, the calculations used a time period of 20, 30, and 40 years. These analysis periods were assigned based on research suggesting various pavement alternatives had a lifespan of 20 or more years.

It is important to note the standard NPV calculation does not directly account for differences in lifespan between alternative materials. The template formula takes this deficiency into account by augmenting it with an adjustment variable for differences in material lifespan. This adjustment is then added to the initial cost. For example, if material A has a lifespan of 20 years and material B has a lifespan of 25 years, a value would be assigned to the additional 5 years of life of material B. This value would then be included in the initial cost portion of the calculation.

The additional lifespan analysis calculation is implemented to capture the savings of longer lasting materials. To capture the lifespan of a given material, the NPV is divided by an annuity factor (AF) for each alternative lifespan²⁴. The calculation for the AF is as follows:

$$AF = [((1+i)^N - 1) / i * (1+i)^N]$$

Where:

AF = annuity factor

i = discount rate

N = material lifespan

The annual equivalent NPV (AENPV) is calculated as $AENPV = NPV / AF$. By determining the AENPV, the benefits of using a material with a higher upfront cost but longer lifespan versus a material with lower cost but shorter lifespan, based on a yearly figure, can be analyzed.

Calculation Template

Once all variables are identified and the data is formatted, the calculation template automatically populates the initial cost, recurring cost, standard and upgraded NPV, and standard and upgraded lifespan calculation (AENPV). Figure 4 shows an example of a portion of the calculation template. Cells are color-coded as follows: blue cells relate to all upgraded cost data, yellow cells relate to all standard cost data, grey cells relate to discount rate, year of expenditure, and lifespan data. Assigned colors help identify formulas used within the cells; the blue and yellow cells represent formula cells. It is important to note the color does not express an analytical value.

An NPV was calculated for standard cost and upgraded cost at 3, 5 and 7 percent discount rates for each of the four projects. Figure 4 shows the calculations for a 20-year analysis period. A similar template was created to calculate NPVs at each discount rate for analysis periods of 30 and 40 years. In addition, this template automatically calculates a lifespan calculation when information is inputted in to those cells in order to account for variances in material lifespan. For example, Figure 4 shows a lifespan calculation when using a standard material with a lifespan of 20 years and an upgraded material with a lifespan of 25 years.

Figure 4

Design Element:		West Houston		
		3%	5%	7%
NPV: Standard Cost		\$ 9,362,443.53	\$ 6,373,055.84	\$ 4,369,765.70
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		20.00	20.00	20.00
One-Time costs:		\$9,990,016.22	9,990,016.22	9,990,016.22
Recurring Cost:		6,919,598.22	6,919,598.22	6,919,598.22
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Standard Material	20	\$ 629,303.27	\$ 511,390.49	\$ 412,474.97
NPV: Upgraded Cost		\$ 10,272,830.37	\$ 6,992,760.10	\$ 4,794,673.70
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		20.00	20.00	20.00
One-Time costs:		\$10,538,102.85	10,538,102.85	10,538,102.85
Recurring Cost:		8,015,771.48	8,015,771.48	8,015,771.48
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Upgraded Material	25	\$ 537,665.20	\$ 452,183.97	\$ 374,971.85
AE % Difference		-14.56%	-11.58%	9.09%

This is a sample calculation using loosely estimated figures for unavailable costs. This is not intended to represent actual figures from data provided.

Figure 4 shows an example output based on the data provided by NYCDOT and DDC. There are many data components missing, so the results shown above are not meaningful; however, the values can be used to illustrate the interpretation of the template results:

Based on the sample data provided, spreading the cost over a 20 year span, at 3% discount rate the standard cost of the West Houston project is about \$9.4 million while the upgraded cost of the project is about \$10.2 million; a difference of about \$800,000 more than the standard cost. The cost of the upgraded material accounts for a higher initial investment of the project. However, the lifespan of the upgraded material is 5 years longer than that of the standard material. Taking into account the lifespan of the materials, the upgraded design is more cost effective; it cost 14.56% less than the standard design over the 20-year period, a savings of \$91,000 per year.

The sample analysis is a simplified version of how to extract the data provided in the templates provided.

Due to major components missing from the dataset, a thorough analysis of the four NYCDOT projects could not be conducted. This has implications for answering the original hypothesis

question: is the use of upgraded materials more cost effective than the use of their standard counterparts? Despite the lack of quantitative data, a solid framework has been developed for future use. When maintenance costs and useful material lifespan data become available, NYCDOT can easily insert line-item data into the template to conduct a lifecycle costing comparative analysis.

LIMITATIONS IN APPLYING LIFECYCLE COST ANALYSIS TO DOT PROJECTS

There are several limitations to the research that were discovered when collecting and parsing out the data. The overall contributing factor is the way data is reported in NYC, which lends itself overall structural issues. This reporting method has implications on how data is managed, what variables are collected, and who collects the data. A maintenance plan must be put in place prior to the construction of the project in order to accurately collect and track this data.

Missing Variables

Projects Actual Cost

Data provided from DDC for Kingsbridge-Fordham, Sands Street, and West Houston were bid costs, as opposed to actual project costs. These costs are inaccurate and can lead to gross misinterpretation of findings. For example the cost of asphalt per square yard was stated to be \$0.01 for one project while in another report it was listed as \$15.00. While it is easy enough to supplement these costs through cross-referencing the materials used in other projects, the use of bid costs overall may introduce erroneous results.

Bid costs are quotes provided by the contractor to DDC. These bids do not accurately reflect the cost of materials, but instead are costed-out in a manner that frontloads expenditures. This practice is prevalent in the construction business for financial purposes; contractors want to ensure the cash flow can cover costs prior to the start of the project. Therefore, activities that occur earlier in the construction process, such as removing old material, are submitted with exaggeratedly high estimates. Consequently, activities that occur at the end of the construction process, such as laying down concrete, are exceptionally under-estimated. DDC evaluates all bid proposals and chooses the bidder that fits their criteria. DDC collects and tracks all bid, design, and construction costs. Therefore, prior to a streetscape project being complete, actual costs are unknown. While an analysis can be done using bid costs, it is important to understand that using noisy data leads to inaccurate analyses and conclusions.

Maintenance Cost

NYCDOT has limited maintenance cost data. Under the City Charter, (Section 1110-a) New York City agencies are required to compile an inventory of the major portions of its physical assets and to report on their condition annually²⁵. Assets to be included in this Asset Management Information System (AIMS) are ones with a replacement cost of at least \$10 million dollars and a useful life of ten years or longer. Agencies are also required to report on the share of needed capital and expense activities they are planning to undertake. The assets of several important

city agencies are excluded, as are smaller assets. Due to the large scope of the reporting requirements and the complexity of the various agencies, the figures reported are understood to be approximations. The data in AIMS are not detailed enough to inform investment decisions; to perform LCCA on capital projects, detailed line item maintenance projections are needed.

Part of the reason for lack of detailed data is because NYCDOT is not responsible for the maintenance of many street design elements. Often, after completion of a street project, the maintenance is taken over by a local private a company or a partnering agency. Because of this, it is difficult for NYCDOT to provide specific maintenance data for the materials used in the projects being analyzed. Similarly, outside sources, e.g., local construction vendors, construction journals, other city websites, and publications, were unable to supplement the maintenance cost data needed in order to conduct LCCA. Research yielded some data, but the numbers proved to be unusable. The figures found had already been manipulated to meet the agenda of the analyzing researcher and could not be disaggregated; other figures did not have enough supporting data available to extrapolate an average cost or percentage to use in the calculation.

Material Lifespan and Serviceable Life

Occasionally, other city agencies or private utility companies must cut the street in order to install or fix infrastructure they own. While this requires a permit from NYCDOT, the agency or utility is generally free to make these fixes as necessary, and cuts, repairs, and construction of this kind are fairly common. While these agencies are also responsible for paving or reinstating the street to its original form, this can shorten the lifespan of streets in ways that are not readily predictable in advance. As a result, lifespan data is very difficult to generalize across various locations within NYC.

Data Management

Currently, agencies across the city operate in silos. Data is sometimes, but not always, collected at the agency level, and disaggregated information sharing is not prevalent amongst public agencies and between private companies. The various tasks of maintaining streetscape projects are assigned to different agencies across the city, making the tracking of maintenance data difficult. Greenery and vegetation are delegated to the Department of Parks and Recreation, who are also responsible for maintaining and replanting trees. These costs are tracked internally in the department. Other responsibilities, such as maintaining plazas or street furniture, can be sold to private companies, or taken care of through business improvement districts, which also track the costs internally. To complicate matters further, sidewalks are maintained by property owners.

Because the data is fragmented across different agencies and companies, it makes it difficult to accurately track the information. While intra-city agencies are willing to share this data, it is reported in a disjointed fashion. Units are not always comparable or compatible. There is also no central agency responsible for the collection of data of streetscape designs from its

inception to its end. To move forward with an accurate LCCA, it is imperative for agencies to collect and keep track of all pertinent data needed to thoroughly analyze streetscape projects from beginning to end.

EXTERNAL BENEFITS OF SUSTAINABLE STREETSCAPE PROJECTS

While LCCA provides valuable information with regard to comparing the full lifecycle costs of project alternatives, streetscape designs and treatments provide additional benefits not captured by LCCA. Not only do designs offer utilitarian and functional benefits, but they can provide several spillover benefits, such as safety or environmental sustainability. The upfront costs of certain street designs could potentially be mitigated through the longevity of the material, the low recurring maintenance costs, or the additional environmental and social benefits offered.

While some advanced cost-benefit research attempts to quantify certain benefits, several assumptions need to be made that are often difficult to justify. However, in comparing street designs, it would be remiss not to evaluate these environmental and social benefits, as research shows they can provide other forms of savings, e.g., qualitative benefits to the taxpayer. This section serves to supplement the LCCA portion in an attempt to evaluate street designs in a more holistic manner. The information presented in this section is derived from a combination of an in-depth literature review, best practices from London's Bike Schemes, best practices from Chicago's Green Alleys program and Cermak/Blue Island Sustainable Streetscape Project, and data from NYCDOT and other supporting city agencies.

Identified Benefits of Sustainable Streetscape Projects

First, it is helpful to identify the categories of qualitative benefits present in sustainable streetscape projects. Mobility and accessibility, safety, economic vitality, and environmental health and sustainability are key benefits essential in evaluating the overall impact of various potential streetscape projects as it relates to NYCDOT's mission. As such, NYCDOT has produced several projects that are directly in line with these benefits. For example, an emphasis on bike lane development throughout the five boroughs addresses several parts of the mission. Other street designs that have been implemented, such as pedestrian plazas, the addition of street furniture, and vegetation also contribute to its mission.

Mobility and accessibility are paramount in urban planning, as there are equity implications for all users. An emphasis on mobility without consideration for access and other community and stakeholder needs does not sufficiently "balance environmental, scenic, aesthetic, cultural and natural resources, as well as community and transportation service needs."²⁶ There are tradeoffs when designing streetscape projects. An emphasis on moving motor vehicles through an area comes at a cost, i.e., less space for pedestrians and cyclists. All users of the roadway must be considered when planning projects, as well as the implications of tradeoffs based on transportation decisions.

Issues of *safety* extend to all streets users, including drivers, pedestrians, bikers, and public transit users. In 2008, 5,000 pedestrians were killed in the United States from traffic crashes, and 120,000 pedestrians were injured.²⁷ The same year, the number of bicyclists killed in traffic accidents rose 2.1 percent. Since 1995, more than 76,000 people have been killed in traffic collisions while doing simple, everyday activities such as crossing the street or walking in their neighborhoods.²⁸ Of these fatalities, children and elderly are overrepresented, and most of these occurrences happen on unsafe streets.²⁹

Environmental health and sustainability are becoming increasingly critical to combat urban heat island effect and other negative environmental forces, such as stormwater runoff. The EPA ranks urban runoff as the fourth largest contributor to the pollution of lakes, rivers and streams.³⁰ In NYC, combined sewage overflow is a large problem and contributes to the City's water pollution. Approximately 2 billion gallons of sewage overflow enters the City's waterways annually, and as a little as 0.1 inches of rain can cause combined sewage overflow.³¹ One of the pillars of PlaNYC is to ensure that the city's waterways are clean, safe and accessible to all. In addition, wastewater treatment is a huge consumer of energy. The electricity required to run the City's 14 treatment plants costs about \$50 million annually³². With increasing energy costs, CO2 emissions, and stormwater runoff, pavement choices (for instance, permeable pavement), bioswales, vegetation and trees can play a pivotal role in reducing the negative impacts of these environmental threats.

Economic vitality is a welcome and natural benefit since investing in complete streets has residual pay-offs for the community. In order to generate economic prosperity, access to safe neighborhoods needs to be created for people using all modes of transportations. These issues are all related to the quality of the environment and accessibility to multiple community interactions³³, or the livability of streets and communities.

Benefits Matrix Database

The team created a benefit matrix database and scorecard to capture relevant and important benefits vis-à-vis the identified economic, environmental and social benefits. It reveals the gradient of positive externalities received from each treatment or street design. The benefits exhibited in the matrix are derived from the literature review, research in outside cities—specifically London's Bike Schemes and Chicago's Green Alleys program and Cermak/Blue Island Sustainable Streetscape Project—and data from DOT and city agencies.

An adjoining scorecard provides an interactive tool where scores can be adjusted and different treatments can be replaced for comparison purposes. It provides a quantitative scale of benefits to accompany each of the design elements and treatments, and supplements the qualitative assessments from the matrix through a scaled scoring of each particular design/treatment. All scores were calculated on a scale between 0-3. 0 is given if the benefit is not evident, 1 if the benefit is mildly evident, 2 if the benefit is moderately evident, and 3 if the benefit is highly evident. Scoring assignments were based on relative benefits. For example, Class I bike lanes were given a 3 in safety while Class II bike lanes were given a 2 in safety. A median with no vegetation receives a total score of 7, while a planted median receives a score

of 11 due to the increase in safety, environmental sustainability, and economic vitality. This creates a comparative analysis that can be extrapolated for additional use by NYCDOT when comparing potential streetscape projects.

General qualitative assessments are outlined according to benefit categories. The matrix is intended to be a resource guide, and is not intended to be comprehensive of all designs and treatments, nor is it intended to be comprehensive of all benefits from each design/treatment. A more detailed analysis for each street design category is listed below and provides a more explanatory version of the information that informs the matrix. The DOT, DDC, and Parks and Recreation have provided all material costs, maintenance costs, and lifespan data unless otherwise noted. A snapshot of the matrix and scoring guide can be found below, and the full table can be found in the supplemental excel document.

Figure 5: Benefit Matrix

Qualitative Benefits for Treatments/Design Elements							
<i>General qualitative assessments are outlined according to benefit categories, material and maintenance costs, and lifespan. This matrix is not intended to be comprehensive of all designs and treatments, nor is it intended to be comprehensive of all benefits from each design/treatment.</i>							
Design Element/Treatment	Benefits				Costs		Lifespan
	Mobility/Accessibility	Safety	Environmental Health & Sustainability	Economic Vitality	Material	Maintenance	Years
Bikes							
Class I Bike Path	Improved bicycle mobility and accessibility	Strong improvement in cyclist and pedestrian safety; Helps reduce traffic speeds; on road bike lanes reduce accidents by 50%	Reduces energy consumption by increasing bicycle use	Increased foot traffic due to traffic calming; Decreased transportation costs for employees/customers now accessing area by bike	*n/a	*n/a	*n/a
Class II Bike Lane	Improved bicycle mobility and accessibility	Moderate improvement in cyclist and pedestrian safety; Helps reduce traffic speeds; on road bike lanes reduce accidents by 50%	Reduces energy consumption by increasing bicycle use	Increased foot traffic due to traffic calming; Decreased transportation costs for employees/customers now accessing area by bike	*n/a	*n/a	*n/a
Sidewalks & Medians							
Curb Extension/Neckdown	Improves pedestrian mobility for seniors / people with limited mobility	Improves pedestrian safety; Helps reduce traffic speeds; Shortens crossing distances;	May encourage more walking by establishing safer pedestrian environment	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales by 20-40%	*n/a	*n/a	*n/a
Curb Extension w/ Vegetation	Improves pedestrian mobility for seniors / people with limited mobility	Improves pedestrian safety; Helps reduce traffic speeds; Shortens crossing distances	Increases vegetation thus reducing pollution and urban heat island effect; Reduces negative environmental impact; May encourage more walking by establishing safer pedestrian environment	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales by 20-40%	*n/a	*n/a	*n/a
Median (no plantings)	Improves pedestrian accessibility in crossing the street	Improves pedestrian safety and helps calm traffic	--	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales by 20-40%	*n/a	*n/a	*n/a
Planted Median	Improves pedestrian accessibility in crossing the street	Improves pedestrian safety and helps calm traffic	Increases vegetation; increase water absorption reducing storm water runoff	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales 20-40%	*n/a	*n/a	*n/a
Standard Sidewalk	Standard pedestrian infrastructure	Standard Pedestrian infrastructure	--	--	\$8.13 SF for 4" Thick \$10.18 SF for 7" Thick	*n/a	15

Figure 6: Benefit Scorecard

Benefit Score						
All scores are calculated on a scale between 0-3. 0 is given if the benefit is not evident, 1 if the benefit is mildly evident, 2 if the benefit is moderately evident, and 3 if the benefit is highly evident.						
Highest possible score: 15						
Design Element/Treatment	Mobility	Accessibility	Safety	Environmental Health & Sustainability	Economic Vitality	Benefit Score
Bikes						
Class I Bike Path	2	1	3	3	1	10
Class II Bike Lane	2	1	2	3	1	9
Sidewalks & Medians						
Curb Extension/Neckdown	2	3	3	0	2	10
Curb Extension w/ Vegetation	2	3	3	2	2	12
Median (no plantings)	2	2	2	0	1	7
Planted Median	2	2	3	2	2	11
Standard Sidewalk	1	1	1	0	0	3
Vegetation						
Connected Tree Pits	1	0	1	2	2	6
Planted Area	1	0	1	2	2	6
Stormwater- Capturing Tree Pit(s)	1	0	1	2	2	6
Street Swale	1	0	1	3	2	7
Tree Pit	1	0	1	2	2	6
Plazas/Public Spaces						
Plaza/Public Space	2	3	2	2	3	12
Plaza / Public Space with Vegetation	0	3	2	3	3	11
Street Furniture- Benches	1	2	0	0	2	5
Materials						
Asphaltic Concrete Roadway	0	0	1	3	1	5
Bioswale	0	0	0	3	1	4
Granite Curbs	0	0	0	3	0	3
Granite Sidewalk	0	0	0	0	0	0
Imprinted Asphalt Roadway	0	0	0	0	1	1
Modular Cobblestone Roadway	0	0	0	0	0	0
Porous Asphalt Roadway	0	0	2	2	0	4
Porous Concrete Sidewalks	0	0	3	1	0	4

While it can be difficult for a street design or treatment to encompass all of these benefits, a few noteworthy street designs possess several of the five identified benefits. **Bike lanes, pedestrian plazas, extended sidewalks/neckdowns, and trees/greenery** promote traffic calming, improve overall safety, and boost economic vitality.

Bike Lanes

Mobility and Accessibility- The inclusion of bike lanes improves accessibility because it allows for multi-modal users to access the road. In urban areas, there is often limited space and compromises must be made (i.e. forfeiting vehicle traffic lanes) to provide adequate space for bike lanes. The use of “bike boxes” (commonly used in London, Amsterdam, and Potsdam, Germany³⁴) or areas at intersections where bicyclists can wait for traffic signals is an example of a measure that improves the mobility of bicyclists. Separated bike lanes provide the safest and most efficient use of the roadways for bicyclists, and also reduce pedestrian and vehicle interaction with bicycle traffic thus increasing safety and mobility for all users.³⁵

Despite the congestion charge imposed to decrease traffic in London, congestion has continued to increase over the past decade. Road construction and disruption has been partly to blame for this increase. The Barclay Cycle Hire scheme has become one of the quickest alternatives to

getting around central London by commuters who do not own a bike. According to a Transport for London (TfL) report, there was a 24 percent increase of bicycle flows in London since the launch of the Cycle Superhighway scheme.³⁶ In addition, the implementation of cycle routes for Barclay's Superhighway scheme increases mobility because the visibility of the bicycle roadways encourages more people to ride throughout London Boroughs.³⁷

Safety- Bike lanes provide a dedicated space for bicyclists to share the road with automobiles. It has been concluded that on-road bike lanes decrease the risk of injury from traffic accidents by 50 percent.³⁸ Bike paths that are separated by a guard or rail are safer than bike lanes with painted lines. Similarly, wider bike lanes offer more safety benefits than narrower bike lanes. The incorporation of bike lanes on streets does more than increase safety for bicyclists while giving them a designated place to ride; it calms traffic by making street space for cars narrower.³⁹ Another great improvement for bicyclists is designated traffic signals. This addition allows bicyclist to start ahead of vehicles, reducing the risk of collision due to turns.⁴⁰

London recently constructed a Bicycle Superhighway with improved road quality. Research from the Centre for Advanced Spatial Analysis at University College in London shows that the bike scheme has improved awareness and visibility of cyclists,⁴¹ resulting in high marks for safety. 60 percent of bicycle commuters felt safer due to improved quality road surface and roadside mirrors.⁴²

Environment Health and Sustainability – Bike lanes help promote sustainable practices by reducing energy consumption and increasing bike usage. This translates to less carbon emissions and consumption of fuel and gas.

The mayor of London is aiming to achieve a 60 percent reduction in London's Carbon Dioxide emissions by 2025.⁴³ The Cycle Superhighway scheme is correlated to the improvement of air quality measures and decreases in traffic and noise, particularly in congestion hot spots in London. The London Atmosphere Emission indicates that reduced emission of local and greenhouse gas pollutants are a result of changes in transportation innovations such as walking and biking. Many companies using the Bicycle Hire Scheme suggest they may also be helping London become greener, as well as helping to create a cycling revolution in the capital.⁴⁴

Economic Vitality – Accommodating all roadway users also increases economic vitality for commercial and retail businesses. A study conducted across 68 cities estimated that traffic congestion cost employers 4.5 billion hours a year due to employee delays. For employees, this equates to 6.8 billion gallons a year in unnecessary fuel consumption, for a combined total of \$78 billion wasted in traffic.⁴⁵ The availability of bike lanes can help alleviate this unnecessary fuel consumption.

The London Barclays Cycle Hire is a prime example of how bike lanes can boost economic vitality. It is not only recognized by residents, but is also recognized as a tourist attraction; this in turn has benefited the economy as new figures revealed businesses are benefiting from the Cycle Hire Scheme. Commuters have also benefited from the bike scheme as well: between 53

and 62 percent of commuters resorted to using the cycle scheme to save money.⁴⁶ Using the scheme is a substantially cheaper way of getting across town compared to using the subway and slightly cheaper than using the buses and driving (due to congestion charges).⁴⁷

Costs- Material and maintenance costs are currently unavailable.

Lifespan- Lifespan is currently unavailable.

Sidewalks and Medians

Mobility and Accessibility- Sidewalks are where citizens interact, walk, eat at outside cafes, window shop, and perhaps most importantly commute or wait for public transit. To facilitate these varied uses sidewalks must be appropriately designed, utilizing well-defined zones. These zones should include, but are not limited to: furnishing zones for transit stops or resting; throughway zones for clear pedestrian travel; frontage zones allowing for the safe entrance and exit of buildings; clearly marked driveway and alleyway crossings; safe placement of utility structures; pedestrian buffer zones for on-street parking; and landscaping.⁴⁸ For seniors and pedestrians with limited mobility, sidewalks and medians improve mobility and accessibility.

Safety- Sidewalks offer a protected space for pedestrians to travel. Designs that include curb extensions or neckdowns improve safety by reducing traffic speeds and shortening the distance pedestrians need to walk. Similarly, medians offer the same benefit of slowing down traffic speeds and shortening walking distances. Accident rates are 18 percent lower on narrower streets, less than 24 feet opposed to 48 feet wide, because of speed deterrence.⁴⁹

Environment Health and Sustainability – Sidewalks encourage walking, which reduces energy consumption. Sidewalks and medians with vegetation reduce pollution and urban heat island effect. Vegetation also reduces negative environmental impact and increases water absorption by reducing stormwater runoff.

Economic Vitality – One aspect of street design that boosts economic prosperity is expanding sidewalks and creating pedestrian roadways. Pedestrianism can increase retail foot traffic by 20 to 40 percent, which drives retail sales. Additionally, it can increase retail rents by 10 to 30 percent, which boosts property taxes.⁵⁰ Municipalities have recognized the importance of pedestrianism and its link to stimulating the economy. For example, Pittsburgh suffered from stagnant growth in its downtown area. To boost the sagging economy, Pittsburgh created a downtown pedestrian commercial district and identified pedestrianization as the key to economic success.⁵¹

*Costs—*Average borough costs for standard sidewalk materials are \$8.13 per square foot for 4" thick and \$10.18 per square foot for 7" thick. Material cost for other treatments and all maintenance costs are currently not available.

Lifespan – A standard sidewalk lasts 15 years. Lifespan for other treatments are currently unavailable.

Vegetation

Mobility and Accessibility- not applicable

Safety- Trees serve as visual aids and help reduce traffic speeds. Additionally, connected tree pits provide a barrier between pedestrians and traffic. Vegetation may also encourage more walking by establishing a safer pedestrian environment.

Environment Health and Sustainability – Increased vegetation reduces urban heat island effect, pollution, and negative environmental impact. The urbanization of cities has been associated with a steady increase in temperatures of about 0.25 to 2.00 degrees Fahrenheit per decade. With an increase in temperature, urban areas have also seen an increase in energy consumption as the use of cooling systems have become a part of daily life in an effort to compensate for the added heat.⁵² In 2007, the collective trees in New York City combat the urban heat island effect and offer a net energy savings (electricity and gas) of \$27.8 million, or \$47.63 per tree.⁵³

Along with the a reduction in heating effects, large trees have the benefit of reducing tailpipe emissions by transforming gas into oxygen and other natural gases, increasing pavement life by up to 60 percent as the shade provides a relief to the pavement expansion/contraction extreme heat causes, and increasing overall human health by providing a calming atmosphere in the area where trees are planted.⁵⁴ In 2007, New York City's forest reduced CO₂ 113,016 tons annually, equivalent to \$754,947 in savings. This translates to an average savings in CO₂ of \$1.27 per tree each year.⁵⁵

Trees and vegetation have the ability to absorb 30 percent of precipitation⁵⁶; this is water that never hits the ground and therefore doesn't add to stormwater runoff. In addition, of the water hitting the ground, trees absorb another 30 percent through their roots.⁵⁷ This absorption results in \$35.6 million in benefits for New York City, or \$61 per tree.⁵⁸ Connected tree pits provide additional benefits as it also improves tree health and decreases stormwater burden on sewers.

Economic Vitality – Adding green space, beautifying parks, and landscaping all contribute to the overall value and appeal of the public space. This in turn leads to higher property values and rent. For example, the development of Millennium Park in Chicago exponentially increased the value of its surroundings. The development of \$1.4 billion in residential buildings was directly associated with establishing the park. Additionally, the park has helped lift employment in Chicago, attract tourists, and gain tax revenue for the local government.⁵⁹ In New York, trees have increased annual property values by \$52.5 million, or \$89.88 per tree.⁶⁰

Costs – Material costs vary for planted areas. See supplemental excel document for specific detail. Maintenance costs for planted areas are \$3 per square yard. Material and maintenance costs for other vegetation are currently unavailable.

Lifespan – 80-100 years on average

Plazas and Public Spaces

Mobility and Accessibility- Public spaces offer access for both youth and adults. Zones that include furnishing zones for transit stops or resting, throughway zones for clear pedestrian travel, frontage zones allowing for the safe entrance and exit of buildings, clearly marked driveway and alleyway crossings, safe placement of utility structures, pedestrian buffer zones for on-street parking, and landscaping, can help increase mobility and accessibility.⁶¹

Safety- Plazas and public spaces can help reduce traffic speeds and promote traffic calming. A study conducted by the USDOT found 80 percent of pedestrians hit by a vehicle traveling 40 mph die. Simply by cutting the speed in half, only 5 percent of pedestrians hit by a car traveling 20 mph will die.⁶²

Environment Health and Sustainability – Open access to plazas and public spaces can reduce energy consumption. A recent PlaNYC study shows that pedestrian plazas in Time Square have been correlated with the improvement of air quality. Specifically, the amount of traffic related pollutants have decreased significantly prior to the installation of the plazas.⁶³ Additionally, plazas with vegetation reduce negative environmental impact, pollution, and urban heat island effect.

Economic Vitality – Plazas increase pedestrian foot traffic, which can lead to increased retail sales and retail rent. Plazas and public space also help improve traffic calming. Overall, a \$1 investment in traffic calming and road diets equates to a \$7.14 in return for the public.⁶⁴ Additionally, plazas with vegetation contribute to the overall public value. The beautification of plazas can attract visitors and pedestrians to area. Similarly, street furniture, such as benches, can attract visitors and pedestrians as well. This in turn can lead to higher retail rents and property value.

Costs – Material costs are currently not available. Maintenance costs for plazas with vegetation are \$3 per square yard. Maintenance costs for other public spaces are currently unavailable.

Lifespan – Lifespan for plazas and public spaces are currently unavailable.

Materials

In addition to differences in streetscape designs, certain materials offer varied benefits. The following illustrates important issues to note when selecting specific materials to create street designs.

Mobility and Accessibility - not applicable.

Safety- Different materials offer distinctive benefits to provide additional safety benefits for drivers and pedestrians. Benefits that help drivers include porous concrete and porous asphalt roadways, which reduce slick road conditions. Another benefit for drivers is asphaltic concrete

as it provides good friction and channels water to the curb. Bioswales can benefit pedestrians' safety by providing a barrier between pedestrians and traffic. Other treatments, such as thermoplastic roadway imprinting and imprinted asphalt roadway, visually define pedestrian areas. Roadway users also benefit from modular cobblestones as it can help calm traffic.

Environment Health and Sustainability – Materials differ in the way they benefit the environment. Materials, such as granite, have a long lifespan. This results in less waste and disposal of worn goods. Other materials intrinsically promote sustainability. For example, asphaltic concrete may be composed of recycle asphalt, while thermoplastic roadway imprinting preserves the existing asphalt below. Treatments such as bioswale, porous concrete sidewalk, and porous asphalt roadways decrease stormwater runoff. The high solar reflective index (SRI) pavements also help with energy efficiency. Lower wattage bulbs are required—250 watts instead of 440 watts—because of the reflective properties of the pavement resulting in an anticipated 49% energy savings below the baseline⁶⁵.

Economic Vitality – Materials can be used to enhance the surrounding space and environment. Treatments, such as bioswale include vegetation, which can increase surrounding property values. Visually appealing materials, such as granite, tinted sidewalks, imprinted asphalt, and cobblestone also help to increase the surrounding property value and attract visitors and pedestrians to the area.

Costs—Granite sidewalk material costs average \$197.50 per square yard; granite maintenance costs are not available at this time. Untinted concrete material costs \$8.13 per square foot for 4" thick and \$10.18 per square foot for 7" thick; maintenance costs are \$10 per square foot for 4" and \$12 per square foot for 7". Tinted concrete material costs \$9.76 per square foot for 4" thick and \$12.69 per square foot for 7" thick; maintenance costs are \$12.00 per square foot for 4" and \$16.00 per square foot for 7". Material costs for untinted steel-faced concrete curbs are \$73.00 per linear feet for Manhattan and \$58.00 per linear feet for other boroughs; maintenance costs are unavailable at this time. Material cost for asphaltic concrete roadway is \$227.00 per square yard; maintenance costs are \$0.08 per square yard. Material cost for porous asphalt roadway is currently unavailable; maintenance costs are \$0.08 per square yard.

Lifespan – Granite sidewalks and curbs lasts 100 years. Tinted and untinted sidewalks last 15 years. Asphaltic concrete roadways have a 7-year lifespan. Porous asphalt roadways have a 20-year lifespan. All other material lifespan are currently unavailable.

The above evidence underscores the importance of including benefits into evaluating street designs. These treatments and designs have the ability to promote traffic calming, improve environmental health, provide safety benefits, and boost economic vitality. By including these benefits into a holistic evaluation process, urban planners and city budgeters can have a better framework for their decision making process.

CONCLUSION

In a time when budgets are slim and spending is limited, LCCA can help determine where scarce public dollars should be allocated, ensuring the best long-term investment of taxpayer dollars. Furthermore, LCCA makes sense not only from a budget perspective but from a sustainability lens as well. City agencies are to be held accountable not only to stakeholders today but those in future generations. By comparing the full costs of owning and operating capital projects from cradle to grave, NYCDOT can ensure they are not unnecessarily burdening future generations. While one of the goals of this research - to determine whether upgraded materials in streetscape projects are more cost effective in the long-term - was not fully realized, valuable information regarding the steps needed in order to conduct LCCA was collected.

Looking Ahead

LCCA has the power to act as a valuable planning tool for project managers to use when requesting funds for capital and expense projects. However, LCCA is only as effective as the data inputted in to the calculation. Detailed data collection and tracking is a process often overlooked by city agencies. A productive first step would be for NYCDOT and other stakeholder agencies to begin centralizing and categorizing the data that is currently available. Once the processes are in place for tracking such data these agencies can begin collecting data not currently available, i.e., maintenance costs and lifespan.

Compromised roadway lifespan through utility cuts is a major problem facing many urban departments of transportation. It is currently one of the main topics for discussion in London. Currently, all utility work on Transport for London Road Network is required to have a permit prior to their commencement in order to ensure that essential work by utilities or third parties causes minimal disruption.⁶⁶ In an effort to discourage utility companies from breaking up the roadway for a longer period of time than necessary, the Mayor's Draft Transport Strategy has developed a procedure whereby utility companies pay a fee to rent the road for the time period of their work.⁶⁷ This is a promising strategy as it has the potential to encourage utility companies to coordinate their workflow in a way that may reduce the number of cuts they make, thus reducing the negative impact on the roadway lifespan. It also generates much needed revenue for TfL. Currently, in an effort to monitor the quality of roadway restoration, TfL repaints and resurfaces the roadways after utility work is completed.

Another example of strategies to reduce problems related to utility cuts is in Chicago where the Chicago Department of Transportation requires special permits for utility work taking place on their sustainable streetscape roadways. This additional gate-keeping role helps limit unnecessary cuts and also helps coordinate work between various utilities. Neither of these approaches addresses the problem of emergency utility work, but provides useful examples as to how NYCDOT could manage utility work differently in an effort to protect the integrity of their capital assets.

PlaNYC has set in motion an inter-agency effort to create a greater, greener NYC for future generations. In order for NYCDOT to realize its mission, as well as its role in achieving the goals

set out by PlaNYC, major inter-agency coordination must take place; NYCDOT cannot do it alone. In addition to the aforementioned importance of coordination amongst utility agencies and NYCDOT, the Parks Department, DDC, the Department of Environmental Protection, and OMB, to name a few, must work together to standardize the way in which data is collected and analyzed. The task forces organized under PlaNYC may be a good place to look for support in the development of such inter-agency data collection systems.

APPENDIX A

DOT Material/Treatment Comparison Table

Upgraded Design	Standard Design
4" CONCRETE SIDEWALK (PIGMENTED)	Unpigmented
4" CONCRETE SIDEWALK (PIGMENTED) (SAW CUT TYPE JOINTS)	Unpigmented
4" CONCRETE SIDEWALK (UNPIGMENTED)	Same
4" CONCRETE SIDEWALK ON EXISTING FOUNDATION (PIGMENTED)	Unpigmented
7" CONCRETE SIDEWALK (PIGMENTED)	Unpigmented
7" CONCRETE SIDEWALK (PIGMENTED) (SAW CUT TYPE JOINTS)	Unpigmented
7" CONCRETE SIDEWALK (UNPIGMENTED)	Same
ASPHALTIC CONCRETE MIXTURE	None
ASPHALTIC CONCRETE WEARING COURSE, 2" THICK	Same
ASPHALTIC CONCRETE WEARING COURSE, 3" THICK	Same
ASPHALTIC CONCRETE WEARING COURSE, TYPE I-4 MIX, 3" THICK	Same
CONCRETE BASE FOR PAVEMENT, 10" THICK (HIGH-EARLY STRENGTH)	Same
CONCRETE BASE FOR PAVEMENT, 7" THICK, CLASS B-32	Same
CONCRETE BASE FOR PAVEMENT, 8" THICK (HIGH-EARLY STRENGTH)	Same
CONCRETE BASE FOR PAVERS, 4" AND 7" THICK, CLASS B-32	Same
CONCRETE CURB	Same
CONCRETE CURB (22" DEEP)	Standard concrete curb
CONCRETE CURB, MOUNTABLE (21" DEEP)	Same
CONCRETE CURB, MOUNTABLE (22" DEEP)	Same
CONCRETE HEADER (8" WIDE X 10" DEEP)	Same
CONCRETE IN STRUCTURES, CLASS A-40	Same
CORNER STEEL FACED CONCRETE CURB (20" DEEP)	Standard concrete curb
CORNER STEEL FACED CONCRETE CURB (22" DEEP)	Standard concrete curb
DEPRESSED STEEL FACED CONCRETE CURB (20" DEEP)	Standard concrete curb
DEPRESSED STEEL FACED CONCRETE CURB (22" DEEP)	Standard concrete curb
EXTRA-HIGH-EARLY STRENGTH CONCRETE	None
GRANITE BLOCK SIDEWALK (GROUTED JOINTS) (FURNISH BLOCK)	Concrete sidewalk
GRANITE BLOCK SIDEWALK (SAND AND GROUTED JOINTS) (FURNISH BLOCK)	Concrete sidewalk
HEXAGONAL ASPHALT BLOCK SIDEWALK, NEW 2" THICK	Same
HIGH-EARLY STRENGTH REINFORCED CONCRETE PAVEMENT (BUS STOPS)	None
INCREMENTAL COST TO CONSTRUCT NEW NY HISTORICAL GRANITE CURB, CORNER, IN LIEU OF CORNER STEEL FACED	Standard concrete curb
INCREMENTAL COST TO CONSTRUCT NEW NY HISTORICAL GRANITE CURB, CORNER, IN LIEU OF CORNER STEEL FACED	Standard concrete curb
INCREMENTAL COST TO CONSTRUCT NEW NY HISTORICAL GRANITE CURB, STRAIGHT, IN LIEU OF STRAIGHT STEEL FA	Standard concrete curb
INCREMENTAL COST TO CONSTRUCT NEW NY HISTORICAL STRAIGHT GRANITE CURB, DEPRESSED & TRANSITIONAL, IN	Standard concrete curb
NEW NY HISTORICAL GRANITE CURB CORNER	Concrete curb

NEW NY HISTORICAL GRANITE CURB STRAIGHT	Concrete curb
REFLECTIVE CRACKING MEMBRANE	Same
REINFORCED 7" CONCRETE SIDEWALK (PIGMENTED)	Unpigmented
STEEL EDGING STRIP	None
STRAIGHT STEEL FACED CONCRETE CURB (20" DEEP)	Standard concrete curb
STRAIGHT STEEL FACED CONCRETE CURB (22" DEEP)	Standard concrete curb
STRAIGHT STEEL FACED CONCRETE CURB (27" DEEP)	Standard concrete curb
SUBBASE COURSE, SELECT GRANULAR MATERIAL	None

APPENDIX B

DOT Sidewalk and Roadway Treatment Benchmark Cost

Table 4

Treatment	Borough	Price	Unit
18" Corner Steel Faced Concrete Curb	Manhattan	\$ 101.00	L.F.
	Others	\$ 81.00	L.F.
18" Curb for 18" Straight Steel Faced Concrete Curb	Manhattan	\$ 73.00	L.F.
	Others	\$ 58.00	L.F.
18" Regular Straight Concrete Curb	Manhattan	\$ 51.00	L.F.
	Others	\$ 41.00	L.F.
Roadway Surface	Bronx	\$ 215.00	S.Y.
	Brooklyn	\$ 200.00	S.Y.
	Manhattan	\$ 310.00	S.Y.
	Queens	\$ 240.00	S.Y.
	Staten Island	\$ 170.00	S.Y.
Unpigmented Concrete Sidewalk 4" Thick	Bronx	\$ 7.98	S.F.
	Brooklyn	\$ 7.92	S.F.
	Manhattan	\$ 8.63	S.F.
	Queens	\$ 8.00	S.F.
	Staten Island	\$ 8.11	S.F.
Unpigmented Concrete Sidewalk 7" Thick	Bronx	\$ 10.22	S.F.
	Brooklyn	\$ 10.73	S.F.
	Manhattan	\$ 11.40	S.F.
	Queens	\$ 9.91	S.F.
	Staten Island	\$ 10.52	S.F.

Source: DOT and DDC

APPENDIX C

DOT Material/Treatment Lifespan and Maintenance Cost

Material	Lifespan (Yrs)	Annual Maintenance Cost	Unit
Paving Materials			
4" concrete sidewalk, standard	15	\$ 10.00	S.F.
4" concrete sidewalk, pigmented	15	\$ 12.00	S.F.
7" concrete sidewalk, standard	15	\$ 12.00	S.F.
7" concrete sidewalk, pigmented	15	\$ 16.00	S.F.
Pervious concrete sidewalk	n/a	n/a	
Granite sidewalk	100	n/a	
Unit paver sidewalk	n/a	n/a	
Concrete curb	n/a	n/a	
Steel-faced concrete curb	n/a	n/a	
Granite curb	n/a	n/a	
Standard asphalt roadway w/ concrete base	7 local, 5 primary	\$ 0.08	S.Y.
Fully concrete roadway	20	\$ 0.08	
Porous asphalt w/ permeable base	20	\$ 0.08	
Unit paver roadway with concrete base	10	n/a	
Landscaping & Trees			
Landscaped area/Greenstreet	n/a	\$ 3.00	S.F.
Street Tree	80-100	\$ 37.00	Tree

Data source:

Paving Materials: Keith Howard, DOT

Landscaped area/ Greenstreet: Adriana Jacykewycz, Department of Parks and Recreation

APPENDIX D

Benefits Matrix Database

Qualitative Benefits for Treatments/Design Elements							
General qualitative assessments are outlined according to benefit categories, material and maintenance costs, and lifespan. This matrix is not intended to be comprehensive of all designs and treatments, nor is it intended to be comprehensive of all benefits from each design/treatment.							
Design Element/Treatment	Benefits				Costs		Lifespan
	Mobility/Accessibility	Safety	Environmental Health & Sustainability	Economic Vitality	Material	Maintenance	
Bikes							
Class I Bike Path	Improved bicycle mobility and accessibility	Strong improvement in cyclist and pedestrian safety; Helps reduce traffic speeds; on road bike lanes reduce accidents by 50%	Reduces energy consumption by increasing bicycle use	Increased foot traffic due to traffic calming; Decreased transportation costs for employees/customers now accessing area by bike	*n/a	*n/a	*n/a
Class II Bike Lane	Improved bicycle mobility and accessibility	Moderate improvement in cyclist and pedestrian safety; Helps reduce traffic speeds; on road bike lanes reduce accidents by 50%	Reduces energy consumption by increasing bicycle use	Increased foot traffic due to traffic calming; Decreased transportation costs for employees/customers now accessing area by bike	*n/a	*n/a	*n/a
Sidewalks & Medians							
Curb Extension/Neckdown	Improves pedestrian mobility for seniors / people with limited mobility	Improves pedestrian safety; Helps reduce traffic speeds; Shortens crossing distances;	May encourage more walking by establishing safer pedestrian environment	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales by 20-40%	*n/a	*n/a	*n/a
Curb Extension w/ Vegetation	Improves pedestrian mobility for seniors / people with limited mobility	Improves pedestrian safety; Helps reduce traffic speeds; Shortens crossing distances	Increases vegetation thus reducing pollution and urban heat island effect; Reduces negative environmental impact; May encourage more walking by establishing safer pedestrian environment	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales by 20-40%	*n/a	*n/a	*n/a
Median (no plantings)	Improves pedestrian accessibility in crossing the street	Improves pedestrian safety and helps calm traffic	--	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales by 20-40%	*n/a	*n/a	*n/a
Planted Median	Improves pedestrian accessibility in crossing the street	Improves pedestrian safety and helps calm traffic	Increases vegetation; increase water absorption reducing storm water runoff	Improved pedestrian environment and calmer traffic, which could lead to increased property values and retail sales 20-40%	*n/a	*n/a	*n/a
Standard Sidewalk	Standard pedestrian infrastructure	Standard Pedestrian infrastructure	--	--	\$8.13 SF for 4" Thick \$10.18 SF for 7" Thick	*n/a	15
Vegetation							
Connected Tree Pits	--	Helps reduce traffic speeds; provides barrier between pedestrians and traffic	Improved tree health; decreased stormwater burden on sewers; reduces urban heat island effect; May encourage more walking by establishing safer pedestrian environment; average savings in CO2 is \$1.27 per tree each year	Increases property values of surrounding neighborhood; In New York, trees have increased annual property values by \$52.5 million, or \$89.88 per tree	*n/a	*n/a	*n/a
Planted Area	--	Helps reduce traffic speeds; provides barrier between pedestrians and traffic	decreased stormwater burden on sewers	Increases property values of surrounding neighborhood	Varies	\$3.00 SY	*n/a
Stormwater- Capturing Tree Pit(s)	--	Helps reduce traffic speeds; provides barrier between pedestrians and traffic	Improved tree health; decreased stormwater burden on sewers	Increases property values of surrounding neighborhood	*n/a	*n/a	*n/a
Street Swale	--	Helps reduce traffic speeds; provides barrier between pedestrians and traffic	Decreased stormwater burden on sewers	Increases property values of surrounding neighborhood	*n/a	*n/a	*n/a
Tree Pit	--	Helps reduce traffic speeds; provides barrier between pedestrians and traffic	Increases vegetation thus reducing pollution and urban heat island effect; Reduces negative environmental impact; May encourage more walking by establishing safer pedestrian environment; average savings in CO2 is \$1.27 per tree each year	Increases property values of surrounding neighborhood; In New York, trees have increased annual property values by \$52.5 million, or \$89.88 per tree	*n/a	*n/a	*n/a
Plazas/Public Spaces							
Plaza/Public Space	Provides access for both youth and adults	Promotes traffic calming	Reduces energy consumption; Improves air quality	Increases pedestrian foot traffic, retail sales, and retail rent	*n/a	*n/a	*n/a
Plaza / Public Space with Vegetation	Provides access for both youth and adults	Helps reduce traffic speeds	Increases vegetation; Reduces negative environmental impact; Improves air quality	Increases property values of surrounding neighborhoods; beautification attracts visitors/pedestrians	*n/a	\$3.00 SY	*n/a
Street Furniture: Benches	Provides access for both youth and adults	--	--	Attracts pedestrians, visitors, that could lead to increased retail sales	*n/a	*n/a	*n/a
Materials							
Asphaltic Concrete Roadway	--	Provides good friction and channels water to the curb	May incorporate recycled asphalt	--	\$227.00 SY	\$0.08 SY	7
Bioswale	--	May provide barrier between pedestrians and traffic	Decreased stormwater burden on sewers	Vegetation increases property values	*n/a	*n/a	*n/a
Granite Curbs	--	--	Long material life	Increases property values	*n/a	*n/a	100
Granite Sidewalk	--	--	Long material life	Increases property values	\$197.50 SY	*n/a	100
Imprinted Asphalt Roadway	--	Defines pedestrian area, calms traffic	--	Increases property values	*n/a	*n/a	*n/a
Modular Cobblestone Roadway	--	Calms traffic	--	Increases property values	*n/a	*n/a	*n/a
Porous Asphalt Roadway	--	Reduces slick road conditions	Reduces negative environmental impact; reduces storm water runoff	--	*n/a	\$0.08 SY	20
Porous Concrete Sidewalks	--	Reduces slick road conditions	Reduces storm water runoff	--	*n/a	*n/a	*n/a
Thermoplastic Roadway Imprinting	--	Visually defines Pedestrian / Shared traffic area	Preserves existing asphalt	--	*n/a	*n/a	*n/a
Tinted Concrete Sidewalks	--	--	--	May increase property values and attract greater foot traffic	\$9.76 SF for 4" Thick \$12.69 SF for 7" Thick	\$12.00 for 4" \$16.00 for 7"	15
Untinted Concrete Sidewalks	Standard Pedestrian infrastructure	Standard Pedestrian infrastructure	Standard Pedestrian infrastructure	--	\$8.13 SF for 4" Thick \$10.18 SF for 7" Thick	\$10.00 for 4" \$12.00 for 7"	15
Untinted Steel-faced Concrete Curbs	--	--	--	--	\$73.00 LF for Manhattan \$58.00 LF for Others	*n/a	*n/a

Benefit Score

All scores are calculated on a scale between 0-3. 0 is given if the benefit is not evident, 1 if the benefit is mildly evident, 2 if the benefit is moderately evident, and 3 if the benefit is highly evident.

Highest possible score: 15

Design Element/Treatment	Mobility	Accessibility	Safety	Environmental Health & Sustainability	Economic Vitality	Benefit Score
<i>Bikes</i>						
Class I Bike Path	2	1	3	3	1	10
Class II Bike Lane	2	1	2	3	1	9
<i>Sidewalks & Medians</i>						
Curb Extension/Neckdown	2	3	3	0	2	10
Curb Extension w/ Vegetation	2	3	3	2	2	12
Median (no plantings)	2	2	2	0	1	7
Planted Median	2	2	3	2	2	11
Standard Sidewalk	1	1	1	0	0	3
<i>Vegetation</i>						
Connected Tree Pits	1	0	1	2	2	6
Planted Area	1	0	1	2	2	6
Stormwater- Capturing Tree Pit(s)	1	0	1	2	2	6
Street Swale	1	0	1	3	2	7
Tree Pit	1	0	1	2	2	6
<i>Plazas/Public Spaces</i>						
Plaza/Public Space	2	3	2	2	3	12
Plaza / Public Space with Vegetation	0	3	2	3	3	11
Street Furniture- Benches	1	2	0	0	2	5
<i>Materials</i>						
Asphaltic Concrete Roadway	0	0	1	3	1	5
Bioswale	0	0	0	3	1	4
Granite Curbs	0	0	0	3	0	3
Granite Sidewalk	0	0	0	0	0	0
Imprinted Asphalt Roadway	0	0	0	0	1	1
Modular Cobblestone Roadway	0	0	0	0	0	0
Porous Asphalt Roadway	0	0	2	2	0	4
Porous Concrete Sidewalks	0	0	3	1	0	4
Thermoplastic Roadway Imprinting	0	0	2	0	1	3
Tinted Concrete Sidewalks	0	0	2	2	0	4
Untinted Concrete Sidewalks	0	0	1	0	1	2
Untinted Steel-faced Concrete Curbs	0	0	1	1	0	2

APPENDIX E

LCCA Calculation Template for West Houston

Design Element:		West Houston		
		3%	5%	7%
NPV: Standard Cost		\$ 9,362,443.53	\$ 6,373,055.84	\$ 4,369,765.70
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		20.00	20.00	20.00
One-Time costs:		\$9,990,016.22	9,990,016.22	9,990,016.22
Recurring Cost:		6,919,598.22	6,919,598.22	6,919,598.22
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Standard Material	20	\$ 629,303.27	\$ 511,390.49	\$ 412,474.97
NPV: Upgraded Cost		\$ 10,272,830.37	\$ 6,992,760.10	\$ 4,794,673.70
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		20.00	20.00	20.00
One-Time costs:		\$10,538,102.85	10,538,102.85	10,538,102.85
Recurring Cost:		8,015,771.48	8,015,771.48	8,015,771.48
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Upgraded Material	25	\$ 537,665.20	\$ 452,183.97	\$ 374,971.85
AF % Difference		-14.56%	-11.58%	-9.09%
		3%	5%	7%
NPV: Standard Cost		\$ 8,391,928.68	\$ 4,713,022.94	\$ 2,675,871.14
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		30.00	30.00	30.00
One-Time costs:		\$9,990,016.22	9,990,016.22	9,990,016.22
Recurring Cost:		10,379,397.33	10,379,397.33	10,379,397.33
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Standard Material	35.00	\$ 390,554.42	\$ 287,832.36	\$ 206,668.12
NPV: Upgraded Cost		\$ 9,295,146.42	\$ 5,220,282.48	\$ 2,963,873.38
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		30.00	30.00	30.00
One-Time costs:		\$10,538,102.85	10,538,102.85	10,538,102.85
Recurring Cost:		12,023,657.23	12,023,657.23	12,023,657.23
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Upgraded Material	40	\$ 402,130.14	\$ 304,228.46	\$ 222,317.59
AF % Difference		2.96%	5.70%	7.57%
		3%	5%	7%
NPV: Standard Cost		\$ 9,817,320.11	\$ 5,513,542.43	\$ 3,130,374.97
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		30.00	30.00	30.00
One-Time costs:		\$9,990,016.22	9,990,016.22	9,990,016.22
Recurring Cost:		13,839,196.44	13,839,196.44	13,839,196.44
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Standard Material	35.00	\$ 456,891.12	\$ 336,721.45	\$ 241,771.25
NPV: Upgraded Cost		\$ 10,946,342.28	\$ 6,147,616.86	\$ 3,490,377.77
Discount rate:		3.00%	5.00%	7.00%
Analysis Period:		30.00	30.00	30.00
One-Time costs:		\$10,538,102.85	10,538,102.85	10,538,102.85
Recurring Cost:		16,031,542.97	16,031,542.97	16,031,542.97
Lifespan Calculation:	Years	Annuity Factor	Annuity Factor	Annuity Factor
Ex Upgraded Material	40	\$ 473,564.80	\$ 358,271.81	\$ 261,810.23
AF % Difference		3.65%	6.40%	8.29%

APPENDIX F

Full Report on Chicago, Illinois

Executive Summary

The Chicago Department of Transportation (CDOT) has taken aggressive steps towards achieving Mayor Richard Daley's goal of making Chicago the greenest city in America by 2020. CDOT has researched best practices, materials and maintenance techniques, and engaged communities to ensure the long-term success of their sustainable streetscape projects. They have addressed the problem of Urban Heat Island and stormwater management through their development of permeable Green Alleys and they have designed and are currently building one of the premier sustainable streetscape projects in the US: Cermak/Blue Island Sustainable Streetscape Project. The Cermak/Blue Island project seeks to address issues of stormwater management, water efficiency, transportation, energy efficiency, recycling, urban heat island and education, beauty and community. Through partnerships with various agencies CDOT is collecting valuable data to ensure compliance with Cermak/Blue Island's project goals. In addition, CDOT has followed rigorous guidelines set out by various ratings agencies such as LEED and Green Roads, and conducted analysis to measure compliance with the various rating requirements in an effort to build a streetscape project on par with the highest rated LEED buildings. Though CDOT does not currently conduct LCCA, the data collection structures used for Cermak/Blue Island are a good step in that direction.

Background

In 2008 Chicago formalized sustainability as a strategic priority in announcing its Climate Action Plan. The Plan was based on projections of the effects climate change could have on Chicago in the future including increases in both precipitation and temperatures. The Plan outlines the efforts of all Chicagoans—from individuals to city agencies and private corporations—can take to reduce greenhouse gas emissions and avoid the realization of the stark forecasts. CDOT has taken a proactive role in establishing Chicago as the greenest city in the US, though CDOT's interest in sustainability predates the formal announcement of the Climate Action Plan. In 2004 CDOT formed a task force to examine how they could organize their efforts to promote sustainable streetscape designs. The task force identified the following categories as being essential to any sustainable streetscape design project: energy efficiency, waste management, air quality, site selection, beauty and community, urban heat island, stormwater management, water efficiency, alternative transportation, and education.

Stormwater Management

Urban runoff, the surface water runoff from rain and melting snow, is a major contributor to the difficult task of stormwater management. The EPA ranks urban runoff as the fourth largest contributor to the pollution of lakes, rivers and streams⁶⁸. Urban runoff from the city of Chicago makes its way to the Gulf of Mexico contributing to what is known as the Gulf of Mexico Dead Zone—an 8000 square mile oxygen deficient zone where marine life is nonexistent⁶⁹. Chicago's 6100 miles of impermeable streets and alleys contribute significantly to urban runoff. CDOT saw a solution to these and several other sustainability issues through the development of

sustainable streetscape projects. Using several strategies commonly employed in LEED-certified building projects, though not often seen in streetscape design, CDOT in partnership with Wight & Company, a premier design and construction firm specializing in sustainability projects, set out to develop streetscape projects that incorporate stormwater and environmental best practices while creating public spaces that promote the health and wellbeing of communities.

Urban Heat Island Effect

Urban heat island (UHI) is an effect whereby metropolitan areas experience higher temperatures than their more rural neighbors. A major factor contributing to UHI is the development of land surfaces using materials that absorb and retain heat. The effects of UHI include: increased deaths during heat waves, decreased air and water quality, and increased production of pollutants. Roadways in Chicago (excluding parking lots) make up about 23% of the land area, a figure consistent with other cities across the country. This expanse of pavement has a direct connection to UHI. Dark pavement absorbs the sun's rays and radiates heat, whereas more reflective materials deflect the energy resulting in less absorption, radiating heat and UHI.

To address the dangers of UHI, CDOT first established a steering committee to look at all surfaces—roofs, areas around buildings and public-right-of-ways—to see what could be done to mitigate the negative effects caused by infrastructure within the city. CDOT discovered that in addition to roadways, industrial areas and parking lots are hot spots for UHI. Not surprisingly, there is also a strong correlation between the canopy cover and the hot spots; i.e., the hottest spots are where there are few trees.

Green Alleys

CDOT saw alleys as a great place to start addressing six of the categories established by the task force: UHI, stormwater management, energy and water efficiency, waste management, and education. Chicago has the most extensive alley system of any city in the world⁷⁰ covering 2100 miles, the equivalent area of more than five Midway airports. Most alleys did not have a storm sewer system and as a result, residents experienced frequent flooding. Common practice had been for CDOT to rebuild the alleys and construct additional sewer systems. This infrastructure does not come cheap; Chicago spends \$50 million per year - out of a \$400 million per year capital budget - on maintaining and upgrading its 4,400 miles of sewer lines and related structures. In addition - similar to municipalities across the country⁷¹ - wastewater treatment is the number one consumer of energy in the city of Chicago⁷².

The Green Alley Program addressed these complex issues by incorporating the following materials into their designs: permeable pavements, recycled materials, high-albedo (reflective) pavements, and dark sky lighting. In addition CDOT, in consultation with S.T.A.T.E. Testing, developed pervious concrete and asphalt mixes using local materials. The pervious hot mix asphalt (HMA) is made with recycled ground tire rubber asphalt cement—the first known use of this material in Illinois.⁷³ They developed a high albedo pervious concrete mix adding slag and lighter aggregates to give it a highly reflective property. CDOT first piloted various materials in six Green Alley projects to determine which materials demonstrated the most durability and

benefits. Once these projects were analyzed CDOT planned to expand the program, using the most sustainable combination of materials, to forty locations citywide.

An important aspect in turning CDOT’s pilots into full-fledged programs is precise tracking, monitoring and evaluation. CDOT tracks its recycled content project goals on many levels such as: Item Description, Recycled Material Description (i.e. what % recycled material of what type), % By Weight Post Consumer, % By Weight Post Industrial, Material Costs per Unit, Year-to-Date Quantities, Recycled Content Product Value, Total Material Costs Installed-to-Date etc. Construction waste management is tracked in a similar way. This data is used to ensure CDOT is meeting its project goals. Six months after the implementation of the first Green Alleys CDOT collected the following data:

Location	Air Temp, F	Pavement Temp, F ¹	Pavement Type	Albedo ²	SRI 5 (0-5 mph) ³	SRI 12 (5-13 mph) ⁴	SRI 30 (13-25 mph) ⁵
1700 W. 106th Street	81	121	Pervious HMA	0.04	1.17	1.01	22.34
10300 S. Avenue G	88	116	Pervious PCC	0.18	19.20	18.81	37.01
2100 N. Rockwell Ave	83	93	Pavers	0.19	20.70	20.34	38.29
5300 N. Glenwood Ave	85	107	Pervious PCC Strip	0.18	18.63	18.27	41.08
	85	90	PCC Edge	0.26	29.41	29.08	45.59
2400 N. Harding Blvd	90	98.5	High Albedo PCC	0.26	29.52	29.19	45.68

CDOT⁷⁴

As seen in the above chart, the high albedo materials developed by CDOT—specifically, those used on Glenwood Ave. and Harding Blvd.—had Solar Reflectance Index (SRI) ratings above 29, which if used in a building site, would earn the project a point on the LEED rating system. The pervious HMA had lower SRI ratings due in part to the nature of the ingredients; the recycled rubber gives it a bumpier, less reflective texture.

Maintenance of Green Alleys

There are 50 wards in Chicago and each is responsible for requesting, funding through discretionary funds, and maintaining their alleys. This decentralized system allows the community to take ownership and run the program once installed. To help communities maintain their alleys, CDOT developed the Green Alley Handbook⁷⁵ to inform property owners of the benefits their Green Alley provide as well as the steps they can take to help maintain their Green Alley. The handbook also includes information on how property owners can implement stormwater best management practices on their property such as recycling or installing their own rain garden. Community engagement, facilitated by the Green Alley Handbook, has been instrumental to the success and maintenance of the Green Alleys program.

When planning the Green Alley program CDOT had difficulty gathering information on maintenance plans as there are not many comparable projects they could look to for best practices. Before the Green Ally program, the alleys had not previously been maintained so any new maintenance costs incurred would be additional. After conducting tests in small areas to determine the best maintenance practices, CDOT created a maintenance protocol whereby city sweepers swept the alleys twice per year, once in the spring and once in the fall. CDOT also prepared maps for each ward so they knew where their Green Alleys were and provided each city sweeper with straightforward instruction cards that could be pasted to the dashboard listing the basic rules for sweeping Green Alleys, the most important of which was to turn off the water jets.

Though each ward has its own sweeper, the budget for cleaning the streets comes from the water department. The reasoning being, the main goal of keeping the streets clean is to keep the catch basins clear so they can handle stormwater runoff.

Since the implementation of the Green Alleys program has been slow the sanitation department has not pushed back in response to the nominal amount of extra work required for maintaining the alleys. Thus far, the maintenance protocol seems to be working fine, though the alleys would benefit from having a high-powered vacuum to occasionally remove leaf debris and other litter. CDOT is investigating purchasing such a vacuum, though figuring out how to share the significant cost of such equipment across agencies is proving to be a challenge.

Encouraged by the results of the Green Alley program CDOT expanded the use of these materials to permeable parking lanes, parking lots, parkways, plazas, and beyond. Permeable materials generally do not fare too well when used in high traffic areas so expansion of the use of these materials is focused on low-traffic portions of the street.

Cermak/Blue Island

The Cermak/Blue Island Sustainable Streetscape Project encompasses 2.13 miles of Cermak Road, a major roadway a few miles outside of downtown Chicago that connects the neighborhoods of Chinatown, Pilsen and a warehouse area on the Chicago River. The Cermak/Blue Island Sustainable Streetscape is a model sustainable streetscape project, encompassing all of the aforementioned benefits as well as incorporating LEED-certified building practices. In an attempt to achieve the equivalent of a platinum LEED rating for the project CDOT established the following aggressive project goals:

Cermak/Blue Island Sustainable Streetscape

Project Sustainable Goals

<i>Stormwater Management</i>	Divert 80% of the typical average annual rainfall and at least 2/3 of rainwater falling within catchment area into stormwater best management practices.
<i>Water Efficiency</i>	Eliminate use of potable water for irrigation, specify native or climate adapted, drought tolerant plants for all landscape material.
<i>Transportation</i>	Improve bus stops with signage, shelters and lighting where possible, promote cycling with new bike lanes, improve pedestrian mobility with accessible sidewalks.
<i>Energy Efficiency</i>	Reduce energy use by min. 40% below a typical streetscape baseline, use reflective surfaces on roads/sidewalks, use dark sky-friendly fixtures. Min. 40% of total materials will be extracted, harvested, recovered, and/or manufactured within 500 miles of the project site.
<i>Recycling</i>	Recycle at least 90% of construction waste based on LEED NC criteria, Post/Pre- Consumer recycled content must be min. 10% of total materials value.
<i>Urban Heat Island</i>	Reduce ambient summer temperatures on streets and sidewalks through use of high albedo pavements, roadway coatings, landscaping, and permeable pavements
<i>Education, Beauty & Community</i>	Provide public outreach materials/self-guided tour brochure to highlight innovative, sustainable design features of streetscape. Create places that celebrate community, provide gathering space, allow for interaction and observation of people and the natural world.
<i>Commissioning</i>	Model Stormwater BMP's in Infoworks to analyze and refine design. Monitor stormwater BMP's to ensure predicted performance and determine maintenance practices.

CDOT⁷⁶

Cermak/Blue Island is scheduled to be completed at the end of the summer of 2011⁷⁷. When finished, the Cermak/Blue Island Sustainable Streetscape will be one of the most comprehensive sustainable roadway projects in the country. The goals of the project will not only create attractive community spaces, but also address critical issues outlined in the Climate Action Plan.

Cermak/Blue Island Stormwater Management

Every year an average of 16 million gallons of precipitation falls on Cermak Road. The project will look at that precipitation not as a problem but as a resource with the ability to enhance the community and environment.

The north side of Cermak Road uses stormwater planters connected to large areas of open-graded aggregate below the sidewalk to collect the runoff. If the aggregate area overflows, it is connected to the existing infrastructure—much of which is kept in place to reduce the unnecessary, wasteful replacement of materials. The south side of Cermak Road consisted of a railroad embankment that will be transformed into a continuous bioswale. Runoff will enter the bioswale through perforated curbs on both sides of the existing stormwater drainage inlet, thus the water will bypass the old system except in cases of unusually heavy precipitation.

To help clean the urban runoff of its worst pollutants before it enters the landscaped areas a layer of zeolite was used in both infiltration zones. Zeolite is a microporous volcanic mineral that trades positively charged ions with those of phosphorous, nitrogen and other common pollutants thereby cleaning the water before it enters the stormwater planters or the bioswale.

The roadway of Blue Island Avenue will have a new bike lane as well as on-street parking that uses permeable pavers made of what is commonly referred to as smog eating cement; the pavers actually remove significant amounts of environmental pollutants. Below the pavers is a three-foot deep catchment of stone with overflow pipes that connect to existing infrastructure. The pavers have a high albedo surface (minimum of .45 SRI) and also have a self-cleaning quality (through the use of photocatalytic cement), which helps them maintain a high SRI. If the cements are not kept clean, the SRI is reduced. As mentioned earlier, SRI is an important strategy for mitigating the negative effects of UHI. The pavers have been used in Italy and the manufacturer has extensive reports⁷⁸ on tests demonstrating their effectiveness.

The high SRI pavements also help with energy efficiency. Lower wattage bulbs are required—250 watts instead of 440 watts—because of the reflective properties of the pavement resulting in an anticipated 49% energy savings below the baseline⁷⁹. In addition, using LED and metal halide lights in combination with high SRI pavement achieves more uniformity of light coverage without increasing night sky light pollution. As described here, the use of innovative pavement technology has the potential to impact much more than stormwater management practices.

Pavement

Since 2006 CDOT has been piloting various pavement technologies to ensure durability. The results of these pilot projects have resulted in what CDOT feels is a durable and sustainable solution and another important component of their far-reaching sustainable streetscape goals. The Cermak/Blue Island project builds on the pavement pilot work by using warm-mix asphalt with fifteen percent Recycled Asphalt Pavement (RAP), ten percent Ground Tire Rubber (GTR) and a covering of high albedo microthin concrete overlay that will achieve at least a .36 SRI. In addition, CDOT has developed and is using concrete that is made using 30 percent recycled aggregates, slag and recycled wash water from the plant⁸⁰.

To further test durability and longevity of the microthin concrete overlay the treatment will be applied to some outer lanes of high Average Daily Traffic (ADT) sections of the roadway as well as the large, highly traversed intersection at Cermak Road and Blue Island Avenue. Results of these tests will inform further use of these materials.

Costs

The Cermak/Blue Island project is projected to cost \$16.6 million. It is being funded through a tax increment financing district in conjunction with a nearly \$450,000 grant from the Illinois EPA 319 nonpoint source pollution program (which funds best management practices such as rain gardens, permeable pavers, and bioswales), \$73,200 from the Federal Highway Administration's Ecological Grant Program, and in-kind services from the Metropolitan Water Reclamation

District of Greater Chicago⁸¹. CDOT conducted statistical analysis on the bids they received for their sustainable streetscape projects and found that the average per block cost was about \$500,000, which is comparable to other traditional streetscape projects. A caveat being, these projects were bid during the economic downturn, which could be an intervening variable, though the results are nonetheless promising. According to Janet Attarian, the Project Director for CDOT's Streetscape and Sustainable Design Program, the Cermak/Blue Island project's bid was 20% below other traditional projects of similar scale. Again, this could be due to the economic downturn and/or the high profile aspect of the project.

Monitoring and Evaluation

The implementation of CDOT's stormwater best practices will be rigorously monitored and evaluated through a partnership with the Metropolitan Water Reclamation District of Greater Chicago to determine their individual and collective effects on stormwater management. In addition, the Cermak/Blue Island project has a meteorological station, installed in coordination with the EPA that compares air and surface temperatures and collects continuous data on humidity and other environmental factors in real time. By comparing the pre-project data with the post project data CDOT will be able to analyze the impact of the use of the highly reflective microthin concrete overlay on the local microclimate.

All CDOT pilot projects are heavily monitored to measure the impacts the new materials have on the environment. In addition, the monitoring helps determine maintenance needs, effectiveness of various maintenance techniques and which elements are most successful in achieving sustainability goals. The monitoring results may or may not support the case for all the elements inclusion in sustainable projects; it is too early yet to draw conclusions on the use of many techniques.

Rating Systems

CDOT modeled their data tracking on the guidelines required by the US Green Building Council (USGBC). This proved a challenging adjustment to their process when interacting with outside contractors. The rigorous post and pre-consumer tracking was a task many in the construction and roadway industry were not familiar with. For example, the contractors were reluctant to break down their budgets by line item delineating labor and material costs. Another example is with regard to tracking locally procured materials. The USGBC has a requirement that materials must be sourced locally, i.e. they must not travel more than 500 miles to the project site. This proved difficult when determining where the aluminum for the light poles was sourced, where they were manufactured and how far they traveled to have their final finish applied. It turned out the poles contained a high percentage of recycled material so CDOT received credit for that and the miles traveled were not a problem. The detail of the documentation required proved time consuming and not as straightforward as one might think. To ensure the data was accurate CDOT had to follow-up and ask many questions of contractors and sub-contractors regarding the specifics of calculations and reporting.

Through this rigorous measurement and reporting CDOT measured their project goals and accomplishments against various national and local rating systems:

CATEGORY	Design Strategy	Rating System			
		I-LAST Rating System (IDOT)	Green Roads Rating System	Sustainable Sites Initiative	LEED-ND
Planning	Identify Stakeholders and develop Stakeholders Involvement Plan	2	-----	-----	-----
	Engage Stakeholders to conduct Context Audit and develop project purpose	2	-----	-----	-----
	Involve Stakeholders to develop and evaluate alternatives	2	-----	4	2
	Employ Stakeholder involvement techniques to achieve consensus for Preferred Project Alternative	2	-----	-----	-----
	Plan for Context Sensitive Solutions (CSS)	-----	5	-----	-----
TOTAL POINTS EARNED:		130	79	100	32
POINTS POSSIBLE:		228	118	250	100
Percentage % of possible points:		57%	67%	40%	32%
Ranking:		N/A	Evergreen (>60% of total)	One Star (Four Star possible)	(need 8 more Points to become "Certified")

CDOT⁸²

CDOT did fairly well by all measures reaching Evergreen status on Green Roads and just missing the LEED-ND rating by 8 points. This is a significant accomplishment especially considering some of these rating systems are not a perfect measure for CDOT's roadway projects.

Inter-agency Coordination

All CDOT sustainable streetscape projects are put into a system whereby any permit pulled for that site has to go through additional, rigorous documentation and review. This allows for coordination between private development projects and CDOT projects. For example, any new building development in Chicago will have a landscape requirement. If there is a CDOT project planned for that site, there will be coordination between CDOT and the developer, which may result in the development project having the landscape requirement waived and CDOT handling the landscaping so as to ensure consistency in design. To avoid disruptions due to utility work at a streetscape project site, before any project enters the design stage, CDOT alerts the Office of the Underground so they can coordinate utility work ahead of time. It is not a perfect system and emergency work falls through the cracks but it works much of the time. One of the biggest challenges will continue to be cross-organizational coordination; an imperative for sustainable streetscape projects to be successful on a broader scale.

Looking Ahead

In developing its sustainable streetscape projects CDOT has been ambitious and methodical. Each program started with extensive research and testing, followed by community outreach and support for pilot programs, then measurement, evaluation and if the data bore results,

scale-up and expansion of the programs. The next logical step for CDOT to take is lifecycle cost analysis. Since CDOT has collected extensive data and kept thorough documentation of materials and costs they should be well poised to take this important next step. In addition, given the wealth of data available for analysis, further research on the costs of CDOT's Sustainable Streetscape Projects could be beneficial to the transportation community as a whole. The time required to collect this data through Freedom of Information Requests is beyond the scope of this research project.

APPENDIX G

Full Report on London, England

Executive Summary

London has developed major additions to their transport network through cycle schemes. The Barclays Cycle Hire and Barclays Superhighway Cycle schemes are the most recent initiatives to gain popularity and have a dominant role in making London become the global leader in cycle schemes. This report will provide the background on these cycle schemes and how they have benefited the public. It will also discuss the capital and operating costs and decision making of specific design materials connected with the cycle schemes. Lastly, this report will examine the challenges that surfaced and lessons learned. This portion will also focus on responses from the Transport for London (TfL) and London Mayor Boris Johnson regarding their next steps for improving the cycle schemes while it is still in its infancy stage of implementation.

London Cycling Initiatives

Over the past few years, there has been a stable increase in demand for mode trends such as cycling, developing in London. Multi-modal transportation with cycling grew by 6 percent between 2001 and 2009. Between 2008 and 2009 cycling transportation modes grew by roughly 5 percent.⁸³ TfL has developed two cycle scheme initiatives, which serve the purpose of constructing alternative transportation routes throughout various parts of London. First, there is the Barclays Cycle Hire scheme; a publicly shared bicycle rental scheme for trips within central London. Next, the Twelve Barclay Cycle Superhighway Scheme; new cycle lanes intended to provide alternative routes for London Borough commuters to cycle inner and central London. Both cycle schemes are partially funded by Barclays Corporation. The goal of both cycle schemes is to promote social and environmental health and low-cost benefits to users. Provided below is a descriptive summary for both cycle schemes and some empirical evidence based on usage and change in travel behavior.

Barclay Cycle Hire

After its launch in July 2010, the Barclay Cycle Hire Scheme, 28 miles (or 45 kilometers) long, has attracted many commuters who formerly used other means of transportation to travel to and from work. It is intended for commuters making trips within central London and comprises of 5,000 bicycles and 350 docking stations.⁸⁴ The pictures provided show the bicycles are featured with Barclay's logo on the rear wheel. They are designed to provide comfort and safety for the user and have unique accommodations such as puncture-resistant tires to increase durability, brakes on each wheel hub, dynamo-powered flashing front and rear lights, a small luggage rack in front of the handlebars with elastic cord to secure possessions, and adjustable saddle height.⁸⁵

In a random survey of 3,750 Cycle Hire users, TfL found about 58 percent of users traveled for work purposes: a 10 to 30 minute trip. The survey also revealed about half of commuters traveled the entire way to work via the Barclays Cycle Hire bicycle. Another 63 percent of users

commuted in a multi-mode way by using the bicycle and the train. The Cycle Hire has resulted in a positive change in travel behavior among individuals that did not cycle before its development. Six in ten registered users had only started cycling since the start of the scheme in July of 2010.⁸⁶

The Cycle Hire scheme consists of over 100,000 members, to date, making 15,000 journeys on the bicycles every day. The average number of trips during weekdays ranges from 21,000 to 24,000. It is also a revenue generating initiative and has reported collecting a total of \$3 million of revenue from user charges as of November 2010. For membership, individuals can register on the TfL website and sign up for one of three levels of access: a daily rate at £1 (\$1.60 USD), weekly rate at £5 (\$8.00 USD) or an annual rate at £45 (\$72 USD). Users are then sent a key in the mail to operate the docking stations requiring an activation fee of £3 (\$4.81 USD) before first time use. Up to four users can be registered under a single account. Scheme members insert the membership key into a docking point key slot and an amber light will indicate that the account is being verified. Once the light turns green, the bicycle can be undocked.⁸⁷ TfL predicts by March 2011, the average number of trips will increase to 27,000 per day and will reach their target goal of 40,000 per day in the future. The target goal is expected to generate \$30.1 million USD.⁸⁸

In December 2010, TfL announced the Cycle Hire scheme was available to casual users to include non-members. Those with a credit or debit card could visit the nearest docking station, and follow the on screen instructions to release a bike. Once the user purchases their desired time period (could be for 24 hours or seven days) the user will enjoy the first 30 minutes free of usage charges. Prices range from £1 (\$1.60 USD) for 1 hour to £50 (\$80 USD) for 24 hours.⁸⁹

Barclays Cycle Superhighways

The Barclay Superhighway Cycle program has the same intended goals as the Barclays Cycle Hire, but on a larger scale. This program extends the benefits to London boroughs consisting of close to 25 miles (40 kilometers) of cycle lanes, providing a safer and faster way of commuting to inner and central London. The bike lanes have visible blue road surfaces that are at least 1.5 meters (or 5 feet) wide and are clearly marked so that motorists can expect cyclists in this area. Additional features include 37 cycle safety trail mirrors at junctions, giving drivers of large vehicles better visibility of cyclists when preparing to turn left, 84 new advanced stop lines at least 5m (16 feet) deep at junctions along both routes, and providing a space for cyclists to wait at lights ahead of traffic. The new segregated cycle lanes installed realign traffic and bus lanes; this creates more space for cyclists on busy roads.⁹⁰

Two of the twelve pilot programs were launched in July 2010. The Mayor and TfL announced they expect all twelve-cycle superhighways to be completed by 2015. Survey results show 52 percent of residents increased cycle use due to the cycle superhighway scheme. 86 percent of users use the scheme to commute to and from work. The average travel time as a whole was 39 minutes, and 17 to 19 minutes for multi-mode users.⁹¹

Overall, both Barclays Cycle Superhighway and Barclays Cycle Hire schemes have accomplished the following:

Improved road safety

Customer satisfaction for cycle lanes has decreased from 53 to 49 percent between 2009 and 2010. The reasons indicated for the decrease is due to the quality of the road surface and maintenance. Indicators also suggest the impact of severe weather during the same time period deteriorated the quality of the pavement.⁹² On the scale of 0 to 10 for 2009 and 2010 (prior to the launch of cycle schemes), London residents in sub-regions were the least satisfied with the quality of the road surface by a mean score of 5.8 (roughly 58 percent were least satisfied) compared to residents that were most satisfied.⁹³

Cyclists of the Superhighway experienced an improvement in road quality and felt safer. It was reported that 60 percent of commuters felt safer due to improved quality road surface and roadside mirrors.⁹⁴ Oliver O'Brien, a researcher at the Centre for Advanced Spatial Analysis at University College in London expressed that both schemes have marginally increased safety to the public. The Cycle Hire scheme has "increased the number of cyclists in the center of the city of London, which allows car drivers and other road users used to seeing cyclists sharing the road."⁹⁵

Increased mobility:

Commuters who do not own a bike know the Barclay Cycle Hire scheme as being one of the quickest alternatives to getting around central London. According to the TfL report, there was about a 24 percent increase of cycle flows in London since the launch of the Cycle Superhighway scheme, resulting in replacement of two thirds of the public, car or taxi, mode of transportation.⁹⁶ In addition, the implementation of cycle routes for Barclay's Superhighway scheme increases mobility because the visibility of the cycle roadways encourages more people to cycle throughout London Boroughs.⁹⁷

Economic Output:

The Barclays Cycle Hire is not only recognized by residents, but is also recognized as a tourist attraction; this in turn has benefited the economy as new figures revealed businesses are benefiting from the Cycle Hire Scheme. Many companies using the hire scheme suggest they may also be helping London become greener, as well as helping to create a cycling revolution in the Capital.⁹⁸ Between 53 percent and 62 percent of commuters resorted to using the cycle scheme to save money.⁹⁹ Mr. O'Brien stated that using the scheme is a substantially cheaper way of getting across town compared to using the subway and slightly cheaper than using the buses and driving (due to congestion charges).¹⁰⁰

Quality of Life & Climate Improvements:

Despite the congestion charge imposed to decrease congestion in London, congestion has continued to increase over the past decade. Road works have been partly to blame for the increase in congestion due to disruption. Cycle Superhighway scheme is also connected to the

improvement of air quality measures, particularly in congestion hot spots in London to reduce congestion and traffic noise. The London Atmosphere Emission indicates that reduced emission of local and greenhouse gas pollutants are a result of changes in transport innovations such as walking and cycling. Along with the Cycle Superhighway scheme, the Mayor of London is aiming to achieve a 60 percent reduction in London’s Carbon Dioxide emissions by 2025.¹⁰¹

Costs

Barclay is partially providing funding over a 5-year period for both schemes in the amount of £25 million GBD (\$40.3 million USD). The first phase of the cycle hire scheme is expected to cost £79 million with an annual operating costs anticipated at £18 million GBD. The cycle hire scheme is expected to be completed in 2012 and will cost at least £140 million GBD over six years (\$224.4 million USD). The user charges and Barclays sponsorship funding are being used to cover the operating costs incurred. The estimated cost of the twelve superhighways is £166 million GBP (\$268 million USD).¹⁰² TfL mostly funds both schemes. The budget consists of the following expenses:

- \$37 million for the two superhighway schemes that launched July 2010;
- \$20.1 million for improvements blue cycle lanes, advance stop sign installation, and modifying junctions;
- \$29million of operating costs;
- Additional “soft” measures include cycle parking, cycle training, maintenance and safety, route promotion, costing \$2.3 million each.¹⁰³

TfL has created a design standard publication for acceptable visual design elements in regards to signage throughout the facilities for both Barclays Cycle schemes, (can be found on their website).¹⁰⁴ Currently, TfL has not provided the specific costs per each material associated with the cycle schemes. However, there are guidelines in their general street design standards publication providing cost estimates of different elements and materials generally used, and construction costs for cycle lanes and global cost of facilities. The Global costs of facilities are listed in Table 1, and construction costs are provided in Table 2. The information is pulled out of the general street design publication. All costs were converted to reflect US Dollars at the currency factor rate of \$1.60 USD to £1 GBD. These costs assist TfL with estimates when dealing with contractors and getting a clear comparison of alternative building options. Depending on contingencies, TfL may need to factor in costs of traffic management during construction. Such costs can double the estimated costs of specific locations.¹⁰⁵ The traffic management costs are not included in any of the tables.

Table 1

Global Costs on Various Types of Facilities (USD)	
Type of Facility	Cost Range per Km
Cycle track w/ major junctions	\$485k-1.3mill
Cycle Track w/simple junctions	\$160k-485K
Segregated path w/ major junctions	\$400K-645K

Segregated path w/ minor junctions	\$160k-322k
Share path many junctions	\$113K-210K
Shared path (conversion), few junctions	\$48k-97K
Curb segregation lane many junctions	\$485k-1.3mill
Curb segregated lane few junctions	\$160k-485K
Cycle Lane with ASL many Junctions	\$64k-130K
Cycle lanes w few junctions	\$32k-64K
Cycle lanes on bus routes	\$32k-64K
Multi Modal/cycle streets	\$485k-1.3mill
Traffic calmed/managed area	\$160k-485K
Quiet routes town centers	\$64k-130K
Quiet routes suburban	\$16k-32k

Transport for London¹⁰⁶

Table 2

Construction Costs (USD)	
Construction	Average Cost
Gravel or limestone path (250mm thick)	\$20 per sq meter
Track (250mm thick, plus bitmac base)	\$40 per sq meter
Extra excavation and disposal	\$25 per sq meter
Extra Surfacing	\$20 per sq meter
Extra concrete curbing	\$38 per meter
Extra edging	\$16 per meter
Extra granite curbing	\$140 per meter
Drainage	
Road gutter including pot	\$1,000
Gutter connection	\$250
Lighting	
Relocate lighting column incl. connections	\$1,350
New Lighting column incl. connection	\$1,350
Illuminated bollard (incl. connection)	\$650
Marking	
White line	\$3 per meter
Raised white line	\$16 per meter
Cycle logo	\$35
Parking	
Sheffield stand	\$280
Cycle locker including base	\$1,600

Signals	
Conversion of Pelican or Toucan	\$28,000
Toucan on single carriageway	\$60,000
Toucan on dual carriage way	\$100,00
Signs(each)	
Small signs (up to .5 sq meter)	\$120
Medium(.5-1 sq meter)	\$160
Extra for sign post	\$160
Illumination on lighting column	\$400
Illumination on post	\$700
Bollard(cast iron or stainless steel)	\$400

Transport for London¹⁰⁷

In order to monitor cost efficiency, TfL has referred to their design standard guide for various facilities and construction costs, in tables 1 and 2, when calculating cost estimates for projects such as Barclays Cycle Schemes. For example, the segregated major junction lanes installed at some locations of the Superhighway Cycle Scheme costing between \$400K and 645k per kilometer (equivalent to .62 miles) include a bundle of construction materials that are listed in the construction cost table (i.e. paint markings and pavement construction). All other construction costs such as lighting, drainage and signs would vary based on location. Also, additional costs can apply if the location requires traffic calmed/managed area, which ranges between \$160k and \$485K. Superhighway Cycle lanes in the outer boroughs of London are relatively cheaper than lanes located within central London. Because they are a unique structure involving technology, the cost for dock stations at Barclay Cycle Hire may cost higher than the cycle lockers noted in the parking section of table 2, which cost roughly \$1,600 USD.

Design Materials

The riding quality of the roadway is important. Hence, careful decisions on the materials are needed. Design materials that have a smooth riding surface and good skid resistance are preferable as it ensures comfort and safety to cyclists. It is also essential that cycle lanes be visible, easy to maintain and durable. The pavement materials that are recommended by TfL design standards for cycle lane surfaces are Stone Mastic Asphalt (SMA), Hot rolled Asphalt (HRA) and Bituminous macadam (Bitmac). These materials have a smooth riding surface, have good skid resistance and are durable.¹⁰⁸ Bitmac, SMA and HRA are normal main road surface materials, and are the recommended material for cycling road surfacing because of their skid resistance, smooth surface texture, durability and color fastness (e.g. they are naturally colored which have better color retention and longer life).¹⁰⁹ Cycle lanes are painted with the standard design color of deep chrome green as it highlights routes in appropriate locations. The life expectancy of these bitmac, SMA and HRA pavements is 20 years and they cost between \$32-40 per square meter. The installation of gullies and curbs are also critical for cycle lanes to

promote proper drainage of storm water run offs. These two elements also support the useful life of the surface road and allow the cycle lanes to serve the purpose of working effectively.

Although some materials have a longer useful life, they are not practical to use for cycle lanes. For example, brick and block pavements have a useful life of 20 years, but they are not the best selection when it comes to skid resistance. Also concrete is good for cycling, but the surface markings that are pertinent to cycling lanes are not clearly visible. Table 2 below provides costs, life span, and skid resistance scores for some design materials published in the general design standards publication.¹¹⁰

Table 3

Material	Cost (per square meter) in USD			Life (years)	Skid Resistance (55 and over is acceptable)
	Normal	Red	Green		
Bituminous Macadam 6mm aggregate (20mm thick)/Footway surface	\$5-6	\$16	\$32	20	60
Anti-Skid(epoxy resin binder)	19	\$21-24	\$21-24	10	70+
Cycle Track Veneer(thermoplastic slurry)	13	\$13	\$13	5	65
Cycle Lane Veneer(polymer binder)	16	\$19	\$19	10	65
Granite stone surface dressing(clear binder)	\$6-8	\$8	\$8	20	60+
Pea Shingle stone surface dressing	\$6-8	n/a	n/a	20	50
Colored stone mastic Asphalt(30mm thick)	n/a	\$32-40	\$32-40	20	60
Block Paving	\$32-48	\$32-48	n/a	20	55

Transport for London¹¹¹

Maintenance of Cycle Schemes

Currently, TfL strategic road network (TLRN) bears the costs for only red routes, which are red lines, clearways, parking and loading bays, bus lanes, yellow box junctions, and banned turns. The constituent boroughs are responsible for the rest. The red routes are located in the north, south and central areas of London and carry a third of all traffic in the Capital. At times, roadwork can damage cycle lanes. TfL recommends that a routine inspection be performed after.¹¹² In 2007, TfL endorsed an agreement with three Highway Works Maintenance Contracts (HMWC) for the routine inspection, maintenance, and improvement of the TLRN worth £1billion (roughly \$1.6billion USD) over 10 years.¹¹³ The contracts allow TfL to engage directly with their contractors and introduced the Incident Support Units(ISU) and twenty-four hour staffed control rooms. These two components in the contract allow for speedy response

to incidents on the network (damaged street furniture caused by a crash) so that road users experience less disruption to their journeys. Depending on the estimated cost of an improvement scheme determines if TfL would contract outside of the HMWC. Costs in excess of £ 500K (roughly \$800K USD) TfL may contract with other agencies.¹¹⁴

Oliver O'Brien mentioned that road disruption caused by utility companies is currently one of the main topics for discussion in London. Utility companies performing the road disruption are currently not liable to repaint or reapply the cycle superhighways after their work is completed. The Mayor's Draft Transport Strategy has formulated a procedure involving utilities renting the road for a specified time period. This effort is to discourage utility companies from breaking up the road for a longer period of time than needed.¹¹⁵ Utility companies performing the road disruption are currently not liable to repaint or reapply the cycle superhighways after their work is completed. The Mayor is in the process of creating a procedure involving utilities renting the road for a specified time period. This effort is to discourage utility companies from breaking up the road for a longer period of time than needed.¹¹⁶

TfL stated that all works on TLRN are required to have a permit prior to their commencement. TfL's work co-ordination teams who have an overview of all works on the TLRN issue these permits. Therefore they are able to ensure that essential work by utilities or third parties caused the minimum of disruption.¹¹⁷

Challenges

Despite the reported positive results from using the schemes some challenges have arisen. Such challenges include the transparency of costs and benefits to the public, safety concerns and the supply and demand of facilities. The Mayor and TfL reflect on these challenges as lessons learned while planning their next course of action for future cycle schemes. These challenges are discussed below:

Transparency of Costs vs. Benefits

Although commuters benefit from both schemes financially—because it is the cheapest route compared to other means of transportation—there exists a lack of cost transparency to effectively measure the bundle of benefits that users receive from the cycle schemes. The public demands that the Mayor and TfL should provide more transparency about the cost and performance of these schemes so that Londoners know what they are actually getting for their money.¹¹⁸

Safety Concerns

Some people have shared concerns regarding the number of recent road incidents involving cycle hire scheme users and the potential for the incidents to increase with the roll out of casual users, which include tourists. Others have expressed that when using the cycle superhighways they were not respected by other road users. In some locations of the cycle superhighway, some users feel that the cycle lanes are too narrow. This has resulted in the space being occupied by other vehicles, lack of lane visibility at busy junctions or covered by parked vehicles.¹¹⁹

Supply and Demand

The cycle hire scheme is very popular among Londoners and tourists. However, the London Assembly Transport Committee reports that problems have developed with having adequate bikes and available docking points to meet the demand, particularly during peak hours. This has also resulted in poor customer service at call centers, as they were overwhelmed with the demand. With the planned expansion of this scheme by 2012, it is important that this problem be addressed. It is important that TfL come up with solutions to resolve these issues, as it is crucial to the success of the cycle hire scheme. Moving towards improvement, TfL should improve collaboration with the London boroughs to better meet demand and improve security at docking stations.

Mayor's & TfL's Response

The Mayor and TfL are currently planning improvements to address these challenges. In order to meet the supply and demand, TfL has revised their plan to deliver additional docking stations and bikes for London Boroughs. The plan consists of making sure demand is also met with the roll out of casual users. TfL is taking steps to resolve the issues at the call centers by hiring additional staff.

Additional improvements involving width expansion to the scheme is also on the list of topics. In a discussion with Wheels for Wellbeing, the Mayor has agreed to expand the cycle hire scheme by including "trikes" for wheelchair bound, or less mobile pedestrians. Although Serco expressed concern that it could be difficult to provide trikes, the Mayor and TfL are still considering this idea because it contributes to maximizing the benefits of the cycle hire schemes. They are also considering installing 20mph speed limits on specific parts of the cycle superhighway, installing 34 safety mirrors to improve visibility of cyclists.¹²⁰ In addition, they are planning to establish road expansion and install a two-way route for cyclists to improve safety. Further feedback and recommendations regarding road safety and lessons learned from current schemes will be announced at the upcoming committee meeting in the spring of 2011.

Conclusion

Before the roll out of the next cycle schemes, the Mayor and TfL are working on revised plans and the needed improvements while applying the lessons learned. It is evident the Mayor and TfL value the cycle schemes by the way they give attention to the concerns from the public. They want the public to value the scheme and therefore endeavor to meet the needs of the individual communities through initiatives. Keeping in mind with maximizing the benefits to the public, it is anticipated that the Mayor and TfL are also able to address the transparency of costs concerns to the public at the meeting in the near future, so that measuring the benefits of the cycle schemes are captured successfully.

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