Street Lighting in Milwaukee:

An Evaluation of Street Lighting Circuit Upgrade Costs and Benefits

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Foreword

Students in the master of public affairs program in the Robert M. La Follette School of Public Affairs at the University of Wisconsin–Madison produced this report for the Budget and Management Division of the Department of Administration in the City of Milwaukee. The opinions and judgments presented in the report do not represent the views, official or unofficial, of the La Follette School or of the clients for whom the students prepared the report.

The authors are enrolled in the Workshop in Public Affairs, the capstone course in their graduate program. The La Follette School offers a two-year graduate program leading to a master of public affairs or a master of international public affairs degree. The workshop provides practical experience applying the tools of analysis acquired during three semesters of coursework to actual issues clients face in the public, non-governmental, and private sectors. Students work in teams to produce carefully crafted policy reports that meet high professional standards within the timeframe of a single academic semester. The reports are research-based, analytical, and when appropriate, evaluative.

This report would not have been possible without the encouragement and leadership of the City of Milwaukee's dedicated employees. A University of Wisconsin–Madison Engage grant for collaborative work from the Division of Information Technology supported additional costs of this report, including travel costs of meeting with clients. The report also benefited greatly from the support of the staff of the La Follette School. Outreach Director Terry Shelton, along with Kari Reynolds, Mary Mead, and Gregory Lynch, contributed logistical and practical support. Karen Faster, La Follette publications director, edited the report and shouldered the task of producing the final bound document.

This report was generated primarily for the educational benefit of its student authors, and the purpose of the project was to improve their analytical skills by applying them to an issue with a substantial policy or management component. This culminating experience is the ideal equivalent of the thesis for the La Follette School degrees in public affairs.

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Executive Summary

The City of Milwaukee's street lights currently receive power from a combination of outdated and modern circuitry. Approximately 42 percent of Milwaukee's lighting system uses older series circuitry, while 58 percent of the system uses newer multiple circuitry. Over the past several decades, the City has been transitioning its series circuitry to multiple circuitry by targeting upgrades to circuits and substations that most frequently experience circuit outages. The outdated series circuitry is expensive for the City to maintain and repair because of costs related to additional repair time, the need for specialized knowledge of series circuitry, and the unique materials required for series circuit repairs. Our study analyzes implementation alternatives for upgrading a significant portion of Milwaukee's existing street lighting capacity over a six-year period, the length of a City of Milwaukee capital improvements plan.

This report reviews four alternatives for completing the street light circuit upgrade project. These alternatives include maintaining the status quo allocation of $1 million annually to the project (approximately 5.6 percent replacement of remaining series circuitry over six years), allocating $2 million annually (approximately 9.6 percent replacement of remaining series circuitry), allocating $12.1 million annually (50 percent replacement of remaining series circuitry), and allocating $24.6 million annually (100 percent replacement of remaining series circuitry). These alternatives were evaluated for cost-effectiveness and political feasibility through the use of cost-benefit, spatial, and funding analyses.

The results of our cost-benefit analysis indicate that the status quo is the most cost-effective alternative for the City of Milwaukee. This alternative offers the lowest net fiscal costs, as well as the lowest net total costs (which account for both the City government and the public at large). In contrast, 100 percent conversion of series circuitry is the least cost-effective alternative because it results in high net fiscal and net total costs.

The results of our political feasibility analysis are mixed. Our spatial analysis results indicate that the status quo results in a narrow distribution of street light upgrade benefits because the circuit upgrades will be concentrated in a small number of areas. This could result in limited political support from Common Council members and residents, especially if upgrades are not completed in a timely manner. In contrast, the larger-scale alternatives allow larger sections of the city to experience street light upgrades, which will likely attract more political support than the status quo.

Meanwhile, our funding analysis indicates that the status quo is the most politically feasible alternative for the City of Milwaukee. The status quo is relatively inexpensive for the City and does not require the City to make programmatic cuts in the capital budget or to raise additional revenue. In contrast, larger-scale

alternatives require additional funding sources and will likely result in financial burdens for the City and Milwaukee residents, making those alternatives less politically popular than the status quo.

Based on these results, we recommend that in the short term the City of Milwaukee maintain the status quo and continue to allocate $1 million annually to the street light upgrade upgrade project. However, our long-term recommendation is that the City of Milwaukee re-evaluate the street light upgrade project in six years.

Introduction

The City of Milwaukee is upgrading the circuitry in its street lighting system. Street light circuits are closed loops of wiring that carry electrical charges to power street lamps (Kuphaldt, n.d). Currently, most of Milwaukee's street light circuits are series circuits. Since the late 1960s, however, the City has been replacing series circuits with more up-to-date "multiple," or parallel, circuits in order to improve the reliability of the city's street lights and reduce the City's street light infrastructure maintenance expenses. The City of Milwaukee Budget and Management Division is investigating the efficiency and costs-savings of accelerating the street light upgrade project so that most or all circuit upgrades are completed within a six-year period. This study evaluates upgrading the remaining circuits according to the status quo rate and several alternative upgrade schedules by determining the costs and benefits that would accrue to the City and the general population of Milwaukee under each option.

Street Light System Background

The City of Milwaukee's street lighting program supports the City's strategic goal of "maintaining quality neighborhoods by enhancing the safety and security of residents and the aesthetics of neighborhoods" (City of Milwaukee, n.d.b). The primary objectives of the City's street light programs are to "illuminate city streets, alleys, and bridges in a cost effective manner, enhance safety and security of city residents, and enhance aesthetics of neighborhoods and business districts" (City of Milwaukee, n.d.a, p. 29). Street lighting has been thought to provide benefits including reduced on-street accidents and crime, increased perceptions of "warmth" and security, streetscape enhancement and stimulation of nighttime economic activity (Willis et al., 2005, p. 2289-90).

The Traffic Engineering and Electrical Services Division of the City of Milwaukee Department of Public Works (DPW) is responsible for constructing, maintaining and operating the City's lighting system (City of Milwaukee, n.d.a, p. 29). This system not only includes individual street lamps, but also circuitry, electrical substations (node facilities that provide electricity to the circuits), control systems, and other components. The City of Milwaukee began installing series circuits for street lights in the late 1910s and early 1920s, when this type of circuitry was preferred for incandescent lighting. Series circuits "operate at high voltage and use a single conductor wire for the distribution of electrical energy" (City of Milwaukee, n.d.a, p. 30). However, starting in the 1960s, the City began the process of transitioning their street light infrastructure from series circuitry to more modern multiple circuitry (Bell et al., 2009). As of 2007, Milwaukee's street light infrastructure was made up of 1,502 circuits, approximately 58 percent of which were multiple circuits (Bryson, 2009, 28 April) and approximately 42 percent of which were series circuits. Multiple circuits operate at lower voltages and use two or more conductor wires to distribute electrical energy. See *Appendix A* for additional information on series and multiple circuitry.

The different characteristics of series circuitry and multiple circuitry have impacts on how Milwaukee's street lighting system functions. Compared with multiple circuits, series circuits can serve larger areas and accommodate more lights per circuit. When series circuits fail, however, larger areas of the city can be affected than when multiple circuits fail.

The City of Milwaukee anticipates that replacing series circuitry with multiple circuitry will increase the operating efficiency of Milwaukee's street lighting system (Bell, 2009, 30 March). After an outage is reported to the DPW, the circuit experiencing the outage is to be repaired within 24 hours (Bell et al., 2009). However, series circuits are costly and time consuming to repair compared with multiple circuits. Each series circuit repair takes roughly six to eight hours and costs between $370 and $580, compared with an average of four hours and $270 to repair multiple circuits (Manzke, 2009, 11 February). Part of the overall cost difference can be attributed to the cost of series circuit components. The City of Milwaukee is the only remaining purchaser of the type of wire needed for its series circuits; in fact, the City had to persuade the wire manufacturer to resume production to ensure the City's supply of the wire for series circuitry maintenance. The series circuits also require unique ballasts for light connections, and the City must produce these ballasts themselves (Bell et al., 2009).[1]

Another component of the overall repair cost difference is the amount of time required for repairs. The underground location of series circuit ballasts accounts for some of the additional repair time for series circuits, but this additional time translates into greater labor costs for repairs. The expertise needed for working on series circuits also varies the labor costs per circuit repair. In the DPW's experience, most City electricians are familiar with how to work on multiple circuits. However, because the series circuitry is obsolete, the City must train new City electricians for a full year before they have the knowledge required to work on series circuits (Bell et al., 2009). This specialized training requires considerable time and City resources and limits the number of City staff that are capable of completing series circuit repairs.

These issues—materials, time, and labor costs—may be preventing the City of Milwaukee from addressing outages as efficiently as possible. Accelerating the process of upgrading from series to multiple circuits could reduce the expenses involved in making repairs. Moreover, there are fewer outages on multiple circuits than on series circuits, which suggests that by making the upgrade, DPW staff may have fewer overall outages to address (Bell et al., 2009). Additionally, the upgrade to multiple circuits will mean that it will take less time to repair outages, which may create additional benefits to the City and residents of Milwaukee by making the city's street lighting more reliable.

[1] Ballast is a coil of wire and/or related electric components that limits the amount of electric current flowing through a lamp (Jayne, 2009).

Secondary Benefits of Improved Street Lighting

Fewer overall circuit outages and decreased outage time may also have the secondary effect of lowering the cost of crime and changing the public's perception of crime. Although studies on the relationship between street lighting and crime and perceptions of crime draw generally positive conclusions (that lighting deters crime and perceptions of crime), the conclusions vary as to the magnitude and the nature of the effect. *Appendix B* discusses the available literature on the relationship between lighting and crime. Research on changes in public perception of crime after street light improvements also generally draws desirable conclusions, but because of the lack of data this factor was not included in the analyses described below.

Though the circuit upgrade may reduce crime and the perception of crime, it is important to remember that the project will only improve street light reliability, as opposed to increasing the brightness of the lights or introducing new lights into Milwaukee neighborhoods. Moreover, while street lighting may act as a psychological deterrent to offenders, it ultimately does not provide a physical barrier to crime (Painter, 1996, p. 200). For this reason, street lights are typically used in conjunction with a number of crime deterrence methods.

Policy Problem

The City of Milwaukee may benefit in a number of ways from completing most or all of the upgrade project over the course of six years (the length of a City of Milwaukee capital improvements plan), but the City must balance the benefits against the costs of making the upgrades. For the past several years, the City has allocated $1 million annually from the DPW capital budget for upgrading remaining series circuits (Bell et al., 2009). Using the current proportion of series and multiple circuits in the street lighting system and the amount of circuits that can be upgraded over the next six years at the status quo rate, our group estimates that it will take approximately 106 years to upgrade all of the remaining series circuits in Milwaukee.

The DPW employees target upgrades to those circuits with high outage rates and upgrade the entire substation to multiple circuitry (Bell et al., 2009). In spite of these procedures, a delay in upgrades could be a concern because it would delay the cost savings that the City may gain from completing the project. These cost savings would accrue to the DPW budget that funds circuit maintenance and repairs (Bell et al, 2009). Also, many Milwaukee series circuits are past their useful life of approximately 30 to 40 years (Bell et al., 2009). While much of the series circuitry performs adequately despite being past this threshold, it is unclear whether and how the functionality of these circuits will deteriorate over the coming years and how any deterioration might contribute to increases in outages.

The costs associated with accelerating the upgrade could also be significant. The City would incur expenses from purchasing multiple circuit components, including wiring, ballasts, and new street light circuit substations. The City would also have to pay labor costs to have the upgrades completed. Depending on the number of circuit upgrades the City seeks to complete over the six years, there may not be a sufficient number of electricians in the DPW to perform the work, requiring the City to hire subcontractors though the DPW estimates that its costs to perform work are 29 percent lower than the cost of contract work. Having the upgrades completed by subcontractors could cost an estimated 29 percent more than having the work performed by City electricians (Manzke, 2009, 13 March). Funding for the capital upgrades would come from the DPW capital budget, which is approximately $70 million (Bell, 2009, 26 March). Dramatic increases in the scale of the upgrade could mean that additional funds would need to be raised or diverted from other projects that fall under the DPW capital budget.

Policy Alternatives

Our group seeks to help the City of Milwaukee evaluate the costs and benefits of four street light circuitry upgrade alternatives, which represent different rates and funding levels for completing the project. Each of the upgrade alternatives outlined below would take place over six years, the length of a City of Milwaukee capital improvements plan. The status quo upgrade alternative entails a capital outlay of $1 million annually (approximately 5.6 percent replacement of remaining series circuits), while the remaining three alternatives include an increase in capital outlays to $2 million annually (approximately 9.6 percent conversion of remaining series circuits), an increase in capital outlays to $12.1 million annually (50 percent replacement of remaining series circuits), and an increase in capital outlays to $24.6 million annually (100 percent replacement of remaining series circuits). The dollar amounts discussed under each of the alternatives would not be spent on repairing or maintaining existing series or multiple circuits; they would be used solely for replacing series circuits with multiple circuits. Table 1 presents the costs and the amount of circuitry converted under each of the alternatives.

Table 1: Policy Alternatives

Alternative	Status Quo	Alternative 1	Alternative 2	Alternative 3
Percentage of Remaining Series Circuits To Be Converted	5.6%	9.6%	50%	100%
Percentage of Total Circuitry To Be Converted	2.37%	4.0%	21.0%	42.0%
Annual Outlay	$1 million	$2 million	$12.1 million	$24.6 million
Total Six-Year Cost	$5.5 million	$11 million	$66.7 million	$135.6 million

Source: Authors' calculations

Status Quo: Capital Outlays of $1 Million Annually Over the Next Six Years (Approximately 5.6 Percent Conversion of Remaining Series Circuits)

Under the status quo, the City of Milwaukee would continue to allocate $1 million annually to upgrading remaining series circuits over the next six years, incurring a total six-year cost of $5.5 million (accounting for inflation). After the six-year project life, approximately 5.6 percent of the City's existing series circuits would be upgraded to multiple circuits. Assuming a constant allocation of $1 million annually, we estimate that it would take 106 years to completely upgrade the street lighting system to multiple circuitry.

Alternative 1: An Increase in Capital Outlays to $2 Million Annually Over the Next Six Years (Approximately 9.6 Percent Conversion of Remaining Series Circuits)

Under this alternative, the City of Milwaukee would increase capital outlays to $2 million annually over the next six years, incurring a total cost of $11 million. Just as under the status quo, this additional $1 million annually would be used solely for converting series circuits to multiple circuits. After the six-year project life, approximately 9.6 percent of the City's remaining series circuits would be upgraded to multiple circuits. Assuming a constant allocation of $2 million annually, we estimate that it would take 63 years to upgrade all series circuits to multiple circuits.

Alternative 2: An Increase in Capital Outlays to $12.1 Million Annually Over the Next Six Years (50 Percent Conversion of Remaining Series Circuits)

Under this alternative, the City of Milwaukee would increase capital outlays to $12.1 million annually to replace 50 percent of remaining series circuits with multiple circuits over the course of six years. The total six-year cost of this alternative would be $66.7 million. As mentioned previously, funds would be used solely for converting the remaining series circuits to multiple circuits; multiple circuits already in place would not be replaced. Assuming a constant allocation of $12.1 million per year, we estimate that it would take 12 years to upgrade all series circuits to multiple circuits.

Alternative 3: An Increase in Capital Outlays to $24.6 Million Annually Over the Next Six Years (100 Percent Conversion of Remaining Series Circuits)

Under this alternative, the City of Milwaukee would increase capital outlays to $24.6 million annually to replace all remaining series circuits with multiple circuits over six years. The total six-year cost of this alternative would be $135.6 million. Multiple circuits already in place would not be replaced. Assuming a constant allocation of $24.6 million annually, we estimate that it would take six years to upgrade all remaining series circuits to multiple circuits.

Time Horizons for Full Replacement

We estimate the time horizons for full replacement of remaining series circuitry using the proportion of the remaining lighting capacity upgraded per year. This proportion varies by alternative. For example, the status quo upgrades 0.94 percent of the remaining lighting capacity per year, so it takes 1/.0094=106 years to upgrade the remaining circuitry if upgrades continue at the current rate. Table 2 displays the time horizons for full replacement.

Table 2: Time Horizons for Full Replacement

Alternative	Status Quo	Alternative 1	Alternative 2	Alternative 3
Proportion of Remaining Street Lighting Capacity Upgraded per Year	0.94%	1.60%	8.33%	16.67%
Replacement Horizon	106 years	63 years	12 years	6 years

Source: Authors' calculations

Evaluation Criteria

Our group used two criteria to evaluate the four alternatives: cost-effectiveness and political feasibility.

Cost-Effectiveness

Street light circuit upgrades are costly because the project requires materials, labor, and other resources that the City of Milwaukee must fund. On the other hand, the street light upgrade project offers a number of potential benefits including decreased maintenance costs and increased public safety. Because the City plans to move forward with the upgrade project, such costs and benefits will likely be experienced at some point. Depending on the schedule of the upgrades, however, the costs may overwhelm the benefits for some of the policy alternatives. The most preferable alternative is the alternative that has the highest net benefit or lowest net cost.

Political Feasibility

Politically relevant benefits of the circuitry upgrade project include the potential safety and amenity benefits of more reliable street lighting, while politically relevant costs include the incidence of funding burdens associated with this project and how the public and City officials perceive such burdens. Public and political support for each alternative is likely to change depending on the location of the street light upgrades and the scale of upgrades. Upper level officials of the City of Milwaukee Budget and Management Division and DPW, the Mayor of the City of Milwaukee, the City of Milwaukee Common Council, and Milwaukee residents are all key stakeholders when determining the political feasibility of each alternative upgrade schedule.

Methodology

This section discusses the methodology used to evaluate the status quo and the three alternatives outlined in this report. The techniques used in this analysis are organized by evaluation criteria.

Cost-Effectiveness

Our group evaluated the cost-effectiveness of the upgrade alternatives using both cost-benefit and fiscal analyses. The cost-benefit analysis includes the costs and benefits incurred by both the City of Milwaukee government and the city's general population, and it identified the net costs under each alternative. This allowed for an examination of the impacts on everyone likely to be affected by the street light circuitry upgrade. The fiscal analysis focused on the costs and cost savings that would be experienced by the City of Milwaukee government under each alternative. This type of analysis enables the Budget and Management Division to understand the likely impact on City revenues and expenditures.

For both the cost-benefit and fiscal analyses, we assigned costs over the six-year life of the upgrade project. Benefits, however, were projected over a 50-year span, the average useful life of a multiple circuit (Bell et al., 2009). We calculated all costs using 2008 dollars and discounted at a rate of 3.5 percent. The costs and benefits included in these analyses are listed below.

Capital Upgrade Costs (Cost Benefit and Fiscal Analyses)

The capital upgrade cost includes all parts and labor related to converting series circuits to multiple circuits. In each case, we discounted the annual cost of the upgrade project to 2008 dollars at a rate of 3.5 percent and summed these costs over the six-year life of the project. Table 3 presents the capital upgrade costs for all alternatives. The methodology for calculating these costs for each alternative is described below.

Table 3: Capital Upgrade Costs Over Six Years (2008 dollars)

Year	Status Quo	Alternative 1	Alterative 2	Alternative 3
Year 1	($1,000,000)	($2,000,000)	($12,086,000)	($24,580,000)
Year 2	($966,000)	($1,932,000)	($11,677,000)	($23,749,000)
Year 3	($934,000)	($1,867,000)	($11,282,000)	($22,946,000)
Year 4	($902,000)	($1,804,000)	($10,091,000)	($22,170,000)
Year 5	($871,000)	($1,743,000)	($10,532,000)	($21,420,000
Year 6	($842,000)	($1,684,000)	($10,176,000)	($20,696,000)
Total	***($5,515,000)***	***($11,030,000)***	***($66,653,000)***	***($135,663,000)***

Source: Authors' calculations

Status Quo: Capital Outlays of $1 Million Annually Over the Next Six Years (Approximately 5.6 Percent Replacement of Remaining Series Circuits)

For the status quo, the capital upgrade cost would be the annual amount being allocated to the upgrade project, $1 million. The total capital upgrade cost for the status quo would be $5.5 million. Under this alternative, the City would upgrade approximately 0.9 percent of the remaining series circuitry each year. The upgrade percentage for the status quo was calculated by dividing the yearly capital allocation ($1 million) by the total cost of a 100 percent conversion if the entire conversion were to be completed using City labor (roughly $106 million).

Alternative 1: Capital Outlays of $2 Million Annually Over the Next Six Years (Approximately 9.6 Percent Replacement of Remaining Series Circuits)

For Alternative 1, the capital upgrade cost would be the annual amount being allocated to the upgrade project, $2 million. The total capital upgrade cost for this alternative would be $11 million. It is important to note that under Alternative 1, the City would experience dis-economies of scale because of the cost premium associated with contracted labor. Unlike the status quo, Alternative 1 would require that additional labor be hired to accommodate the larger project. The City currently has the capacity to complete $1 million of series circuit upgrades per year, and it is assumed that the remaining $1 million of series circuit upgrades would be completed using contract labor, although our sources indicate that the City cost of performing work is 29 percent lower than contract work (Manzke, 2009, 10 March). For this reason, the City would not complete upgrades under Alternative 1 as efficiently as it would complete upgrades under the status quo.

Only 1.6 percent of the remaining series circuits would be upgraded per year under Alternative 1. We calculated the upgrade percentage for Alternative 1 by splitting the yearly capital allocation ($2 million) into upgrades completed by City labor and upgrades completed by contractors ($1 million and $1 million, respectively). Each $1 million in contract labor purchases roughly $710,000 worth of City work. Finally, we summed the City and contract labor values. We then divided this value by the total cost of a 100 percent conversion if the entire conversion were to be done by City labor (roughly $106 million).

Alternative 2: Capital Outlays of $12.1 Million Annually Over the Next Six Years (50 Percent Replacement of Remaining Series Circuits)

We determined the capital upgrade cost for Alternative 2 by estimating the total cost to replace 50 percent of the remaining series circuits, assuming the City would complete all work. We calculated the cost of the upgrade by adding the substation costs, lighting unit costs, and substation reconfiguration costs, using City figures (Manzke, 2009, 3 April). The substation cost was determined by multiplying the installed unit cost per substation (including the cost of installation labor) by the number of additional substations needed to accommodate the new multiple circuits. We determined the lighting unit cost by multiplying the cost per lighting unit by the number of lighting units to be upgraded. Finally, we determined the substation reconfiguration cost by multiplying the cost per substation by the number of substations to be reconfigured. Table 4 presents the capital upgrade costs associated with Alternatives 2 and 3.

Table 4: Capital Upgrade Costs for Alternatives 2 and 3

Item	Cost Per Unit Including Installation Labor	Number for 50% Replacement (Alternative 2)	Number for 100% Replacement (Alternative 3)
Lighting Units	$3,500	14,178	28,355
Pad Mount Substations	$25,000	50	100
Substation Reconfiguration	$100,000	23	46

Source: Manzke, 2009, 3 April.

The sum of these costs represents the total upgrade costs if the entire upgrade project were completed in year one using City labor, so we divided this figure by six to obtain the annual upgrade cost to spread it over the six-year period. To account for the cost premium of contract labor, we separated circuit upgrade work for each year into work that would be completed using only City labor, $1 million and work that would be completed by a third-party contractor. The work that would be completed by a third-party contractor was multiplied by 1.41 to account for City labor costing 29 percent less (Manzke, 2009, 10 March).[2] We discounted each annual cost to 2008 dollars at a rate of 3.5 percent and summed this value over six years.

[2] City costs = 0.71 * contract costs
1/.71=1.41→ Contract costs = 1.41 * city costs

Alternative 3: Capital Outlays of $24.6 Million Annually Over the Next Six Years (100 Percent Replacement of Remaining Series Circuits)

We determined the capital upgrade cost for Alternative 3 using the same methodology as Alternative 2. Alternative 3, however, involves different amounts of lighting units and substations. Table 4 above presents the capital upgrade costs associated with Alternative 3.

Benefits Resulting from Avoided Series Circuitry Maintenance Costs (Cost-Benefit and Fiscal Analyses)

We determined avoided circuitry maintenance costs by developing an estimate of the cost savings that would accrue from 1) making repairs on a street light system composed of series circuits rather than multiple circuits and 2) having to make fewer overall repairs. Multiple circuits are more reliable than series circuits, and series circuits fail roughly twice as frequently as multiple circuits when the number of circuit failures is standardized for direct comparison. In 2007, there were 1,465 series failures, 896 multiple failures, and 2,485 total circuit failures.[3] In 2008, there were 1,044 series failures, 708 multiple failures, and 1,912 total circuit failures.

These numbers are not directly comparable, however, so we made comparisons by estimating the number of failures that would occur if 100 percent of Milwaukee's lighting capacity used one type of circuitry. We made this estimation using the number of series and multiple circuit failures and the proportion of lighting capacity on series and multiple circuitry. For example, in 2008, multiple circuits were 58 percent of lighting capacity and there were 708 multiple failures. Therefore, if 100 percent of City street lights used multiple circuits, there would be 708*(1/0.58)=1,221 failures in 2008. Table 5 presents the circuit types and failure rates for 2007 and 2008.

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[3] The series and multiple failures do not sum to total circuit failures because our data set included outages that did not identify a circuit or identified "ALL" circuits. In these cases, we could not determine if the recorded outages affected series circuits or multiple circuits.

Table 5: 2007 and 2008 Failure Rates by Circuit Type

	2007	2008	Total
Series Failures	1,465	1,044	3,029
Multiple Failures	896	708	1,604
Total Failures	2,485	1,912	4,397
Series Proportion, as Percentage of City Lighting Capacity	42.9%	42.0%	--------
Multiple Proportion, as Percentage of City Lighting Capacity	57.1%	58.0%	--------
Number of Failures if 100% of Capacity is in Series Circuits	3,415	2,486	5,901
Number of Failures if 100% of Capacity is in Multiple Circuits	1,569	1,221	2,790

Sources: Manzke, 2009, 10 March; authors' calculations.

As described previously, multiple circuit repairs are less expensive and less time-consuming than series circuit repairs. As a result of the upgrade project, we expect that the City would save roughly $100 to $310 in operation and maintenance funds for each multiple circuit repair as opposed to a series circuit repair. The value we used for the cost difference per repair ($205) is the average of the high and low values ($100 to $310) of the difference in circuit repair costs. Since the lighting system is expected to experience fewer overall failures as circuit conversion takes place, we estimated the number of fewer outages per year and multiplied this by the full cost of making a series circuit repair ($475) to calculate the cost savings from making fewer repairs.

We multiplied the cost difference per repair ($205) by the total number of outages per year (2,199 in base year, decreasing thereafter and varying by year and alternative) and the percentage of total circuits that would be converted to multiple circuits to determine the yearly cost savings from repairing multiple circuits as opposed to series circuits. This figure was added to the cost savings from making fewer repairs, the calculations for which are described above. Estimated reductions in overall outages vary by year and alternative, and the full cost of a series circuit repair, as opposed to average overall repair costs, was used for the sake of conservative estimates. The benefit from reduced maintenance costs varies for each of the first six years, and remains constant (in nominal dollars) after the upgrade is completed. Table 6 outlines the proportions of the total City lighting capacity that would use multiple circuits in each year of the upgrade plan for each alternative.

Table 6: Multiple Circuitry
as a Proportion of Total Lighting Capacity (%)

Year	Status Quo	Alternative 1	Alternative 2	Alternative 3
Base Year	58.00	58.00	58.00	58.00
Year 1	58.94	59.60	61.50	65.00
Year 2	59.88	61.20	65.00	72.00
Year 3	60.82	62.80	68.50	79.00
Year 4	61.76	64.40	72.00	86.00
Year 5	62.70	66.00	75.50	93.00
Year 6	63.64	67.60	79.00	100.0

Sources: Bell et al., 2009; authors' calculations.

We estimated the reduction in overall circuit failures using the difference of the probability of circuit failure between series and multiple circuits (series circuits experience approximately 0.65 more outages per circuit per year than multiple circuits) and an estimate of the number of circuits replaced per year (varies by alternative and year). These figures also account for the difference in the number of overall circuits, as multiple circuits cover less area and fewer lighting units than series circuits. These calculations also used estimates for the number of lighting units on a series or multiple circuit to convert between lighting units and circuits (though in reality this number varies for each circuit). See *Appendix C* for a detailed explanation of this conversion rate. Table 7 presents the reductions in overall circuit failures over the course of six years.

Table 7: Reductions in Overall Circuit Failures

	Status Quo	Alternative 1	Alternative 2	Alternative 3
Year 1	5	8	44	87
Year 2	10	18	87	174
Year 3	15	26	131	262
Year 4	20	35	174	349
Year 5	25	44	218	436
Year 6	30	53	262	523

Source: Authors' calculations

We calculated yearly benefits for each of the first six years to account for the different proportions of upgraded circuits and then projected these benefits over 50 years. The benefits were calculated in 2008 dollars using a 3.5 percent discount rate and were summed over 50 years.

Because the benefits from maintenance savings are directly proportional to the number of circuits converted, and the City would convert fewer circuits per dollar beyond $1 million worth of work, returns from maintenance savings would decrease as the City invests more than $1 million in annual capital upgrades.

Benefits Resulting from Avoided Crime Costs (Cost Benefit Analysis)

We determined the crime reduction benefits of circuitry upgrades by assessing the difference in the number of crimes occurring within spaces served by series and multiple circuits during times when the circuits have failed and street lights have gone out. Series circuits and multiple circuits differ both in terms of the square miles of the city that they are estimated to serve (0.09 and 0.05 square miles, respectively), and the amount of hours it takes to repair them (an average of 7 hours and 4 hours, respectively). The City would experience fewer overall outages as circuit conversions take place. Because of these differences, we assumed that series and multiple circuit outages create different impacts in terms of crime and costs.

Appendix C provides a comprehensive discussion of how a dollar figure representing this difference in outage-related crime costs was calculated. In sum, we calculated the average number of incidents for eight types of potentially lighting-related crimes in the City of Milwaukee per square mile per hour. We multiply these incidents by the number of square miles that each series or multiple circuit serves, along with the number of hours that the street lights on that circuit would not be functioning while the circuit was being repaired. Finally, we multiplied each set of incidents by a factor of 8 percent, which represents the percentage of crime that is likely attributable to poor lighting. This factor, explained in *Appendices B* and *C*, was based on a review of studies evaluating the relationship between street lighting and crime in U.S. cities (Farrington and Welsh, 2007, p. 215). Table 8 provides an example of how we calculated assault incidents for series and multiple circuit outages.

Table 8: Estimated Lighting-Related Assaults per Circuit Outage

	Series Circuits	Multiple Circuits
Average Number of Crimes per Square Mile	92	92
Square Miles per Circuit	0.09	0.05
Assaults per Circuit Service Area per Year	8	5
Assaults per Circuit Area per Hour	0.00095	0.00053
Percents of Assaults due to Lighting	0.08	0.08
Assaults per Circuit per Hour due to Lighting	0.00008	0.00004
Hours Required for Outage Repair	7	4
Lighting-Related Assaults per Outage	0.00207	0.00074

Sources: Manzke, 2009, 11 February; authors' calculations.

We then multiplied the number of incidents of each of the eight crimes that would occur per multiple or series circuit outage by a corresponding estimate of the cost of each type of crime. We then summed the total costs of each type of crime to get an overall cost of crime per series or multiple circuit outage. The difference between the total cost per outage for series and multiple circuits was $33.

To determine the yearly avoided cost of crime, we multiplied the avoided cost per circuit failure ($33) by the number of outages per year and the percentage of total circuits that would be converted to multiple circuits. The percentage of total circuits that would be converted to multiple circuits is assumed to vary for years one through six and remain constant for years six through 50. The percentage of total circuits that would be converted does not include the proportion of circuits that had already been converted prior to the six-year upgrade plan.

We calculated yearly benefits for each of the first six years to account for the different proportions of upgraded circuits. These benefits were then projected over the course of 50 years, discounted to 2008 dollars and summed. Because the benefits from avoided crime are directly proportional to the number of circuits converted, and the City converts fewer circuits per dollar beyond $1 million worth of work, returns from avoided crime decrease as the City invests more than $1 million in annual capital upgrades.

Best-Case and Worst-Case Scenario Analysis

For a number of these variables, the data available may be inconsistent, unreliable, or reflect ranges other than the point estimates used in the analysis. To address these issues, we analyzed the best-case scenario and worst-case scenario for each alternative by varying several of the cost and benefit parameters. The parameters that were varied include the number of series circuit failures per year, the cost associated with series circuit repairs, the crime costs associated with street light outages, and the reduction in circuit failures per year. The best-case scenario reflected the most desirable estimates of these parameters in terms of the benefits the upgrade project would generate, while the worst case scenario examined net benefits using the least desirable estimates. More information about the best-case and worst-case scenario analysis is available in *Appendix D.*

Political Feasibility

We evaluated the political feasibility of each alternative based on how that alternative's implementation would affect both the geographic distribution of circuit upgrades and the impacts associated with funding those upgrades.

Spatial Analysis

Residents and businesses in Milwaukee would experience the benefits and costs of the upgrade project depending on the number of circuit conversions scheduled for their area. If the entire upgrade project is completed within a relatively short period, the geographically incurred political conflict in response to upgrade scheduling would likely be minimal. If, however, the upgrade effort stretches out for a long period of time, communities that may not receive upgrades until the end of the project may be more likely to complain to their district Council member. As previously mentioned, the DPW follows the policy of upgrading the circuits experiencing the most frequent outages first and upgrading the entire substation rather than individual circuits. This policy will likely produce the most cost savings for the City of Milwaukee because of reduced repair and maintenance costs. If many unreliable circuits are concentrated in only a few districts, however, Council members in districts with few or no upgrades scheduled may fight implementation of that scheduling alternative because the series circuits in their districts may not receive upgrades to multiple circuitry in the foreseeable future. As a result, their constituents would not receive the immediate benefits of the street light upgrade.

To assess the relevance of these issues to each alternative, our group identified the locations of series circuits that have experienced the most frequent outages and compared their locations to the borders of the Common Council districts. We identified series circuits with high failure rates using outage data provided by the DPW (City of Milwaukee, 2008a). *Appendix E* outlines the spatial analysis methodology in greater detail. It is important to note that the spatial analysis assumes that the substations will be upgraded according to their failure rates and does not take into account any outside factors that may influence where and in what order the upgrades would take place, such as coordination with street-paving projects.

Funding Analysis

We addressed other elements of political feasibility through a funding analysis. This involved discussions with representatives of the City of Milwaukee Department of Administration's Budget and Management Division, the DPW, and others to ascertain the potential incidence of funding burdens. Depending on the rate at which the City of Milwaukee seeks to complete series circuit upgrades, the City may need revenues to supplement current capital outlays. To generate these revenues, the City may choose to issue additional bonds or propose new taxes; these options would spread costs across residents and businesses throughout the City. Alternatively, the City could charge special assessments to residents or businesses located near series circuits to get upgrades completed; this would place the burden on specific individuals or groups. Levels of political support are likely to vary for each funding alternative.

Data

The DPW provided data regarding the number and location of existing series and multiple circuits (and related components) (City of Milwaukee, 2008a). The DPW also provided information on the costs related to maintaining and repairing series circuits as well as on the costs of installing multiple circuits. We used data from the Milwaukee Police District Statistics website on criminal activity in Milwaukee to incorporate crime costs into the cost-benefit analysis (City of Milwaukee, 2008b). The techniques used to incorporate this data into the cost-benefit, fiscal, and political feasibility analyses are discussed in appendices as appropriate.

Assumptions

We made several assumptions in order to determine the results of this analysis. First, street light upgrades are assumed to take place according to substation viability. That is, those substations that experience the most outages would be upgraded before the substations with few or no outages. Another assumption was that series circuit failures would continue at the present rate**.** A third assumption was that no energy savings are associated with an upgrade from series circuits to multiple circuits (Bell, 2009, 30 March). A fourth assumption was that the upgrade from series circuits to multiple circuits would not change the probability that the City will be able to collect compensation related to circuit damages caused by a third party.

Results

This section presents the results of the analyses of the status quo and the three alternatives based on cost-effectiveness and political feasibility criteria.

Cost Effectiveness

This section presents the results of the report's cost-benefit analysis, fiscal analysis, and best-case and worst-case scenario analyses.

Cost-Benefit Analysis Results

Table 9 summarizes the results of the cost-benefit analysis. As the table shows, the City experiences net fiscal and net total costs for all of the alternatives. The status quo, however, yields the lowest net fiscal and net total costs for the City of Milwaukee while Alternative 3 yields the highest net fiscal and net total costs.

Table 9: Cost-Effectiveness Analysis Results

Costs	Status Quo	Alternative 1	Alternative 2	Alternative 3
Capital Upgrade Costs	($5,500,000)	($11,000,000)	($66,700,000)	($135,600,000)
Reduction in Maintenance Costs	$900,000	$1,500,000	$4,800,000	$9,600,000
Net Fiscal Costs	*($4,600,000)*	*($9,500,000)*	*($61,900,000)*	*($126,000,000)*
Avoided Crime Costs	$100,000	$200,000	$600,000	$1,200,000
Net Total Costs	*($4,500,000)*	*($9,300,000)*	*($61,100,000)*	*($124,800,000)*

Source: Authors' calculations

Status Quo: Capital Outlays of $1 Million Annually Over the Next Six Years (Approximately 5.6 Percent Replacement of Remaining Series Circuits)

The status quo would impose the least fiscal and total costs for the City, with net values of $4.6 million and $4.5 million, respectively. This results from the low capital upgrade costs and the benefits associated with reduced series circuitry maintenance costs and avoided crime costs. Under this alternative, the City would experience the lowest capital upgrade costs (approximately $5.5 million) over six years, because of the small amount of circuitry being replaced. Meanwhile, there would be benefits of $900,000 in avoided maintenance costs and $100,000 in avoided crime costs.

Alternative 1: Capital Outlays of $2 Million Annually over the Next Six Years (Approximately 9.6 Percent Replacement of Remaining Series Circuits)

Alternative 1 is the next best alternative in terms of net fiscal and net total costs, with values of $9.5 million and $9.3 million, respectively. Alternative 1 would require approximately double the capital upgrade costs of the status quo, ($11 million) and would accrue a bit less than double the benefits associated with reduced series circuitry maintenance costs ($1.5 million) and avoided crime costs ($200,000).

Alternative 2: Capital Outlays of $12.1 Million Annually Over the Next Six Years (50 Percent Replacement of Remaining Series Circuits)

Alternative 2 would entail net fiscal costs of $61.9 million and net total costs of $61.1 million. These large net costs occur because of the large increase in capital upgrade costs ($6.7 million) but relatively small increases in benefits associated with reduced series circuitry maintenance costs ($4.8 million) and avoided crime costs ($600,000).

Alternative 3: Capital Outlays of $24.6 Million Annually Over the Next Six Years (100 Percent Replacement of Remaining Series Circuits)

Alternative 3 would involve the highest net fiscal costs ($126 million) and net total costs ($124.8 million). These large net costs are the result of high capital upgrade costs of $135.6 million and relatively small increases in benefits associated with the upgrade. In this instance, the benefits associated with reduced series circuitry maintenance costs would be $9.6 million, and the benefits associated with avoided crime costs would be $1.2 million.

Best-Case and Worst-Case Scenario Analysis

Tables 10 and 11 present the results of the best-case and worst-case scenario analysis. Table 10 shows the net fiscal costs associated with each alternative under the best-case scenario, the original cost-benefit calculations, and the worst-case scenario (as defined in *Appendix D*). Table 11 presents the net total costs associated with the best-case scenario, the original cost-benefit calculations, and the worst-case scenario for each alternative.

Table 10: Best-Case and Worst-Case Scenario Analysis, Net Fiscal Costs

Net Fiscal Costs	Status Quo	Alternative 1	Alternative 2	Alternative 3
Best-Case Scenario	$4,000,000	$8,400,000	$58,900,000	$119,900,000
Projected	$4,600,000	$9,500,000	$61,900,000	$126,000,000
Worst-Case Scenario	$5,100,000	$10,300,000	$64,200,000	$130,700,000

Source: Authors' calculations

Table 11: Best-Case and Worst-Case Scenario Analysis, Net Total Costs

Net Total Costs	Status Quo	Alternative 1	Alternative 2	Alternative 3
Best-Case Scenario	($3,600,000)	($7,600,000)	($56,600,000)	($115,400,000)
Projected	($4,500,000)	($9,300,000)	($61,300,000)	($124,800,000)
Worst-Case Scenario	($5,100,000)	($10,300,000)	($64,200,000)	($130,700,000)

Source: Authors' calculations

The results of the best-case and worst-case scenario analysis align closely with the results of the cost-benefit analysis. The status quo remains the alternative with the lowest net fiscal costs under both the best-case scenario and the worst-case scenario and the lowest net total costs under both the best-case scenario and worst-case scenario. Alternative 3 remains the least cost-effective of all the alternatives for both the best-case scenario and worst-case scenario.

Political Feasibility

This section presents the results of the political feasibility analysis. The status quo and the three alternatives' implications for the geographic distribution of upgrade benefits and funding burdens are outlined below.

Spatial Analysis

The spatial analysis indicates that 61 substations experienced one or more series circuit failures during 2008. *Appendix F* identifies the substations with the highest rates of series circuit outages and the Common Council districts in which these problematic substations are located. *Appendix G* provides a map of the Common

Council districts in Milwaukee. Table 12 summarizes the results of the spatial analysis, and the implications of these results are discussed below.

Status Quo: Capital Outlays of $1 Million Annually Over the Next Six Years (Approximately 5.6 Percent Replacement of Remaining Series Circuits)

Approximately 58 percent of Milwaukee's series street light circuits have been upgraded to multiple circuits since the start of the upgrade project in the 1960s (Bryson, 2009, 28 April). Continuing the current policy of replacing the circuits experiencing the highest failure rates first would be a short-term solution to the problems related to series circuits. After six years, the status quo would have only upgraded 5.6 percent of the city's street lighting capacity. Under this option, certain Common Council districts in Milwaukee might not receive substation upgrades for the foreseeable future. Districts that are experiencing or will experience low to mild levels of series circuit outages would be superseded by the needs of more troublesome areas.

The 9th and 11th Common Council districts are experiencing the most frequent outages and will likely be targeted first for upgrades. Because the circuit upgrade benefits of the status quo would be confined to these two districts, areas receiving the upgrades would likely provide solid political support while Council members and residents of the areas not receiving priority in the upgrade project might begin to voice political opposition.

While a select number of Common Council districts in the city are plagued by heavy series circuitry outages, this amount could change over the course of six years. This analysis assumes that rates of series circuit failures will remain constant over time, but because all of the series circuits in the city are beyond their estimated lifespan, increases in outage rates may result from an accelerated deterioration in circuit quality. For example, at the current replacement rate it would take the City of Milwaukee 106 years to upgrade all of its circuitry to multiple circuits. Series circuits currently in the system would certainly not be able to remain operational over this long time period. Our study was unable to determine whether the series circuit failure rates are likely to increase or when an increase in failure rates may take place.

As a result, Common Council districts that are currently experiencing low to mild levels of series circuitry outages, such as the 1st, 12th, and 14th, could begin to experience increases in series circuit outages if the series circuits start to rapidly deteriorate. If this were to occur, many of the 15 Common Council districts would be in need of timely upgrades, but the City would not be able to respond adequately to this increase in demand because the status quo does not provide the resources for the City to respond to a sharp increase in outages. This potential problem could lead to increased political pressure from residents and elected representatives alike.

Alternative 1: An Increase in Capital Outlays to $2 Million Annually Over the Next Six Years (Approximately 9.6 Percent Replacement of Remaining Series Circuits)

Alternative 1 nearly doubles the conversion rate of the status quo because 9.6 percent of the series circuits rather than 5.6 percent would be replaced in six years. If the City continues to first upgrade series circuits with the highest rates of failure, one implication of this alternative would be that locations experiencing the most frequent circuit outages would be upgraded in a shorter time span. In particular, the spatial analysis indicates that the 5th, 6th, 9th, and 11th Common Council districts are experiencing the highest series circuit failure rates, and these districts are spatially distributed between the north and south sides of the city. Council members and residents on the north and south sides of the city would be more likely to support this alternative because it would allocate more resources to their areas. As many of the substations lie on or near the borders of Common Council districts, replacing the circuits may likely provide benefits to more than one Common Council district at a time. This could prove to be politically important because the City officials could garner a wider base of support for this alternative.

This alternative, however, would upgrade only 9.6 percent of the city's entire street lighting capacity, so its effects would still be very limited and localized to a few areas of the city. This alternative would not allow for upgrading all of the districts identified as experiencing high outage rates and would not be large enough in scope to upgrade the areas experiencing fewer outages. Areas on the east and west sides of Milwaukee would not be upgraded in a timely fashion, and this could produce political opposition if their failure rates increase. Moreover, as with the status quo, under Alternative 1 the City would not have the resources to accommodate additional upgrades if the series circuits begin to fail more frequently than at the current rate.

Alternative 2: An Increase in Capital Outlays to $12.1 Million Annually Over the Next Six Years (50 Percent Replacement of Remaining Series Circuits)

This alternative would more rapidly upgrade outage-prone series circuits on the north and south sides of Milwaukee, while also replacing a number of series circuits in areas of the city experiencing less frequent outages. Specifically, substations experiencing 14 or more failures per year would be slated for upgrades, assuming the City would continue to follow its current practice of upgrading the substations with the most series circuit failures first. Expanding the scope of the upgrade project would provide benefits to more Common Council districts and residents, thus likely generating more political support. In particular, the spatial analysis indicates that the 8th, 12th, and 14th Common Council districts have substations with mild levels of series circuit failures. Under the status quo and Alternative 1, these areas of the city would not be scheduled for upgrades, because the resources would not be available to do so.

The areas of the city that would not be receiving upgrades within six years are the areas that have substations currently experiencing the lowest series circuit failure rates (substations with fewer than 14 failures per year). It is unlikely that the residents and Council members of such areas would provide strong political opposition to this alternative for a number of reasons. First, within the span of six years these areas could experience a sharp increase in their series circuit failure rates. If sharp increases in failure rates were to occur, however, the City would have enough resources to begin to upgrade the street lights in these areas. Second, the expanded scope of this project may draw wider support from the Common Council, thus making it difficult for a couple of Council members to voice opposition to a politically popular project. This alternative would distribute the benefits to a larger geographic area of the city, and by doing so may insulate it from being perceived as providing political benefits to a narrow constituency.

Alternative 3: An Increase in Capital Outlays to $24.6 Million Annually Over the Next Six Years (100 Percent Replacement of Remaining Series Circuits)

Converting all of the city's remaining series circuits to multiple circuits within six years would entail a very short project time span when compared with the 58 percent series circuit replacement that has occurred since the 1960s (Bryson, 2009, 28 April). The benefits of the upgrade project would be felt citywide and with minimal delay. The policy of replacing the most frequent outages first would be of little concern as the low to mild outage areas would experience upgrades in a relatively short time span compared with the other alternatives. The scope of this alternative would eliminate the possible perception that the benefits of the project would be experienced by a narrow group or in limited geographic locations.

Table 12: Spatial Analysis Results

Alternative	Degree of Political Feasibility
Status Quo	**Poor:** Under the status quo, only the substations with the highest rates of circuit failures would receive upgrades. At this rate, most of the city would receive no upgrades in the foreseeable future. The inability of the City to upgrade significant portions of its street lighting capacity may generate political opposition should series circuits begin to fail at an increased rate.
Alternative 1	**Fair:** Alternative 1 would double the replacement rate of the status quo, but it would also fail to upgrade the majority of the city's street light circuits. While more series circuits would be upgraded, the benefits would still be concentrated among a very limited number of Common Council districts.
Alternative 2	**Good:** Alternative 2 would be a substantial improvement over the status quo and Alternative 1 in terms of upgrading the city's street lighting circuitry. The most troubled areas in both the north and south sides would receive upgrades, thus more widely distributing the political benefits among Common Council districts.
Alternative 3	**Very Good:** Alternative 3 distributes the benefits of the circuitry upgrade over the entire city because 100 percent of the city's series circuits would be upgraded. Areas experiencing the most outages would still receive upgrades first, but the remaining areas of the city would not have to wait long for their upgrades to begin.

Source: Authors' analysis.

Funding Analysis

This section presents the results of the funding analysis for the status quo and the three alternatives, which are also summarized in Table 13.

Status Quo: Capital Outlays of $1 Million Annually Over the Next Six Years (Approximately 5.6 Percent Replacement of Remaining Series Circuits)

The funding for the status quo of $1 million annually over the course of six years can be maintained by drawing upon the current total DPW capital budget of $70 million (Bell, 2009, 26 March). No tax increases, bonds, special assessments, increases in the vehicle registration fee, or similar actions would be necessary. Because there would be no need for new or increased taxes, the Mayor, Common Council, and residents would be likely to support this alternative, because no one would have to bear the political burden of advocating for new revenue-raising policies.

Because the status quo would proceed with upgrades at a comparatively less rapid rate than the other alternatives, maintenance costs associated with the street lighting system would continue to increase, perhaps resulting in increased political pressure to complete the upgrades. Both the DPW and the Department of

Administration's Budget and Management Division have voiced concerns that continuing the current funding schedule for series circuit upgrades will only compound the problem of rising ongoing maintenance costs (Bell et al., 2009). As the series circuits continue to degrade, the City will have to allocate scarce resources to an increasing number of maintenance and repair needs in the street lighting system. This will continue to put pressure on an already strained budget. The Mayor and the Common Council's main concern associated with street lighting is ensuring that the lights are functioning and that resident-reported outages are repaired within the designated 24-hours (Bell, 2009, 26 March). Street lights that are not functioning are noticeable and are of concern to residents for safety and other reasons; as a result, outages draw a quick and focused public response. The City is currently able to respond to discovered and reported outages in a timely fashion, but this could change if the series circuit system degrades at an increased rate.

Alternative 1: An Increase in Capital Outlays to $2 Million Annually Over the Next Six Years (Approximately 9.6 Percent Replacement of Remaining Series Circuits)

Alternative 1 would not be able to be funded exclusively by the $1 million that is currently allocated annually from the $70 million DPW capital budget. Increasing the proportion of funding allocated from the capital budget would not be possible because of existing projects and programs. To replace 9.6 percent of the series circuits in six years, the City would need to allocate $2 million annually to the upgrade project, at a fiscal net cost of $9.5 million. This alternative, which would be more expensive for the City than the status quo, could create financial burdens for the City.

To come up with the additional $1 million per year, the City would have to draw from additional sources of revenue, and different political concerns would be raised depending on the revenue sources that would be sought. Issuing additional bonds or new taxes to supplement the capital outlays would spread the incidence of funding burdens across the entire city. New taxes and spending, however, would likely be unpopular if a few Common Council Districts or areas of the city are perceived as receiving the majority of the benefits while other areas are unlikely to see upgrades in the foreseeable future. Also, the current economic and financial climate would make it politically difficult to justify increased spending programs funded through tax increases.

One possible source of funding could be revenues from the recently implemented Milwaukee vehicle registration fee because one of its stated purposes is to provide funding for street lighting (Bell, 2009, 26 March). The fee generates approximately $6.6 million per year, and the 2009 budget has allocated $300,000 from the fee revenue for street lighting (Bell, 2009, 26 March). By law, however, the vehicle registration fee cannot be increased until 2012, so this would not be a viable revenue stream for the City to draw upon immediately for implementing Alternative 1. A $3 increase in the fee could provide the additional $1 million in revenue, but increasing the fee to generate all or part of the additional revenue needed to implement this alternative would likely attract political opposition. The fee was controversial when it was first introduced and caused political conflict between the Common Council and the Mayor; in fact, the previous $20 increase in the vehicle registration fee was only enacted after the Common Council overrode a mayoral veto (Sandler, 2008). As such, it is unlikely that the Common Council and the Mayor will approve a fee increase in such a short period of time and without extensive political discussions. Also, residents, particularly those with vehicles, might resist an additional fee increase. The benefits of the street light circuit upgrade project would have to be shown to offset the burdens of the fee increase, and it is unlikely residents would perceive the need for street light upgrades to be significant.

Alternatively, special assessments to residents and businesses could be used to fund street lighting upgrades in those areas most affected by outages. Under this option, costs would be directed at those benefiting the most from the project, but political opposition from Common Council members, residents, and businesses could arise if they view the special assessments to be an unfair burden

Alternative 2: An Increase in Capital Outlays to $12.1 Million Annually Over the Next Six Years (50 Percent Replacement of Remaining Series Circuits)

The DPW's capital budget of $70 million does not have the capacity to fund the street lighting upgrade project beyond the current allocation levels ($1 million per year). In order to generate the revenue required for this alternative, the City would need to enact new bonds, taxes, vehicle registration fees, and/or special assessments. All of these potential revenue sources would be likely to draw political opposition for varying reasons and from different groups.

Issuing additional bonds and/or enacting new taxes to raise the supplemental revenue for the upgrade capital outlays would spread project costs across the city, thus reducing the burden placed upon individual residents. As the fiscal cost of this alternative is $61.9 million, the considerable amount of funding needed for this alternative would attract a great deal of attention from residents, the media, and from elected officials across the city. The 50 percent conversion target would distribute the benefits of upgraded street lighting over a large portion of the city, and multiple Common Council Districts would benefit. However, a tax increase that would sufficiently offset the capital costs would become a politically contentious issue. Significantly raising taxes in difficult economic times would be unpopular, particularly among those who may not believe they derive clear benefits from the upgrades.

The vehicle registration fee and special assessments would relieve the tax burden on some Milwaukee residents, but the shift to taxation of specific groups would likely elicit a degree of negative political response. The substantial fiscal demands of 50 percent conversion would require the vehicle registration fee to be increased by a large amount. It is unlikely residents with vehicles would support this and they would likely voice opposition to their Council members and the

Mayor. Also, the Council members and the Mayor would be reluctant to draw negative attention to themselves when the City and DPW can continue to upgrade lights and repair them without increasing tax burdens. Because of the increased scale of the project, special assessments would be spread across a wider number of groups, but it is unclear whether residents or businesses value street light circuit improvements to an extent that would compensate for the political consequences of the assessment.

Alternative 3: An Increase in Capital Outlays to $24.6 Million Annually Over the Next Six Years (100 Percent Replacement of Remaining Series Circuits)

As with Alternatives 1 and 2, Alternative 3 would require the City to look to other revenue sources to supplement the current capital outlay of $1 million per year over the six-year upgrade effort. A 100 percent conversion would cost a total of $126 million over the course of six years; this is approximately $65.6 million more than the DPW capital budget of $70 million (Bell, 2009, 26 March).

Issuing additional bonds and/or implementing new taxes would spread the cost of the rapid circuitry upgrade over the entire city. Because all areas of the city would experience at least some benefits of the rapid upgrade program, this distribution of funding burdens would be appropriate. The needed revenue, however, would require substantial increases in taxes to cover project costs. Even those Common Council districts that will receive the upgrades first are unlikely to agree to tax increases. Council members across the city and the Mayor would have a difficult time justifying such a rapid and expensive street light upgrade.

Increases in the vehicle registration fee and special assessments would also be politically contentious funding options. To supplement the current $1 million allocated for street light upgrades, the vehicle registration fees would have to be increased to a level that would be politically impossible for Council members and the Mayor to support. The level of controversy surrounding the initial passing of the vehicle registration fee was high; increasing the fee in such a short time period and to such a high degree would garner little, if any, political support around the city (Sandler, 2008).

Using special assessments to fund the street lighting upgrade would pose another set of political problems. Since this alternative would have impacts for the entire city, targeting specific Common Council districts or areas would be difficult to justify since the benefits would be widespread. Imposing different assessment rates in different areas of the city would become a difficult position to justify and support politically because Council members representing the districts most affected by the special assessments would find it difficult to support.

Table 13: Funding Analysis Results

Alternative	Degree of Political Feasibility
Status Quo	**Very Good:** The status quo would not require any additional revenue sources. It would be unlikely to draw significant political opposition because no increases or new forms of taxes would be required.
Alternative 1	**Fair:** Alternative 1 would require the City to introduce new taxes or increase existing taxes. This could be done using a variety of options, which range from bonding to increasing the vehicle registration fee. Increased or new taxes would likely draw criticism from Council members and their constituents, even if they were to be minimal.
Alternative 2	**Poor:** Alternative 2 would require substantial increases in revenues. Introducing new taxes or increasing existing taxes by a significant amount to obtain the required revenue would likely receive little political support from Council members or citizens. If street lighting infrastructure were maintained in such a way that residents did not perceive major problems with the system, it is unlikely that City officials would be willing to take the political risk of promoting new or increased taxes.
Alternative 3	**Very Poor:** Alternative 3 would have the same problems as Alternative 2 but to a greater degree. The current capital outlays do not come close to providing the revenue necessary to complete the project. Finding political support to raise taxes and/or fees among any of the officials would not likely be feasible.

Source: Authors' analysis.

Comparison of Alternatives

This section evaluates how the status quo and the three alternatives fare with regard to the cost effectiveness and political feasibility criteria. Table 14 summarizes the results of these evaluations.

Table 14: Comparison of Alternatives

Goal	Status Quo	Alternative 1	Alternative 2	Alternative 3
Cost-Effectiveness	Poor	Poor	Very Poor	Very Poor
Political Feasibility	Good	Fair	Poor	Very Poor

Source: Authors' analysis.

Status Quo: Capital Outlays of $1 Million Annually Over the Next Six Years (Approximately 5.6 Percent Replacement of Remaining Series Circuits)

The status quo would generate the lowest fiscal and net costs, as the City would incur $4.6 million in net fiscal costs and $4.5 million in net total costs. This option would do the least to reduce ongoing maintenance costs, but the City of Milwaukee would avoid much of the controversy surrounding potential tax increases for funding a more ambitious street light upgrade project. Under this alternative, DPW would continue to focus its attention on its limited upgrading schedule and on ensuring that outages are repaired within 24 hours. As long as residents perceive that the City is maintaining the street light system to an acceptable degree, it is unlikely that residents will push for a significant upgrade of the existing series circuits. However, the status quo creates the potential for future political confrontation if remaining series circuits rapidly degrade over the next several years. While it is difficult to predict when and where circuits will fail in the future, if such rapid circuit degradation occurs, the City will be forced to adjust capital improvement priorities and/or seek new revenue.

Alternative 1: An Increase in Capital Outlays to $2 Million Annually Over the Next Six Years (Approximately 9.6 Percent Replacement of Remaining Series Circuits)

Converting 9.6 percent of the city's series circuits would entail net total costs and net fiscal costs of $9.5 million and $9.3 million, respectively. The City would be faced with many of the same political concerns as under the status quo, although this alternative fares worse in terms of fiscal costs. A very limited number of additional substations would be able to be replaced within six years because the resources to do more would not be available with a budget allocation of approximately $2 million per year. Meanwhile, the need for additional funding could require the City to implement new and potentially unpopular tax or fee policies. Because the benefits of this alternative are limited to a few particularly troublesome substations, any political support generated would be focused on only a few areas. Council members and residents throughout the city would be unlikely to respond positively to city-wide tax increases if only two or three districts are perceived to receive all of the benefits. Focusing the funding burdens specifically on the areas receiving the upgrades is an option, but this could exhaust the political support of those who would bear this burden. The political concerns surrounding the cost implications of this alternative would make it difficult for members of the Common Council and the Mayor to support it, and because the costs associated with this alternative would not provide a fiscal benefit to the City, current budget constraints make it infeasible to justify politically.

Alternative 2: An Increase in Capital Outlays to $12.1 Million Annually Over the Next Six Years (50 Percent Replacement of Remaining Series Circuits)

If 50 percent of the city's remaining series circuits were converted to multiple circuits, the City would experience net fiscal costs of $61.9 million and net total costs of $61.3 million. Because these the costs heavily outweigh the benefits of reduced maintenance costs and avoided crime costs, the City would very likely encounter political opposition. While this alternative would allow for circuit upgrades in virtually all of the Common Council Districts, it would also likely require the City to increases taxes, fees or other revenue-raising measures to provide the necessary funding. The current economic and political climates are very unfavorable for tax increases of any kind, and when net costs are considered, generating political support among the residents of Milwaukee would likely be very difficult. Unless the numbers of outages on series circuits dramatically increase in a short time period or the City finds a way to cut the capital costs associated with circuit upgrades, it would likely be politically infeasible to implement this alternative.

Alternative 3: An Increase in Capital Outlays to $24.6 Million Annually Over the Next Six Years (100 Percent Replacement of Remaining Series Circuits)

If 100 percent of the city's remaining series circuits were converted to multiple circuits, the City would encounter even greater net total costs ($124.8 million) and net fiscal costs ($126.0 million) than under the previous alternative. Although replacing all of the substations would spread the benefits of the alternative throughout the city, funding this activity would likely hinge upon new or increased taxes or other revenue sources. These options would likely be met with opposition from elected officials and their constituents. Because the costs of this alternative are significantly greater than any fiscal benefits that it provides, justifying such an undertaking to the public would likely be infeasible. This circuit upgrade alternative would likely be a very public and politically charged undertaking for all parties involved, and it would likely receive little support because of its current cost and political shortcomings.

Recommendations and Conclusions

We have divided our recommendations regarding the City of Milwaukee's street light circuitry upgrades project into short-term and long-term groups. In the short term, which would be the next six-year period, we recommend that the City of Milwaukee maintain the status quo of allocating $1 million annually for the conversion of series circuits to multiple circuits. The status quo is superior to the three alternatives because it imposes the least cost on the City and the population of Milwaukee at large. Maintaining the status quo would not force the City to implement any new taxes or to increase fees, while each of the other three alternatives would require the City to engage in politically contentious revenue-raising efforts. The parties that would bear the additional funding burdens and the extent of these burdens would vary across the three other alternatives, but all would require using politically unpopular revenue sources to supplement the current capital outlay of $1 million. While the status quo upgrade plan would not complete the upgrade project as quickly or on as wide of a geographic area, it constitutes the most politically and fiscally sound option.

We do not recommend the status quo as a long-term solution. Should the City continue to follow the status quo upgrade rate until the project is completed, it would take 106 years before all of the remaining series circuits were replaced. By that time, many of the circuits will be beyond their useful life and the city may have few properly functioning street lights. At this point, we cannot predict the rate at which series circuits will deteriorate in the future. Therefore, we recommend that the City re-evaluate the policy for upgrading series street light circuits in another six years. At that time, the likelihood and extent to which series circuit degradation may increase will likely be clearer. Moreover, the level and nature of political interest in the street light upgrade project may be different, and the City may be in a better position to raise and allocate more revenue to the project.

A re-evaluation of the street light upgrade project in six years would provide the City with an opportunity to collect additional data on series and multiple circuit failures. To prepare for a future re-evaluation of the street lighting system, we recommend that the City collect detailed data related to the causes of circuit failures (such as weather events, construction, and other factors) when possible. This data collection effort should be tailored so that it may be easier to identify series circuits that may rapidly deteriorate in the near future. We also recommend that the City examine other options for upgrading its street lighting infrastructure, especially options that could provide benefits beyond increased circuit reliability and reduced outage time.

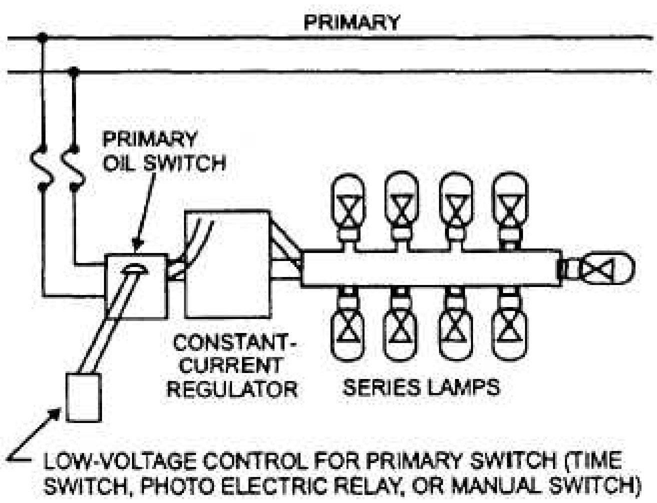
Appendix A:
Description of Series and Multiple Circuitry

This appendix provides a concise description of the technical aspects of series and multiple circuitry, such as the circuitry used by the City of Milwaukee.

Series Circuitry

Series circuits are supplied with electrical energy by a regulating transformer that provides a constant current to the lighting circuit. As Figure 1 below illustrates, the base primary distribution lines supply power to the series circuit via fuse cutouts to the oil switch. From the oil switch, electrical charges travel through a constant-current regulator, which supplies power to the series loops and the individual lamps (Integrated Publishing, n.d., p. 6-17).

Figure 1: Series Circuitry



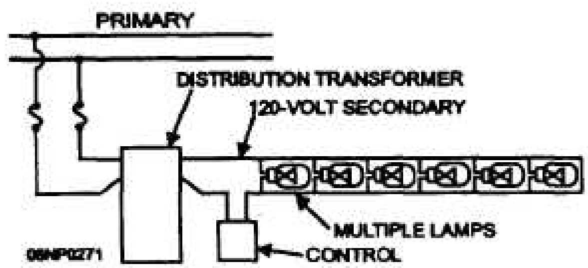
Source: Integrated Publishing, n.d., figure 6-16.

The series circuit current remains constant at approximately 6.6 amperes, but the voltage of the circuit equals the sum of the voltage of each individual lamp as well as the voltage in the drop in the wire (Integrated Publishing, n.d., p. 6-17). The voltage of an average series circuit in Milwaukee is approximately 4,500 volts (Bell et al., 2009). While the series circuit can be easily controlled, any break in the series loops interrupts the entire circuit (Integrated Publishing, n.d., 6-17) and causes outages.

Multiple Circuitry

The multiple circuit is supplied with electricity by a distribution transformer that delivers a constant, low voltage. As Figure 2 below illustrates, the power for the multiple circuit is supplied by the base primary distribution system through the fuse cutouts and directly to the transformer and the lamps (Integrated Publishing, n.d., 6-19). While the figure below does not represent Milwaukee's multiple street light circuitry, it outlines the differences between series circuitry and multiple circuitry.

Figure 2: Multiple Circuitry



Source: Integrated Publishing, n.d., figure 6-19.

The selection of transformer output voltage depends on the voltage required for the individual lamps that are installed. This voltage can range from 120 volts to 480 volts (Integrated Publishing, n.d., 6-19).

Appendix B: Secondary Benefits of Street Light Circuitry Upgrades

This appendix outlines the benefits the City and general population of Milwaukee might experience from the street light circuitry upgrade that are not included in the reduced maintenance costs. Benefits commonly associated with effective, reliable outdoor lighting include reductions in "on street accidents and crime," improved perceptions of public safety, streetscape enhancement and stimulation of the night-time economy (Willis et al., 2005, p 2289). This analysis focuses in particular on the potential crime reduction benefits that could be generated by improving street lighting, which, in this instance, would involve upgrading the street light circuits from series to multiple circuits. This would reduce the amount of time street lights are out when the circuits fail. This appendix also discusses the potential impacts street light improvements may have on reducing the public perception of crime.

Street Lights and Crime Reduction

Multiple perspectives exist on why street lights might help reduce crime. The first theory describes street lighting as a "situational" crime prevention method because it improves visibility and increases the number of people on the street after dark. Both of these factors lead to increased surveillance of street activity and help deter potential offenders (Farrington and Welsh, 2002, p. 2). Alternatively, improved lighting within a community is a sign of positive investment, which may instill a greater sense of "community pride, optimism, and cohesion" in residents (Farrington and Welsh, 2002, p. 3). Such community pride may foster greater levels of informal social control, which may in turn reduce criminal activity. This second theory has prompted some researchers to note that attempts to measure the effects of improved lighting should not concentrate purely on crimes occurring at night (Farrington and Welsh, 2007, p. 210). When considering the relationship between lighting improvements and crime, it is important to remember that the city's street light circuitry upgrade will only improve street light reliability, as opposed to increasing the brightness of the lights or introducing new infrastructure into Milwaukee neighborhoods. Residents may notice that area street lights are more reliable, though, so both theories may be relevant in terms of the project's influence on crime.

In areas devoid of people (and thus lacking surveillance), it is possible that lighting may actually improve offenders' abilities to commit crimes and then escape (Farrington and Welsh, 2002, p. 4-5). Moreover, while street lighting can act as a psychological deterrent to offenders, it ultimately does not provide a physical barrier to crime (Painter, 1996, 200). For these reasons, street lights are typically used in conjunction with a number of other crime deterrence methods.

In general, findings regarding the relationship between street lighting and crime in U.S. cities have been mixed (Willis et al., 2005, p. 2290). Research on this issue in the United States took place predominantly during the 1970s and effectively ended after the release of the Tien et al. report in 1979, which concluded that the lack of reliable and uniform data and the inadequacy of available evaluation studies "preclude a definitive statement regarding the relationship between street lighting and crime" (Pease, 1999, p. 50). Farrington and Welsh later reviewed evaluations of street lighting and crime in the United States and found that lighting projects in Atlanta, Georgia; Fort Worth, Texas; and Milwaukee[4] were effective in reducing property and violent crimes, while one such project helped to reduce violent crime in Kansas City, Missouri (2002, p. 26-27). Street lighting improvements in Portland, Oregon; Harrisburg, Pennsylvania; New Orleans, Louisiana; and Indianapolis, Indiana were found to be ineffective in reducing crime (Farrington and Welsh, 2002, p. 23-24).

These mixed results have been partly attributed to the fact that studies finding street lighting to be effective accounted for crimes committed both at night and during the day, while studies noting negligible effects reviewed crimes occurring only at night. In their review, Farrington and Welsh calculated an odds ratio for crime of 1.08 across all eight cities they reviewed, which compares changes in crime levels in control areas to crime levels in areas with improved lighting (2002, p. 28). According to this ratio, street lighting improvements have a desirable if small effect on crime, reducing it at an estimated rate of 7.5 percent.

In the 1980s, research in the United Kingdom was initially skeptical of a relationship between street lighting and crime (Willis et al., 2005, p. 2290), but Painter's studies in the cities of Dudley, Stoke-on-Trent, and London during the 1990s identified marked decreases in crime in response to public lighting improvements. For example, after a lighting upgrade that effectively "doubled the amount of useful light" in an experimental area in Dudley, crime dropped 41 percent, while decreasing only 15 percent in the control area (Painter and Farrington, 2001, p. 4). In the Stoke-on-Trent experiment, tungsten lamps were replaced with high-pressure sodium lamps, after which crime decreased by 43 percent in the experimental area, 45 percent in adjacent areas, and 2 percent in non-adjacent control areas (Painter and Farrington, 2001, p. 5).

Based on the above studies, it is possible to argue that street light improvements generate reductions in crime. This effect may vary widely, however, depending on the type and scale of the street lighting project, the characteristics and level of crime in targeted areas prior to improvements, the issues offenders consider when deciding to commit crimes, and a number of other factors. In our study we

[4] The Milwaukee-based project reviewed in the Farrington and Welsh study was the 1974 High Intensity Lighting Project. This project improved street lighting by increasing the intensity of the light (up to seven times) in designated areas. A review that took place seven months after the improvements found that crime decreased by 5.6 percent in experimental areas and 29.9 percent in control areas (Farrington and Welsh, 2002, p. 26).

included crime reduction as a benefit in the cost-benefit analysis, because it may generate increases in the quality of life for Milwaukee residents, businesses, and visitors.

Street Lights and Public Perception of Crime

The literature on street lighting often distinguishes between the relationship between lighting and fear of crime and the relationship between lighting and actual crime reductions. Atkins et al. write, "Fear of crime affects travel and activity patterns, constrains participation in social activities, generates psychological stress, and is arguably a severe limitation on individual liberty" (1991, p. 1). By modifying the night-time environment through street lighting, individuals may feel more comfortable traveling and engaging in outdoor activities—including patronizing area businesses—at night.

As with the research on lighting and crime reduction, most recent evaluations of street lighting's influence on perceptions of crime have taken place in the United Kingdom. A survey conducted in conjunction with a project improving street lamps in Great Britain found that for residents in both relit and non-relit areas, the project did not strongly influence residents' concerns about certain types or probabilities of crime (Atkins et al., 1991). This evaluation also found that the project did not produce significant changes in unreported crime, travel after dark, or harassment. The perceived safety of women walking alone after dark improved, however, and "the reaction of residents to the re-lighting scheme was overwhelmingly favorable" (Atkins et al., 1991, p. 20). Similarly, contingent valuation survey research regarding a nationwide street lighting improvement program in Great Britain reported that the majority of respondents felt that street lights reduce crime (61.3 percent), make property more secure (66.4 percent), and would make them feel safer (75.4 percent) (Willis et al., 2005, p. 2295). Willis et al. also found that safety was one of the statistically significant determinants of individual willingness to pay for improved street lighting (2005, p. 2298).

Painter's research into people's responses to lighting improvements shows particularly dramatic results. Surveys conducted in conjunction with her studies of lighting improvements in Edmonton and Tower Hamlets in London found that over 60 percent of residents in both areas felt safer using the street after dark. In Edmonton, approximately 80 percent of survey respondents attributed their increased sense of safety to the improved lighting (Painter, 1996, p. 197). These benefits were greater for those living in urban areas. In general, the amount of data on actual changes in people's behavior in response to lighting improvements is more limited. Even so, Painter's evaluation of a targeted lighting improvement in the Hammersmith and Fulham borough of London shows a 101 percent increase in males and 71 percent increase in females using area roadways after dark (1996, p. 195).

Decreasing residents' fear of crime at night may not only increase local quality of life and local economic activity, but it could also have political implications, because residents may be more likely to support initiatives or representatives that address their concerns about public safety. For this reason, public perception of crime and its relationship to street lighting should be considered as the City of Milwaukee moves forward with the circuitry upgrade project. However, because of the lack of research on public reaction to efforts to make street lighting more reliable as opposed to introducing lighting into new areas or increasing the brightness of existing lighting, this analysis does not attempt to include this factor in the cost-benefit analysis. Ideally, a contingent valuation study, similar to the one conducted by Willis et al. should be used in Milwaukee to estimate the extent to which members of the general public value improved street lighting for its ability to reduce their fear of crime (2005). Contingent valuation surveys ask that respondents quantify their willingness-to-pay for a good or a service that is not actually traded in markets.

Appendix C: Costs of Crime

This appendix reviews the calculations of the benefits the street light circuitry upgrades may generate in terms of reduced criminal activity and costs of crime. Because series circuits can take longer to repair and are assumed to cover wider areas than multiple circuits, series circuit outages may cause more widespread loss of lighting for a longer period of time than would multiple circuit outages. This loss of lighting can reduce on-street visibility, which may limit street surveillance and may decrease the risks of criminal activity for potential offenders.

We determined the crime reduction benefits of circuitry upgrades by assessing the difference in the number of crimes occurring within spaces served by series circuits and spaces served by multiple circuits during an hour that the street lights are out. We then multiplied the number and types of crimes by their respective costs and the number of hours it takes to repair each type of circuit to determine "cost of crime per outage" for series and multiple circuits, respectively. The difference in the series circuit outage crime costs and the multiple circuit outage crime costs was ultimately included in the cost benefit analysis.

Several limitations are important to note. First, we do not account for the fact that the number of square miles covered by an individual series or multiple circuit may vary considerably across circuits. In reality, the area of Milwaukee affected by a given circuit outage may vary considerably. Second, this analysis assumes that all lights on both series and multiple circuits go out when a circuit fails. Depending on the nature of the failure, however, it is possible that some lights on the circuit may continue operating. Third, the number of different criminal offenses occurring in a given year was based on data pertaining to the entire city of Milwaukee. In reality, crime levels are likely to differ from one part of the city to another. Fourth, we assume that the loss of lighting has the same influence on the occurrence of crime across all types of crimes. In reality, the extent to which levels of lighting and surveillance influence whether a crime is committed may vary across different types of crime.

Street Lights and Areas of the City Served by Series and Multiple Circuits

According to street light circuitry infrastructure data provided by the City of Milwaukee for 2007, a total of 66,888 street lamps were on series and multiple circuits, excluding special lighting, alley lighting, and W.E.P. street lights **(**City of Milwaukee, n.d.d). Because data were not available for the total number of street lamps in the City of Milwaukee in 2008, we calculated an estimate of this total based on increases and decreases in the total number of lamps in the city between 2003 and 2007. Our estimates assume a 0.1 percent increase in the number of street lamps in Milwaukee between 2007 and 2008, resulting in a total of 66,995 street lights (City of Milwaukee, n.d.d). Using the geographic area of the city of

Milwaukee, which is 96.63 square miles, we estimate that there are 693 street lights per square mile (City of Milwaukee, 2008b, p. 1).

Data on the number of series and multiple circuits in Milwaukee's street lighting system between 1970 and 2007 were used to determine the number of lights on individual series and multiple circuits, respectively (City of Milwaukee, n.d.d). This data show that on average there are approximately 59 lights on a series circuit and 35 lights on a multiple circuit. In reality, the number and type of street lights served by a given circuit can vary considerably (Manzke, 2009, 10 March). These calculations are only meant to provide an estimate of the difference in the number of lights that can be accommodated by each circuit type so that the size of the areas served by series and multiple circuits can be estimated. As a result, we assume that a series circuit serves 0.09 square miles on average while a multiple circuit serves 0.05 square miles on average. Table 15 summarizes these figures.

Table 15: Lights and Area Served per Circuit Type

Circuit Type	Estimated Lights per Circuit	Estimated Lights per Square Mile	Estimated Circuits per Square Mile	Estimated Square Miles Served per Circuit
Series	59.44	693	11.65	0.09
Multiple	35.22	693	19.68	0.05

Sources: Manzke, 2009, 10 March; authors' calculations.

Crime Levels in the City of Milwaukee

Our analysis, guided by the types of offenses examined in previous studies of street lighting and crime, included data on incidents of graffiti, assaults, burglaries, robberies, sex offenses, thefts, vehicle thefts, and homicides (Painter, 1996, p. 6; Painter and Farrington, 2001, p. 4). The estimates of crime levels for the city of Milwaukee that we used in this analysis were drawn from the Milwaukee Police District Statistics database, which is produced by the Milwaukee Police Department (City of Milwaukee, 2008b, p. 9). This source details the incidents of several Wisconsin Incident Based Report Group A offenses for each year from 2005 to early 2009 (City of Milwaukee, 2008b, p.1), along with violations (specifically graffiti) occurring during those years.[5]

[5] A Group A offense is distinguished from other types of offenses based on several criteria, including the seriousness of the crime, the frequency or volume of its occurrence, the likelihood that the offense will come to the attention of law enforcement, and other factors (Wisconsin Office of Justice Assistance, 2005, p. 18).

Our analysis used incident data for the city of Milwaukee as a whole, given thatif the 50 percent or 100 percent upgrade options are selected, work would be conducted throughout the city. For more information on the locations of substations likely to be upgraded first, see *Appendix F.*

We examined fluctuations in offense rates using data from 2005 through 2008, and because no clear trends in crime increases or decreases were found, we averaged the number of offenses per year for relevant crimes using data from 2005 through 2008 (City of Milwaukee, 2005; City of Milwaukee, 2006; City of Milwaukee, 2007; City of Milwaukee, 2008b). Table 16 shows the types of offenses examined along with the average number of incidents per year and per square mile per year.

Table 16: Average Rates of Offenses per Year

Offense Type	Average Rate per Year (2005-2008)	Average Rate per Square Mile per Year (2005-2008)
Assault	8,934	92
Burglary	5,743	59
Robbery	3,360	35
Sex Offense	71	8
Theft	14,336	148
Vehicle Theft	7,297	76
Homicide	101	1
Graffiti	10,208	106

Sources: City of Milwaukee, 2005; City of Milwaukee, 2006; City of Milwaukee, 2007; City of Milwaukee, 2008b; authors' calculations.

Crimes Attributed to Street Lighting Outages

Appendix B describes existing literature on the relationship between street lighting and criminal activity. Several studies (particularly those which examined both day and night-time crimes) have found that areas where street lighting was improved saw decreases in crime compared with control areas (Painter, 1996; Painter and Farrington, 2001; Farrington and Welsh, 2007).We assume the converse, which is that the absence of effective, reliable street lighting may increase criminal activity.

We attribute approximately 8 percent of offenses to the absence of effective, reliable street lighting, which would be the case during circuit outages. This figure is based on results of a meta-analysis by Farrington and Welsh that reviewed eight studies of the relationship between street lighting improvements and crime in U.S. cities (Farrington and Welsh, 2007, p. 215). Farrington and Welsh used the results of these eight studies to calculate an odds ratio of 1.08, which explains that overall, crimes increased by 8 percent in control areas compared with areas where street lighting was improved (2007, p. 215). The present analysis assumes that areas of the city experiencing outages function much like the control areas of studies in Farrington and Welsh's review; both are presumed to include lighting that is malfunctioning or insufficient in such a way that it reduces visibility and decreases potential offenders' perception of risk. Both of these factors have the potential to increase criminal activity.

Our estimation is limited in several ways. First, even areas that are well lit may not be crime free if offenders believe they will not be recognized or reported to the police (Pease, 1999, p. 49). Thus, even if circuits are improved and lighting becomes more reliable, if offenders feel they will not be detected or reported based on other observations they make about their environment, they may continue to commit crimes. How offenders perceive risk can also vary considerably across individuals (Ramsay, 1991, p, 11).

Farrington and Welsh's odds ratio may also introduce some concerns. First, the body of studies they included was somewhat mixed in terms of street lighting's effect on crime. Second, the type of lighting improvements varied across the studies. Moreover, it is unclear whether any of the studies included reflect the type of street lighting reliability improvements that would likely be provided by the circuitry upgrade project. In spite of these limitations, however, this estimation is beneficial in that it provides a way to capture the role that lighting may play in offenders' decisions to commit crimes, which is likely greater than zero. As Pease notes, "To say that lighting effects are conditional is not to say they will not be common" (1999, p. 49).

Crime Occurrences per Circuit Outage

The following procedure was used to determine the number of each type of offense occurring during a series or multiple circuit outage:

1. We divided the average number of crimes per year by the number of square miles in the city of Milwaukee to get the average rate per square mile per year.
2. We divided the average rate of offenses per square mile per year by the area covered by a series or multiple circuit, respectively, to determine the number of offenses occurring within a given circuit's service area per year.
3. We then divided this number by the number of hours in a year to determine the number of offenses occurring within a circuit's service area during a given hour.

4. We then multiplied the number of offenses occurring within a circuit's service area per hour by 8 percent to determine the number of crimes per hour that can be attributed to lighting levels.
5. We then multiplied the number of lighting-related offenses occurring in a circuit's service area per hour by the number of hours required to repair either a series or a multiple circuit.

According to the City of Milwaukee, multiple circuits take an average of four hours to repair, while series circuits can take between six and eight hours to repair. We used an estimate of seven hours per series circuit repair to calculate crime costs. This yielded the total number of crimes per circuit outage for both series and multiple circuits.

We used this procedure across all crime types. Table 17 shows the figures used to generate the total criminal activity that may occur during a multiple circuit outage, while Table18 shows the figures used to calculate such activity for series circuit outages. The hours required for the repair may not encompass all of the time the street light is out. Street lights may be out for longer periods depending on when the outage is reported or discovered.

Table 17: Criminal Activity Attributable to Multiple Circuit Outages

Crime Type	Crimes per Multiple Circuits Service Area per Year	Crimes per Multiple Circuits Service Area per Hour	Percent of Criminal Activity Attributable to Lighting	Crimes Attributable to Lighting per Multiple Circuit Service Area per Hour	Crimes per Multiple Circuit Outage
Assaults	4.623	0.00053	0.08	0.00004	0.00017
Burglaries	2.971	0.00034	0.08	0.00003	0.00011
Robberies	1.739	0.00020	0.08	0.00002	0.00006
Sex Offenses	0.394	0.00004	0.08	0.00004	0.00001
Thefts	7.418	0.00085	0.08	0.00007	0.00027
Vehicle Thefts	3.775	0.00043	0.08	0.00003	0.00014
Homicide	0.052	0.00001	0.08	0.0000005	0.00002
Graffiti	5.287	0.00060	0.08	0.00005	0.00019

Sources: Farrington and Welsh, 2007, p. 215; Manzke, 2009, 11 February; authors' calculations.

Table 18: Criminal Activity Attributable to Series Circuit Outages

Crime Type	Crimes per Series Circuits Service Area per Year	Crimes per Series Circuits Service Area per Hour	Percent of Criminal Activity Attributable to Lighting	Crimes Attributable to Lighting per Series Circuit Service Area per Hour	Crimes per Series Circuit Outage
Assaults	8.321	0.00095	0.08	0.00008	0.00053
Burglaries	5.348	0.00061	0.08	0.00005	0.00034
Robberies	3.130	0.00036	0.08	0.00003	0.00020
Sex Offenses	0.708	0.00008	0.08	0.00001	0.00005
Thefts	13.352	0.00152	0.08	0.00012	0.00085
Vehicle Thefts	6.796	0.00078	0.08	0.00006	0.00043
Homicide	0.094	0.00001	0.08	0.000001	0.00001
Graffiti	9.517	0.00109	0.08	0.00009	0.00061

Sources: Farrington and Welsh, 2007, p. 215; Manzke, 2009, 11 February; authors' calculations.

Costs of Crime

We assigned costs to each of the eight crime types using three studies: a 1996 study of victim costs by Miller, Cohen and Wiersema; a study by McCollister that analyzed the costs of crime to society; and a study by Eck and Martinelli estimating the costs of graffiti (Miller, Cohen and Wiersema, 1996, p. 9; McCollister, n.d., p.12; Eck and Martinelli, 1998, p. 41). Cost figures from the Miller, Cohen and Wiersema study—which were applied to assaults, burglaries, robberies, sex offenses, vehicle thefts, and homicides—incorporate both tangible and intangible costs (1996, p. 9). These tangible costs include those related to lost productivity; medical care and ambulance; mental health care; police and fire services; social and victim service; and property losses and damage (Miller et al., 1996, p. 9). Intangible costs are those that do not have a market price but represent losses that victims would pay to avoid, including pain, suffering, and reduced quality of life.

Meanwhile, we used the costs of theft from McCollister's research because we thought they better represented multiple types of theft (such as petty versus grand larceny). Her cost figure also includes both tangible costs—including medical expenses, cash losses, property theft or damage, lost wages, mental health care costs, criminal justice system costs, and productivity losses incurred by perpetrators—and intangible costs, such as pain and suffering (McCollister, n.d., p. 7-10). Meanwhile, the Eck and Martinelli study estimated the costs related to graffiti removal (1998, p. 41).

Costs of Crime per Series or Multiple Circuit Outages

We then multiplied the number of crimes per circuit outage by the estimates of the costs of each type of offense. This provided a dollar figure of the costs of a given type of offense per circuit outage. Tables 19 and 20 describe these offense costs for series and multiple circuit outages, respectively.

Table 19: Cost of Crime per Series Circuit Outage

Crime Type	Crime per Series Circuit Outage	Cost per Crime	Costs of Crime per Series Circuit Outage
Assaults	0.00053	$14,006	$7.45
Burglaries	0.00034	$2,086	$0.71
Robberies	0.00020	$19,920	$2.38
Sex Offenses	0.00005	$129,629	$5.87
Thefts	0.00085	$1,532	$1.31
Vehicle Thefts	0.00043	$5,513	$2.40
Homicide	0.00001	$4,380,559	$26.41
Graffiti	0.00061	$1,981	$1.21

Sources: Miller, Cohen and Wiersema, 1996, p. 215; McCollister, n.d., p. 12; authors' calculations.

Table 20: Cost of Crime per Multiple Circuit Outage

Crime Type	Crimes per Multiple Circuit	Cost per Crime	Cost of Crime per Multiple Circuit Outage
Assaults	0.00017	$14,006	$2.37
Burglaries	0.00011	$2,086	$0.23
Robberies	0.00006	$19,920	$0.76
Sex Offense	0.00001	$129,629	$1.86
Theft	0.00027	$1,532	$0.42
Vehicle Theft	0.00014	$5,513	$0.76
Homicide	0.000002	$4,380,559	$8.38
Graffiti	0.00019	$1,981	$0.38

Sources: Miller, Cohen and Wiersema, 1996, p. 215; McCollister, n.d., p. 12; authors' calculations.

Based on these calculations, we estimate that the total cost of crime per series circuit outage is $48, while the cost per crime of a multiple circuit outage is $15. These figures were used to generate a crime cost differential of $33. This value accounts for differences in the avoided costs of crime when a multiple circuit is being repaired rather than a series circuit.

Appendix D:
Best-Case and Worst-Case Scenario Analysis

Table 21 presents the parameters that were varied to conduct a best-case and worst-case scenario analysis, along with the values that were used for each scenario.

Table 21: Parameters Used in Best-Case and Worst-Case Scenario Analyses

	Best-Case Scenario	Cost-Benefit Analysis	Worst-Case Scenario
Number of Circuit Failures per Year	2,699	2,199	1,699
Repair Cost Differential per Circuit Failure	310	205	100
Full Repair Cost per Circuit Failure	580	475	370
Crime Cost Differential per Circuit Failure	103	33	0
Full Crime Cost per Series Circuit Failure	143	48	0
Reduction in Circuit Failures per Year	80% of original calculation	As calculated	120% of original calculation

Source: Authors' calculations

Number of Circuit Failures per Year

Based on circuit failure data from 2007 and 2008 (City of Milwaukee, 2008a), 2,199 is the average total circuit failures that occur over the course of the year. We then added and subtracted approximately 20 percent (or 500 failures) of this total to generate 2,699 total circuit failures under the best-case scenario and 1,699 total circuit failures under the worst-case scenario.

Repair Costs Differential per Circuit Failure

According to the DPW, an average multiple circuit failure costs approximately $270 to repair while a series circuit failure costs between $370 and $580 to repair (Manzke, 2009, 11 February). Thus, the repair cost differential per circuit failure ranges between $100 and $310. In the cost-benefit analysis, we used the average of this range, which is $205 per circuit failure. For the best-case scenario, we used the higher cost differential estimate of $310, while in the worst-case scenario. we used the conservative cost differential estimate of $100.

Full Repair Cost per Circuit Failure

In the cost-benefit analysis and the best-case and worst-case scenario analysis, we assumed that reductions in circuit failures would offset the repair costs of a series circuit (though in reality, reductions in circuit failures could offset the cost of either series or multiple circuit repairs) for the sake of conservative estimates. The full cost of repairing a series circuit varies between $370 and $580, depending on the duration of the repair and the wage or salary specified in labor agreements.

Crime Cost Differential per Circuit Failure

To account for the difference in crime costs associated with series circuit repairs and multiple circuit repairs, we used a value of $33 per circuit failure in the cost-benefit analysis calculations. The worst-case scenario value of $0 assumes that the percentage change in criminal activity attributable to lighting is zero. The best-case scenario value of $103 uses the largest possible percentage of criminal activity that can be attributed to lighting, which is 17.4% (Farrington and Welsh, 2007, p. 215). In addition, the best-case scenario assumes the largest amount of time to repair a series circuit failure, which is eight hours (Manzke, 2009, 11 February).

Full Crime Cost per Circuit Failure

Because we assumed that all reductions in circuit failures would offset the cost of repairing series circuits, the full crime cost per circuit failure must also reflect this assumption. The full crime cost per circuit failure is the crime cost per series circuit failure, and varies based on the degree to which crime is attributable to street lighting and the area of the lighting outage. The full crime cost is projected to be $48 per series circuit failure, $143 per series circuit failure in the best-case scenario, and $0 per series circuit failure in the worst-case scenario. The $0 figure reflects the assumption that, under the worst-case scenario, street lighting has no effect on crime.

Reductions in Circuit Failures per Year

As the City replaces series circuits with multiple circuits, there will be fewer overall circuit failures. These reductions vary by alternative and year. Table 6 shows base reductions in circuit failures by alternative. Because we varied overall circuit failures by 500 in the best-case and worst-case scenario analysis, the reduction in circuit failures needs to be consistent with the overall number of circuit failures. Since 500 is roughly 20 percent (500/2199= 22.7 percent) of the number of overall circuit failures per year, we varied the reductions in circuit failures by 20 percent in the best-case and worst-case scenario analysis.

Appendix E: Spatial Analysis Methodology

We used the City of Milwaukee's data on 2008 circuit outages (City of Milwaukee, 2008a) to determine which series circuits had the highest failure rates. This data set reported the substation ID code and number of failures for each circuit. Those circuits that were identified with a letter code were assumed to be multiple circuits and those circuits that were identified with a number code were assumed to be series circuits, per information from DPW staff (Bell et al., 2009). We organized these data by substation and summed the outages to find the total series outages and total multiple outages for each substation. Records of outages that did not identify a circuit or identified "ALL" circuits were dropped from the analysis because we could not determine whether the recorded outages affected series circuits or multiple circuits. In total, 236 outages were dropped from the analysis.

To determine the relative geographic location of circuits that need upgrades, we superimposed a map of the City of Milwaukee Common Council districts on the City of Milwaukee's map of substations (City of Milwaukee, n.d.c). Each substation was then labeled with the total number of series circuit outages occurring on that substation in 2008. Series circuits and relevant substations were then ranked according to the number of outages they experienced in 2008. This ranking can be used to approximate where circuit upgrades will occur first; according to the DPW's policy, circuits that experience the greatest number of outages will be upgraded first (although the City also considers whether upgrades can be coordinated with street paving projects).

Appendix F: Spatial Analysis Results

The spatial analysis indicated that 1,044 series circuit outages and 708 multiple circuit outages occurred across all substations during 2008. Sixty-one substations have series circuits that failed one or more times during 2008. Table 22 presents the top 30 most problematic substations in 2008.

Table 22: Series and Multiple Circuit Failures by Substation

Substation	Common Council District	Total Series Failures	Total Multiple Failures
NM	1	73	0
SP	11	67	0
ND	6	43	2
NR	5	43	0
NG	1	42	0
NP	2	40	0
NQ	5	38	0
SG	13	35	2
WX	10	32	1
SR	13	29	1
NL	2	27	5
WP	10	27	0
WJ	10	25	6
SL	12	25	1
NK	5	25	0
SJ	8	22	2
NO	5	22	1
T6S	13	22	0
T1C	6	21	1
T11S	11	21	0

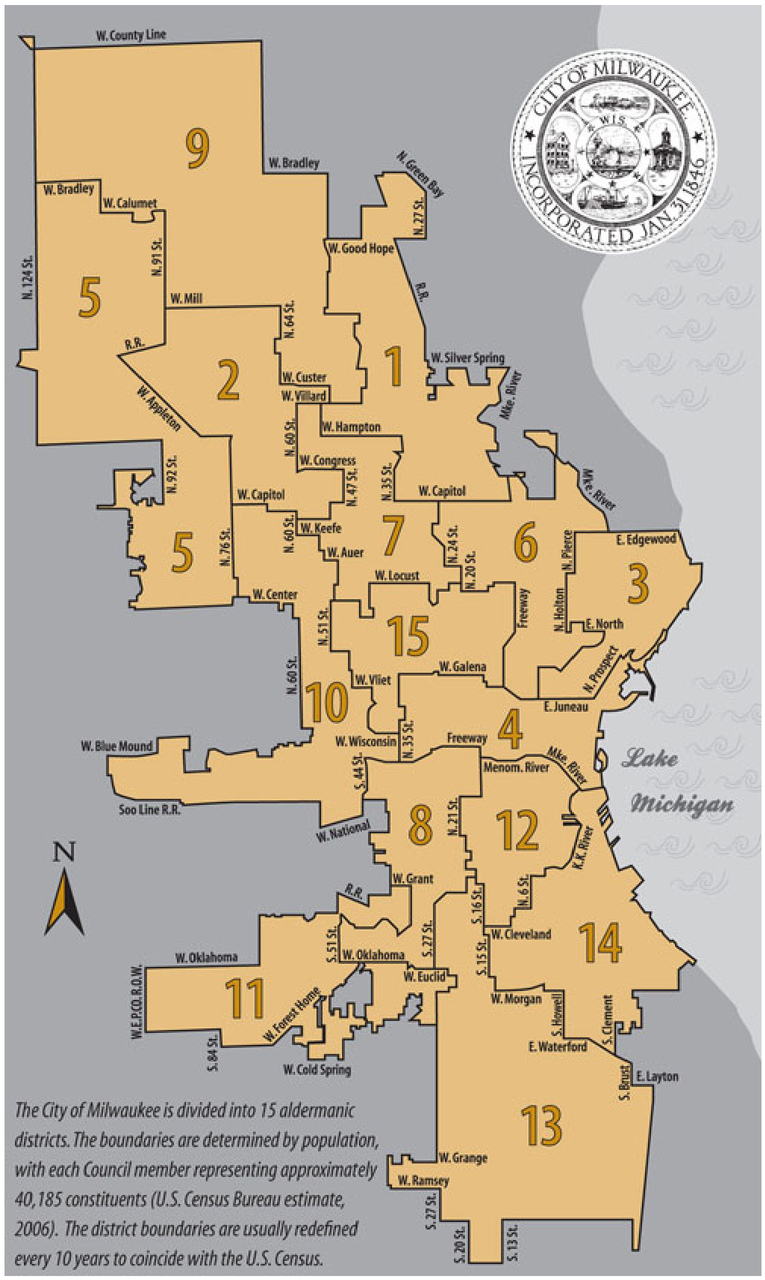
Substation	Common Council District	Total Series Failures	Total Multiple Failures
EP	14	20	0
SQ	13	20	0
NJ	1	19	0
NH	1	17	6
NA	6	16	3
WK	15	15	21
SC	12	15	0
T1NW	1	15	0
SB	12	14	2
EO	14	14	1
NV	1	14	0
SF	8	14	0

Sources: City of Milwaukee, 2008a; authors' calculations.

Appendix G:
Map of Milwaukee Common Council Districts

Figure 3 is a map of the Milwaukee Common Council districts that are discussed in the results of the spatial analysis.

Figure 3: Map of Milwaukee Common Council Districts



Source: City of Milwaukee Common Council, n.d.

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