Challenges and Approaches to Assess the Impacts of Utility Cuts with Limited Pavement Condition Data

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Abstract

Municipal agencies are faced with the challenge of managing utility cut installations on their roadway networks. Recent studies have indicated that the impacts of utility cuts can be quantified, and that the associated reduction in roadway asset value and pavement serviceability can be calculated.

In 2023, the City of Whitehorse (the City) with the assistance of Tetra Tech Canada Inc. (Tetra Tech) completed a study to understand the impact on pavement performance resulting from the presence of utility cuts on its roadway network. The outcome from this study provides the City with the information to consider a future initiative to establish pavement degradation fees that reflect the actual loss of service life and costs of an accelerated rehabilitation program resulting from utility cut installation.

Key aspects of this study include:

- There are 126 recorded utility cuts completed in the last 10 years on the City's 200 centreline kilometres of network.
- The City historically collected pavement condition data for use in their pavement management system (PMS).
- In 2018, the City switched evaluation methods for indexing their road network pavement condition to the Pavement Conditions Index (PCI) method. Since then, 73 utility cuts on pavements with PCI ratings were completed.
- The PCI ratings were completed by different teams with the help from summer students. As such, consistency in how the PCI database was produced varies.

In the development of the impact analysis, the following approaches were adopted:

- Conducted statistical analyses to examine the quality and significance of the PCI database. PCI values were analyzed using regression and KS-test to determine the significance within roadway sections with/without utility cuts. The statistical analyses provided the basis for further study.
- Examine the general tread of PCI changes with/without utility cuts at three ranges of pre-utility cut PCI conditions: very good, good, and fair.
- Developed two PCI models: 1). accelerated deterioration model that considered both the immediate PCI drop and PCI deterioration due to the potential long-term impact of utility cuts. 2). typical deterioration model that considered only the immediate PCI drop due to utility cuts.

Outcomes from the study include a quantified "Impact Cost" in utility cuts $/m^2 for roadway classes of Arterials, Collectors, and Locals, where the impact cost considered the loss in roadway service life from the utility cut installation. A utility cut impact matrix was ultimately produced that allows the City to assess the potential impact based on the pre-cut roadway PCI condition at the time of the installation.

Introduction

Researchers and engineers have found that pavement utility cuts and maintenance work represent an increasingly significant challenge for urban municipalities to manage[1,2]. The impact of utility cuts on the serviceability of pavements was assessed as a 22 % loss of service life within the roadway network of Calgary[3]. It is reported that, among the investigated pavement sites, 65 % exhibited structural damage in the cut zone, 55 % needed additional overlay to compensate for structural damage due to cut, and pavements with higher PCIs experienced more functional damage than pavements with lower PCIs[4].

Additional money was required to maintain the roadway pavements at certain levels of serviceability[2]. Excessive utility cuts and inconsistent construction practices re-instated the roadway pavement at the utility cut locations puts significant pressure on the existing roadway infrastructure by reducing ride quality and serviceability.

To appropriately manage the negative impacts of utility cuts, various policies and technologies have been developed including incentives to encourage using of trenchless technology, less damaging types of cuts, or using shared trenching[2]. The National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices[5] has recommended the step-by-step procedures to minimize the impact on pavement of new access boxes as well as step-by-step procedures to minimize the impact on pavement of access box repairs.

In practice, utility cuts cannot always be avoided, and that unanticipated work is often required to maintain essential public services. Based on investigations and studies, many agencies have imposed utility cut fees by considering factors of roadway functional classification, pavement age, PCI, and utility cut depth and orientation.

Background

The City owns and operates about 200 centreline kilometres of roadway surfaced with asphalt concrete pavement (ACP). This roadway network includes roadway classes of Arterials, Collectors, and Locals. In addition to the asphalt surfaced roadway network, the City's network includes 100 centreline kilometres of bituminous surface treatment (BST) surfaced roadway segments and gravel roads. The City has recognized that utility cuts can lead to significant deterioration of the City's pavements. The installation, replacement and maintenance of these utility cuts can result in a rougher pavement and a more distressed asphalt surface, ultimately resulting in a reduction in the service life of a pavement.

Records indicate that there were 126 utility cuts completed between 2014 and 2020 on the City's road network and the impact on the service life of the road network could be significant. Although the City has attempted to administer a standard for the reinstatement of these utility cuts, they have recognized that in practice, there are inconsistencies in how these utility cut repairs are constructed. These inconsistencies result from a range of City departments, private contractors, and developers completing these utility cuts for a wide range of purposes: emergency repairs, property utility connections, etc.

In 2023, the City, with Tetra Tech, completed a study into the potential impact utility cuts have on the City's roadway infrastructure. The primary objective of this impact analysis was to determine if the amount of pavement degradation and loss of pavement serviceability could be quantified using the City's pavement utility cut database combined with the City's roadway network condition databases. This paper provides a summary of this study.

Premise and Challenges for this Study

The installation of utility cuts can result in a rougher pavement and more distressed pavement surface, resulting in a reduction in the service life of a pavement. The loss of pavement service life can be assessed in several ways. The City recognized that it is important in establishing an "impact cost" as a result of a single utility cut installation, and that the condition and classification of the roadway subject to the utility cut needs to be considered in calculating this cost. For example, the installation of a utility cut in a pavement in excellent condition has a greater impact on loss of services, and loss of asset value than one installed in a pavement in poor condition. Also, the impact of the utility cut is different for different roadway classifications, with higher class roads (e.g., Arterials) impacted more than lower class roads (e.g., locals). The City recognized also that the "impact cost" is to understand the true cost of a utility cut, allowing the City to establish a utility cut to be assessed at the time of the installation.

The unique challenges of this study are:
- The relatively small data size of utility cuts with available PCI ratings.
- The relatively large range in roadway PCI for different road classes.

In another study[6], one PCI deterioration model was developed based on the regression analysis of collected PCIs. However, given the unique challenges in this study, regression analysis provides a basis for more robust analysis and two PCI deterioration models (instead of one) were developed to assess the impact of utility cuts. This study specifically focused on answering the following questions:
- Is there a difference in PCI for roadway segments where utility cuts are installed compared to roadway segments without utility cuts?
- If a difference in condition is observed and can be quantified, is the magnitude of the change influenced by the pre-utility cut condition of the roadway (utility cuts in good condition pavements vs. poor condition pavements)?
- Can these changes in performance be quantified in terms of an equivalent loss in service life, and if so, a loss in pavement asset value?
- Can this loss in pavement asset value be used to determine a utility cut installation impact cost?

Pavement Asset Management and Practices of Utility Cuts in The City

Asset Management

In 1992, the City retained the services of UMA Engineering Ltd. (UMA) to develop a PMS. This PMS development included completing pavement condition evaluation of the existing roadway infrastructure and the development of a maintenance and rehabilitation program for the complete roadway network. At that time, the method for completing the pavement condition ratings were based on "windshield" type surveys of pavement samples. This method tends to be subjective based solely on the visual inspection and evaluation of the roadway and the inherent bias that comes with non-automated data collection methods. Expected service life by road class was obtained from the City's PMS, where Arterials reach an overlay trigger value at 20 years of age, Collectors at 25 years, and Locals at 30 years.

Starting in 2018, the City switched from the UMA based pavement condition rating to PCI, which provides a snapshot of the pavement health of a roadway. It is measured on a scale of 0 to 100 (where 100 means a newly paved road). A typical (or standard) roadway segment size of 2,200 m^2, representing about 200 m centerline lengths of a 2-way roadway, was assessed in this study to calculate the theoretical rehabilitation cost for a roadway segment of "typical" size within the City's network.

Additional background information was provided by the City in the following documents:
- City-wide road network shapefile from the City's Geographic Information System (GIS).
- ACP and BST overlay projects completed between 2015 and 2021.
- City-wide roadway segments PCI report from 2018 to 2020.
- Computer-aided design files with utility cuts and street occupancy permits from 2014 to 2021.

- Unit costs (in the year of 2023 dollars) for typical pavement rehabilitation treatments including:
    - 60 mm mill and replace ACP at the unit price of $56.64/m^2,
    - 60 mm cold milling at $12.60/m^2; and
    - 60 mm ACP overlay at $43.62/m^2.

Utility Cuts

The City's Servicing Standards Manual[7] was reviewed during this study. However, no specification exists specific to the restoration for utility cuts on existing roadway segments.

A geodatabase on the City's utility cut records was extracted from the City's GIS database and incorporated into the roadway network condition. As shown in Table 1, there were 126 utility cuts completed from 2014 to 2021. The typical utility cut size was 43.5 m^2, representing a utility cut of 5.8 m in width with a distance (length) to the water main or sewer main, which is about 7.5 m in length.

Table 1. Roadway Utility Cuts in the City

Year	Number of Cuts
2014	12
2015	12
2016	8
2017	7
2018	10
2019	20
2020	43
2021	14
Total	126

Practices of Utility Cuts and Pavement Degradation Fees in Other Municipalities

Utility cuts in pavements are known to negatively affect the pavement serviceability with premature deterioration, increased pavement roughness, and decreased pavement asset values. Studies in the City of Calgary[1] and the City of Toronto[8] assessed a pavement degradation fee due to the loss of service life and the additional rehabilitation costs due to the construction of utility cuts. The City of Vancouver has implemented pavement degradation fees based on the total area of pavement excavated, the estimated cost of pavement degradation, and the age of street in years since last re-surfaced as determined by the street utilities committee[9]. These studies evaluated the impacts separately for arterial, collector, and local roads. City of Edmonton established pavement degradation fees in 2005 which are applied in instances where a company excavates, breaks up, otherwise breaches any hard surfaced area of any municipal rights-of-way. Fees are adjusted annually based on the increase of the consumer price index[10].

A summary of pavement degradation fees in various municipalities is provided in Table 2. Comments on the information provided in Table 2 for various municipalities are:

- Four of the five municipalities provide a utility cut fee schedule for three roadway classifications: Arterial roads, Collector roads, and Local roads.

- Three of the five municipalities provide a "sliding scale" fee schedule based on pavement age, where "newer" roadways carry a higher fee than older roads.
- Four of five municipalities administer the fee schedule based on dollars per square metre ($\$/m^2$), where square metres ($m^2$) represent the area of the utility cut.
- The $\$/m^2$ cost varies widely among municipalities and by road class and pavement age.
- The City of Edmonton administers a fee schedule based on dollars per linear metre ($/Lin. m). The City of Edmonton calculates the pavement degradation charges based on the length of the total alignment on a per linear metre rate on a one time per project basis.

Table 2. Pavement Degradation Fees in Various Municipalities

<table>
<tr><th colspan="2">Year of Study
(e.g., $ value of the year)</th><th>2022</th><th>2013</th><th>2024</th><th>2023</th><th>2019</th></tr>
<tr><th>Road Class</th><th>Pavement Age at Utility Cut (years)</th><th>Vancouver[9]
($\$/m^2$)</th><th>Calgary[1]
($\$/m^2$)</th><th>Edmonton[10]
($/Lin. m)</th><th>Toronto[11]
($\$/m^2$)</th><th>Saskatoon[6]
($\$/m^2$)</th></tr>
<tr><td rowspan="8">Arterial</td><td>0-5</td><td>60.67</td><td>57.00</td><td rowspan="24">2.47</td><td rowspan="3">55.97</td><td rowspan="2">162.85</td></tr>
<tr><td>5-10</td><td>48.53</td><td>52.00</td></tr>
<tr><td>10-15</td><td>36.42</td><td rowspan="2">47.00</td><td rowspan="6">119.71</td></tr>
<tr><td>15-20</td><td>24.29</td><td rowspan="2">44.77</td></tr>
<tr><td>20-30</td><td rowspan="4">12.13</td><td>38.00</td></tr>
<tr><td>30-45</td><td rowspan="3">29.00</td><td>33.57</td></tr>
<tr><td>45-55</td><td>25.17</td></tr>
<tr><td>55-70</td><td>15.40</td></tr>
<tr><td rowspan="8">Collector</td><td>0-5</td><td>60.67</td><td>51.00</td><td rowspan="3">47.59</td><td>128.72</td></tr>
<tr><td>5-10</td><td>48.53</td><td>47.00</td><td>94.62</td></tr>
<tr><td>10-15</td><td>36.42</td><td rowspan="2">42.00</td><td rowspan="6">61.84</td></tr>
<tr><td>15-20</td><td>24.29</td><td rowspan="2">37.80</td></tr>
<tr><td>20-30</td><td rowspan="4">12.13</td><td>34.00</td></tr>
<tr><td>30-45</td><td rowspan="3">26.00</td><td>28.00</td></tr>
<tr><td>45-55</td><td>19.61</td></tr>
<tr><td>55-70</td><td>12.61</td></tr>
<tr><td rowspan="8">Local</td><td>0-5</td><td>60.67</td><td>46.00</td><td rowspan="3">47.59</td><td rowspan="8">37.37</td></tr>
<tr><td>5-10</td><td>48.53</td><td>42.00</td></tr>
<tr><td>10-15</td><td>36.42</td><td rowspan="2">38.00</td></tr>
<tr><td>15-20</td><td>24.29</td><td rowspan="2">27.00</td></tr>
<tr><td>20-30</td><td rowspan="4">12.13</td><td>30.00</td></tr>
<tr><td>30-45</td><td rowspan="3">23.00</td><td>28.00</td></tr>
<tr><td>45-55</td><td>19.61</td></tr>
<tr><td>55-70</td><td>12.61</td></tr>
</table>

Pavement Condition Data Analysis and Discussion

Assembly and Overview of 2018 and 2020 Roadway Network Condition Data

The City's roadway database was reviewed and refined to identify roadway segments that 1) had available PCI data before and after a utility cut installation, and 2) had available PCI data where no utility cuts had been installed. This refinement included:

- Removing roadway segments that had undergone ACP overlays or BST treatments after any utility cuts, as identified in a roadway treatment geodatabase provided by the City. It is assumed that roadway segments that had treatments following utility cuts would be more challenging in assessing potential impacts.
- Removing roadway segments that have no PCI ratings and keep only roadway segments that have PCI ratings in 2018, 2019, and 2020 (years where PCI assessments have been completed).
- Assembling a database containing the 2018, 2019, or 2020 roadway PCI for roadways meeting the criteria described above. The database was further filtered to four secondary Datasets for this study:
  - ➢ Dataset 1: Roadway segments without utility cuts ever – to assess rates of roadway deterioration without cuts.
  - ➢ Dataset 2: Roadway segments that had utility cuts before 2018 – to assess rates of roadway deterioration with cuts (over time).
  - ➢ Dataset 3: Roadway segments that had utility cuts in 2019 only – to assess the direct (immediate) impact of utility cuts.
  - ➢ Dataset 4: Roadway segments that did not have utility cuts in 2019 – to assess/compare the direct impact of not completing utility cuts (for comparison to Dataset 3).

For the four datasets, their averaged PCI and other relevant information, is summarized in Table 3.

Table 3. Roadway Datasets and PCI Comparison between 2018 and 2020

Dataset	Roadway Segments Count	Average PCI (2018)	Average PCI (2020)	PCI Change (between 2018 and 2020)
1 – Without cuts ever	272	82.38	81.58	-0.80
2 - With cuts between 2014 and 2018	20	80.42	78.54	-1.88
3 - With cuts in 2019	5	89.29	76.02	-13.27
4 - Without cuts in 2019	277	81.23	80.78	-0.45

Comparison of the PCI for Roadway Segments With / Without Utility Cuts

PCI values for roadways with/without utility cuts were examined from various perspectives:

- Comparison of average PCI and its standard deviation for the four datasets.
- Regression analyses of the PCI values between Dataset 1 and Dataset 2, and between Dataset 3 and Dataset 4.
- Two-sample Kolmogorov–Smirnov test (KS-test) assessing whether the PCI differences from Step 1 and Step 2 is attributed to random variations of the PCI values in the datasets.

The purpose of the analyses was to confirm that the PCI for roadways with utility cuts deteriorate faster than those without utility cuts (as suggested by the data presented in Table 2). In consideration of the relatively small data size of available PCI ratings, and the relatively large standard deviation of PCI for the four datasets, the averaged PCI values or the results from regression analyses were not used directly to develop PCI deterioration models. Instead, the average PCI values, statistical analyses, and the trends of PCI deterioration are all examined and are used for the ultimate development of the PCI deterioration models in this study.

Comparison of Average PCI in 2018 and 2020

Dataset 1 – No Utility Cuts Ever
For the 272 roadway segments without utility cuts ever, the average PCI and its standard deviation are shown in Figure 1. The PCI for the roadway segment without utility cuts decreased from an average value of 82.38 to 81.58 from 2018 to 2020. The PCI change of 0.80 illustrates the "typical" rate of roadway deterioration for the City's network when no utility cuts are installed.

Dataset 2 – Utility Cuts Completed Between 2014 and 2018
For the 20 roadway segments with utility cuts completed between 2014 and 2018, the average PCI and its standard deviation in 2018 and 2020 are shown in Figure 2. The PCI for Dataset 2 decreased from an average value of 80.42 to 78.54. The PCI change of 1.88 illustrates the "typical" rate of roadway deterioration for the City's network when utility cuts were installed historically.

Dataset 3 – Utility Cuts Completed in 2019
For the 5 roadway segments with utility cuts in 2019 that have PCI ratings in both 2018 and 2020, the average PCI and its standard deviation are shown in Figure 3. The PCI for the roadway segments with utility cuts in 2019 decreased significantly from an average value of 89.29 to 76.02 from 2018 to 2020. The PCI change of 13.27 shows the direct impact of a utility cut installation by comparing the year before and year after PCI data.

Dataset 4 – No Utility Cuts Completed in 2019
For the 277 active roadway segments without utility cuts in 2019, the average PCI and its standard deviation are shown in Figure 4. The PCI for roadway segment without utility cuts in 2019 decreased from an average value of 81.23 to 80.78 from 2018 to 2020. The PCI change of 0.45 illustrates the typical rate of deterioration without utility cut installation.

A summary of observations:

- As shown by Figure 1 though Figure 4, the PCI decreased (as it was expected) from 2018 to 2020 for all the roadway segments regardless of whether a utility cut had been installed. However, the rates of PCI decrease vary for the four datasets: Dataset 1 - without cut ever, Dataset 2 - with cut between 2014 and 2018, Dataset 3 - with cut in 2019, and Dataset 4 - without cut in 2019.
- By comparing the dataset without utility cuts ever (Figure 1) and that with utility cuts between 2014 and 2018 (Figure 2), the PCI for roadway segments without utility cuts decreased by 0.80 from 2018 to 2020. In contrast, the PCI for roadway segments with utility cuts installed between 2014 and 2018 decreased by 1.88 from 2018 to 2020. This difference in the PCI (0.80 - 1.88 = -1.08) supports the conclusion that the installation of utility cuts negatively impacts the long-term typical rates of expected roadway deterioration.

Figure 1. PCI Condition Comparison for Dataset 1

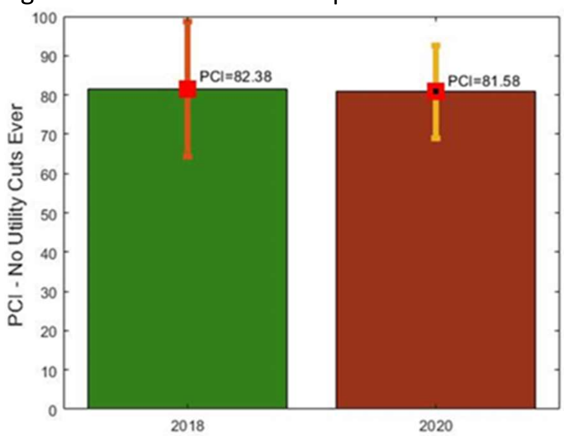


Figure 2. PCI Condition Comparison for Dataset 2

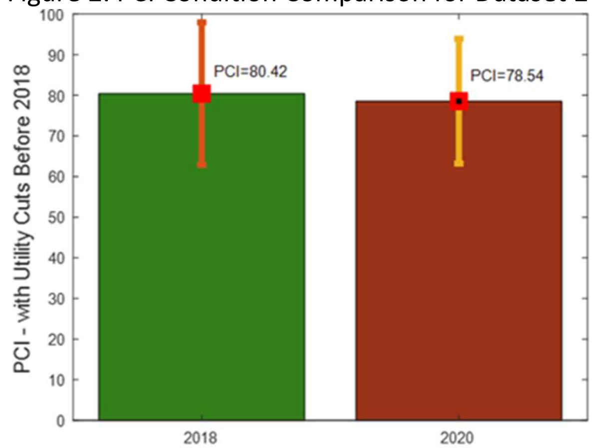


Figure 3. PCI Condition Comparison for Dataset 3

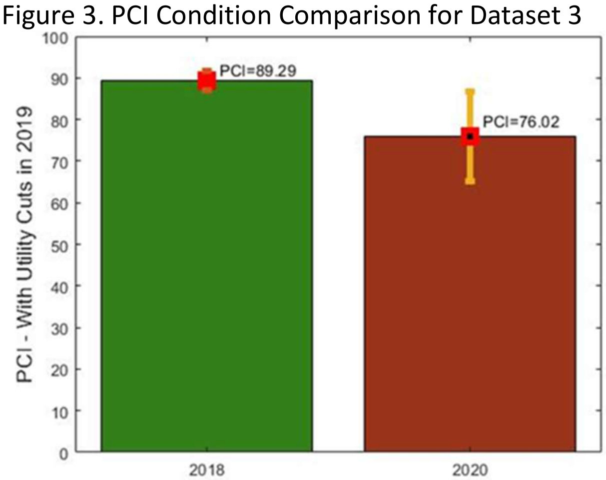
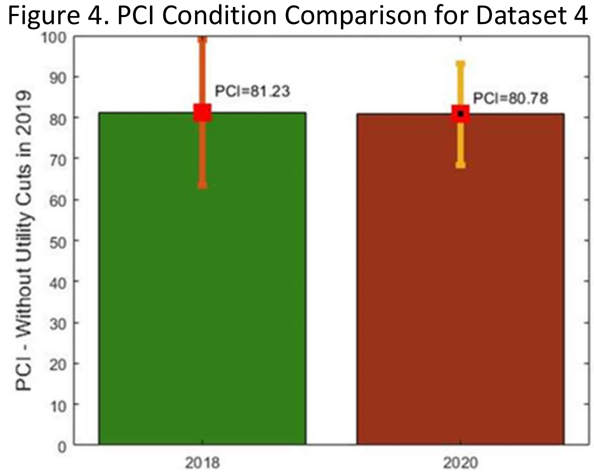


Figure 4. PCI Condition Comparison for Dataset 4



- By comparing the dataset with utility cuts in 2019 (Figure 3) and that without utility cuts in 2019 (Figure 4), the PCI for roadway segments without utility cuts in 2019 decreased by 0.45 from 2018 to 2022. In contrast, the PCI for roadway segments with utility cuts in 2019 decreased significantly by 13.27 from 2018 to 2022. This difference of the PCI of (0.45-13.27 = -12.82) shows the immediate impact on pavement condition as the result of utility cut installation.
- The above observations indicate that the utility cuts impact the pavement PCI in two ways: 1) Long-term impacts, with increased rates of PCI deterioration; and 2) An immediate impact right after the utility cut is installed. To quantify these two types of impacts, further analyses were completed.

PCI Regression Analysis for Roadway Segments with / without Utility Cuts

Results for Dataset 1 – No Utility Cuts Ever

A linear regression analysis was completed for reported PCI values in 2018 and 2020 for Dataset 1 as shown in Figure 5. Since this regression analysis was conducted at a significance level of 5%, and the P-value is almost zero and well below 5% in this analysis, this provides very strong evidence that this analysis is statistically significant. The expected PCI values in 2020 can be predicted based on their PCI values in 2018 for the roadway sections in Dataset 1 as follows:

- $PCI_{2020\text{-no-cut}} = 42.02 + 0.48 \times PCI_{2018\text{-no-cut}}$

To assist the comparison between Dataset 1 and Dataset 2, a corresponding linear fitted regression with zero intercept for Dataset 1 is:

- $PCI_{2020\text{-no-cut}} = 0.97 \times PCI_{2018\text{-no-cut}}$

Results for Dataset 2 – Utility Cuts Completed Between 2014 and 2018

Similarly, a linear regression analysis was completed for PCI in 2018 and 2020 for Dataset 2 as shown in Figure 6. Given the calculated P value is almost zero, this regression analysis is significant at a 5% significance level. The expected PCI values in 2020 can be predicted based on their PCI values in 2018 for the roadway sections in Dataset 2 as follows:

- $PCI_{2020\text{-with-cut}} = 16.53 + 0.75 \times PCI_{2018\text{-with-cut}}$

The corresponding linear fitted regression with zero intercept for Dataset 2 is:

- $PCI_{2020\text{-with-cut}} = 0.94 \times PCI_{2018\text{-with-cut}}$

Figure 5. Regression Analysis of PCI for Dataset 1

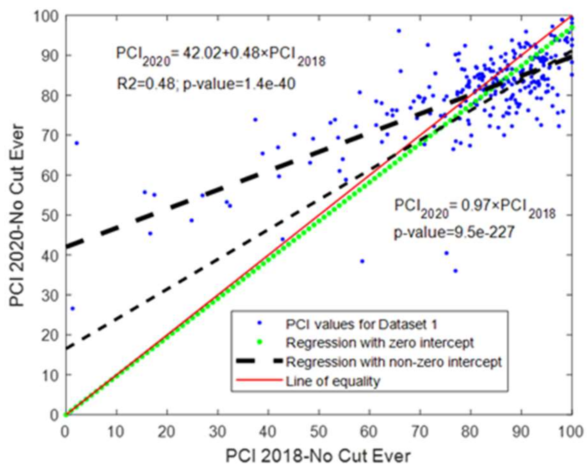
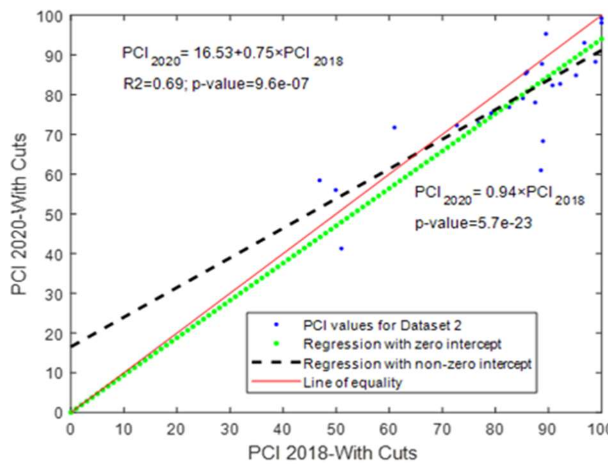


Figure 6. Regression Analysis of PCI for Dataset 2



Comments on the results for Dataset 1 and Dataset 2

By comparing the regression analyses with zero intercept for roadway segments of Dataset 1 and Dataset 2:

- $PCI_{2020\text{-no-cut}} = 0.97 \times PCI_{2018\text{-no-cut}}$
- $PCI_{2020\text{-with-cut}} = 0.94 \times PCI_{2018\text{-with-cut}}$

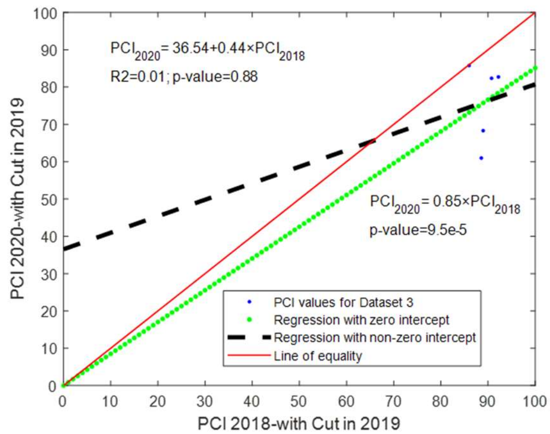
The roadway segments with utility cuts (Dataset 2) show about 3% (0.94-0.97 = -3%) more decrease in PCI over the two-year analysis period (2018 to 2020) compared with those without utility cuts (Dataset 1). This regression analysis confirms from another perspective that the PCI for roadway sections with utility cuts deteriorate faster in terms of annual change in PCI than those without utility cuts.

Comments on the results for Dataset 3 and Dataset 4

Similar regression analyses were also conducted for Dataset 3 and Dataset 4. The results for Dataset 3 are presented in Figure 7. It is not unexpected that the regression analysis is not significant (P-value =0.88 and is above the trigger value of 0.05) for Dataset 3 given that there are only 5 roadway sections with utility cuts with PCI ratings. As such, no further regression analysis or comparison are conducted for

Dataset 3 and Dataset 4. This observation indicates it is inappropriate to use only the regression analysis to determine the PCI deterioration models.

Figure 7. Regression Analysis of PCI for Dataset 3



Two-Sample KS-Test for Roadways with/without Utility Cuts

As an additional statistical check on whether the utility cuts have significant impacts on pavement PCIs, 2 two-sample KS-tests were conducted.

KS-Test for Dataset 1 and Dataset 2

- Sample 1 is defined as the PCI difference between 2020 and 2018 for roadway segments without utility cuts (Dataset 1).
- Sample 2 is defined as the PCI difference between 2020 and 2018 for roadway segments with utility cuts in various years prior to 2018 (Dataset 2).

In summary, the samples are defined as shown below:

- Sample1 = $PCI_{2020} – PCI_{2018}$ (for Dataset 1)
- Sample2 = $PCI_{2020} – PCI_{2018}$ (for Dataset 2)

The KS-test was conducted at a significance level of 5%. The P-value = 0.3504, which is above the trigger value of 0.05. This observation suggests that the difference of PCI values between Dataset 1 and Dataset 2 does not have significant differences from a statistical analysis perspective. In another words, it may not be appropriate to develop PCI deterioration models based solely on the regression analyses.

KS-Test for Dataset 3 and Dataset 4

- Sample 3 is defined as the PCI difference between 2020 and 2018 for roadway segments with utility cuts in 2019 (Dataset 3).
- Sample 4 is defined as the PCI difference between 2020 and 2018 for roadway segments without utility cuts in 2019 (Dataset 4).

In summary, the samples are defined as shown below:

- Sample3 = $PCI_{2020} – PCI_{2018}$ (for Dataset 3)
- Sample4 = $PCI_{2020} – PCI_{2018}$ (for Dataset 4)

This KS-test was conducted at a significance level of 5%. The P-value = 0.0457, which is below the trigger value of 0.05. This observation suggests that the difference of PCI values between Dataset 3 and Dataset 4 have significant differences from a statistical analysis perspective.

Conclusions and Comments of PCI Analyses

Based on the analyses shown previously, it can be concluded that:

- The utility cuts installation impacts the pavement PCI in two ways: Long-term impact and immediate impact right after utility cuts.
- The impact of utility cuts can be quantified. However, it may not be appropriate to develop PCI deterioration models based solely on the regression analyses due to the relatively small data size of available PCI ratings, and the relatively large standard deviation of the available PCI.
- To quantify the impact of utility cuts and develop the PCI deterioration models, in addition to these statistical analyses, the trends of PCI deterioration curves need to be examined.

Development of Pavement Serviceability Loss Models

PCI Trigger Value of Pavement Rehabilitation In the City

There are 23 roadway segments that were ACP overlaid between 2018 and 2020. The average PCI in the year prior to the ACP overlay was calculated as 73.3. This observation suggested it will trigger a pavement rehabilitation when the pavement reaches a PCI value of about 73. Therefore, a PCI value of 73 was used as the rehabilitation trigger value in the following steps of this impact study.

Development of PCI Deterioration Models

Since there were no available PCI deterioration curves in the City for use, PCI deterioration models for Arterials, Collectors, and Locals are developed in this study with the following approach:

- Calculate the percentile and cumulative percentile for the four datasets as presented in Table 3. Due to limited pavement condition data, an escalation factor was considered but not implemented in this study for pavement sections with more than one utility cut.
- Review the PCI-cumulative percentile curves for the four datasets to assess the potential PCI drop due to utility cut installation.
- Assess PCI drop due to long-term impact of utility cuts:
  - ➢ By comparing the PCI in 2020 correspondingly with that in 2018 for roadway segments without utility cuts ever (Dataset 1) – a PCI drop of 3.5 points was assessed.
  - ➢ By comparing the PCI in 2020 correspondingly with that in 2018 for roadway segments had utility cuts before 2018 (Dataset 2) – a PCI drop of 5 points was assessed.
  - ➢ The difference of PCI between the above two pairs of comparisons indicate a long-term PCI drop of 1.5 (5.0 to 3.5) due to utility cuts that were installed prior to 2018. These comparisons are illustrated in Figure 8 and Figure 9.
- Similarly, the immediate PCI drop due to utility cuts was assessed:
  - ➢ By comparing the PCI in 2020 correspondingly with that in 2018 for roadway segments with utility cuts in 2019 (Dataset 4), a PCI drop of 7 points was assessed.
  - ➢ By comparing the PCI in 2020 correspondingly with that in 2018 for roadway segments without utility cuts in 2019 (Dataset 3), a PCI drop of 3.5 points was assessed.

- The difference of PCI between the two pairs of comparisons above indicate an immediate PCI drop of 3.5 (7.0 -3.5) due to utility cuts in 2019. These comparisons are illustrated in Figure 10 and Figure 11.

Figure 8. PCI Deterioration Trend for Dataset 1

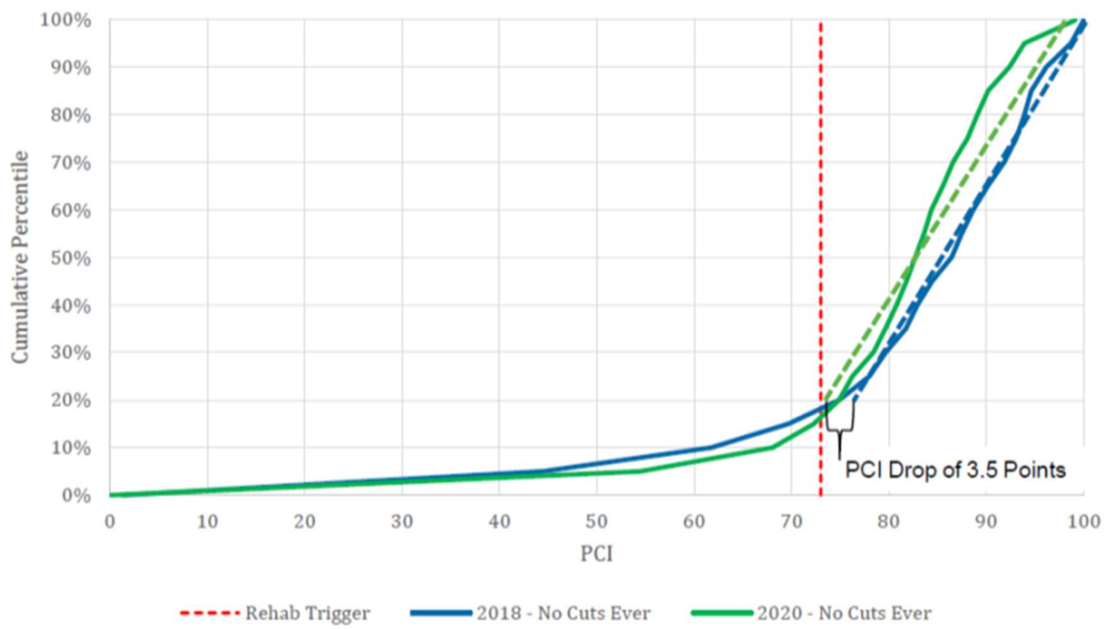


Figure 9. PCI Deterioration Trend for Dataset 2

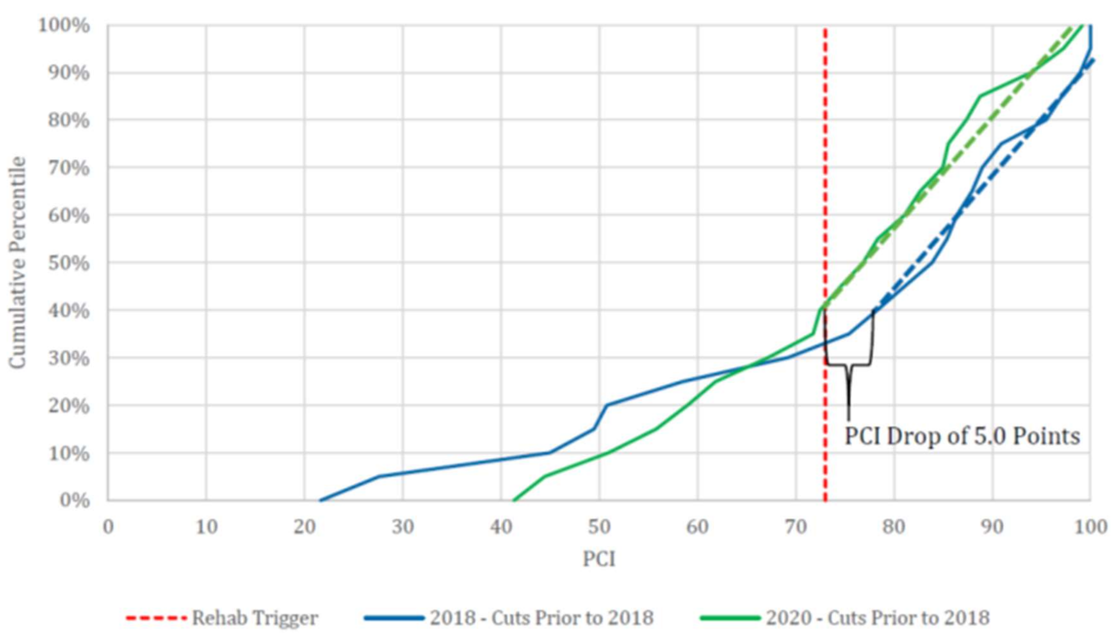


Figure 10. PCI Deterioration Trend for Dataset 3

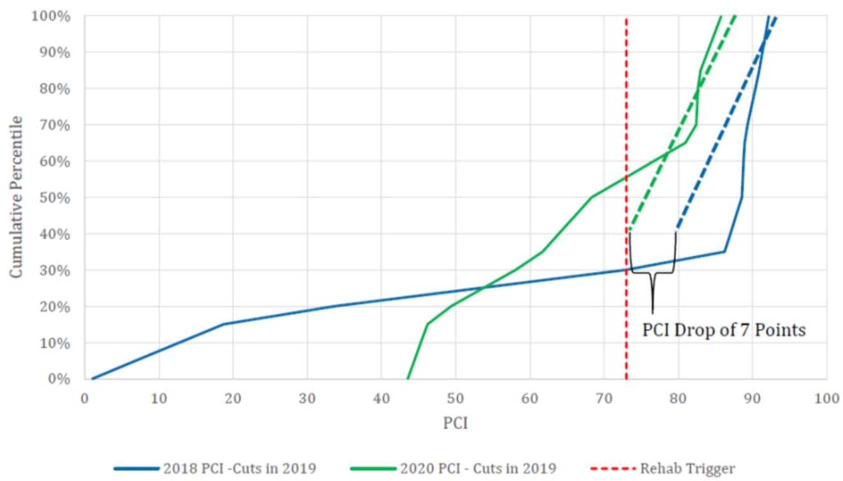
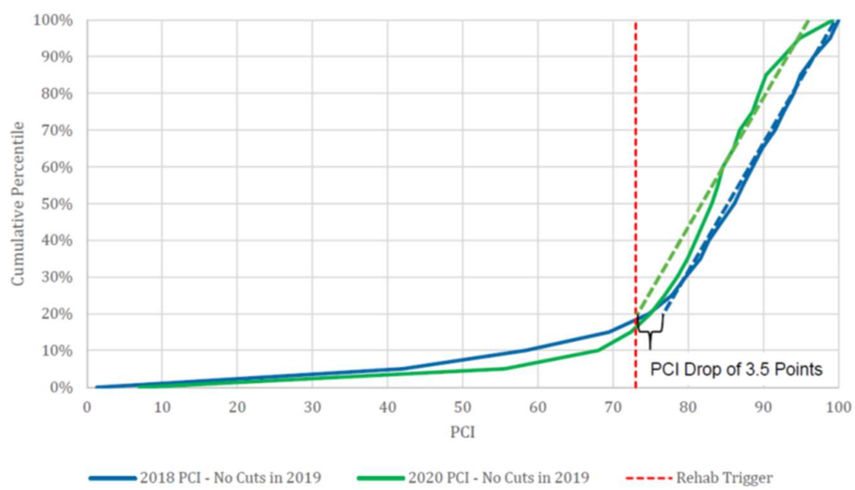


Figure 11. PCI Deterioration Trend for Dataset 4



Based on the assessed PCI drops discussed above, the age of pavement segments, the latest rehabilitation year of the pavement, discussion with the City, and engineering judgement, two PCI deterioration models were developed for each roadway class of Arterials, Collectors, and Locals.

- Model 1: Accelerated deterioration model that considered both the immediate PCI drop (measured the year before and after the cut was installed) and PCI deterioration due to the potential long-term impact of utility cuts. This model serves as the high limit of a utility cut impact.
- Model 2: Typical deterioration model that considered only the immediate PCI drop due to utility cuts (measured the year before an after the cut was installed), and typical PCI deterioration based on the performance of the City's roadway network. This model serves as the low limit of a utility cut impact.

To quantify the impact cost, three ranges of pre-utility cut PCI conditions were examined to simulate the pavement condition of:

- 90 to 100 (very good to excellent condition)
- 80 to 90 (good condition)

- 70 to 80 (fair condition)

PCI conditions less than 70 were not considered in the analysis given that the City typically plans to rehabilitate roadway segments at a PCI of approximately 73.

Summary of Utility Cut Impact Analysis Results

One major difference between the analysis completed in this study and the pavement degradation fee structures developed by other agencies is that this analysis estimated the apparent impact of utility cuts based on pavement condition (PCI range) instead of pavement age. Through discussion with the City, it was determined that records of pavement age are not always available. In addition, the age of the pavement does not always correlate well with the overall pavement condition. The City is fortunate in that they have recent roadway condition PCI data to support this approach to the analysis.
The general methodology that was followed in completing this impact analysis was:

- Step 1: Estimate the rate of deterioration using the two PCI deterioration models.
- Step 2: Select a range of PCI roadway conditions to simulate the installation of a utility cut.
- Step 3: Simulate a utility cut and apply a PCI adjustment for the two PCI impact deterioration models.
- Step 4: Estimate the loss in pavement service life (in years to the next planned rehabilitation) based on the PCI triggers presented in Section 7.1.
- Step 5: Estimate the present value cost of a “typical” roadway rehabilitation treatment based on: 1) the typical roadway segment size, and 2) the year when the PCI condition reaches the assigned trigger value. The present value cost is based on projecting the deterioration of a roadway from the time at which it was new.
- Step 6: Estimate the impact cost of the utility cuts in \$/m² based on the typical utility cut size for each roadway classification.

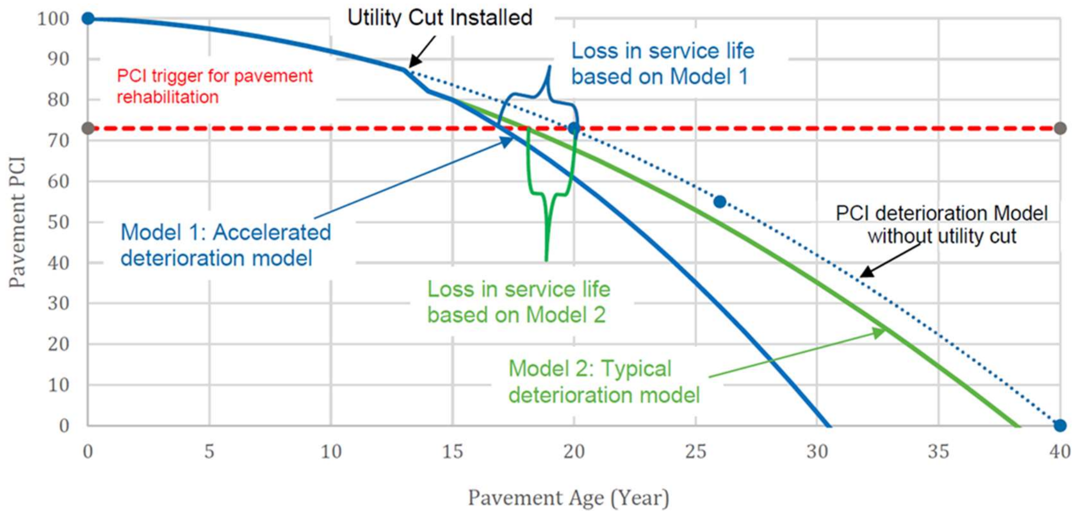
Other inputs required to complete the impact analysis were:

- Assumed the average “typical” treatment cost was \$56.64/m² for treatment of 60 mm cold mill and replace ACP.
- Discount rate of 4%.
- Typical utility cut size: 43.75 m².
- For establishing the PCI impact analysis, an assumed “as-new” pavement condition with an initial PCI condition of 100 was assumed for all utility cut simulations.

<u>Utility Cut Impact for Arterial Roads</u>

As an example, Figure 12 shows the pavement deterioration models for an Arterial road when a utility cut was conducted at a PCI between 80 and 90 (good condition). A pavement service life loss of 3 and 2 years are determined based on deterioration Model 1 and Model 2, respectively.

Figure 12. PCI Deterioration Model with Utility Cuts at PCI between 80 and 90 for Arterials



Following the same steps, the losses of pavement service life were assessed for Arterials at PCIs between 90 and 100, and between 70 and 80. The impact in terms of cost per utility cut per m^2 from the two models for Arterials are summarized in Table 4. The adjusted impact cost is based on the impact cost from Model 2 plus 15% of the difference between the cost from Model 1 and Model 2.

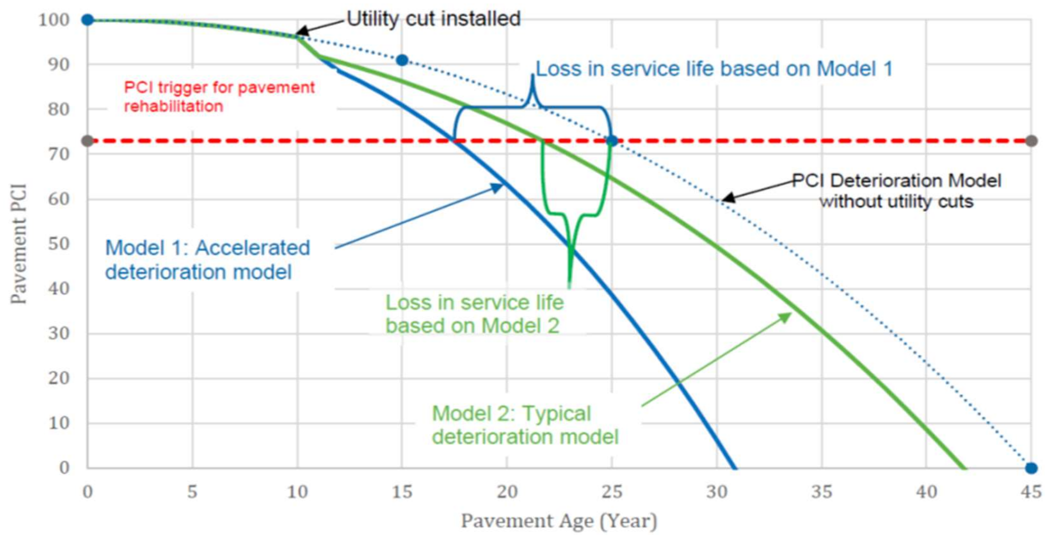
Table 4. Impact Cost of Utility Cut for Arterials

Utility Cut at PCI Condition	PCI (90 to 100)		PCI (80 to 90)		PCI (70 to 80)	
Pavement Age when cut	6		13		18	
Years to Rehabilitation without cut	14		7		2.5	
Rehabilitation cost - if no cut (Present Value $)	71,958		94,692		115,207	
PCI Deterioration Model	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Years to Rehabilitation with cut	7	10	4	5	1.5	1.5
Loss in Service Life (Years) - due to Cut	7	4	3	2	1	1
Rehabilitation cost (Present Value $)	94,692	84,181	106,515	102,419	118,900	118,900
Difference of Cost (Compared to no-cut)	22,734	12,223	11,824	7,727	3,693	3,693
Impact Cost of Utility Cut ($/m^2)	523	281	272	178	102	102
Adjusted Impact Cost of Cut ($/m^2)	317		187		102	

Utility Cut Impact for Collector Roads

As an example, Figure 13 shows the pavement deterioration models for Collectors when a utility cut was conducted at a PCI between 90 and 100 (very good). A pavement service life loss of 7 and 4 years are determined based on deterioration Model 1 and Model 2, respectively.

Figure 13. PCI Deterioration Model with Utility Cuts at PCI between 90 and 100 for Collectors



The impact in terms of cost per utility cut per m^2 on roadway PCI conditions for Collector roads is provided in Table 5. The adjusted impact cost is based on the impact cost from Model 2 plus 10% of the difference between the cost from Model 1 and Model 2.

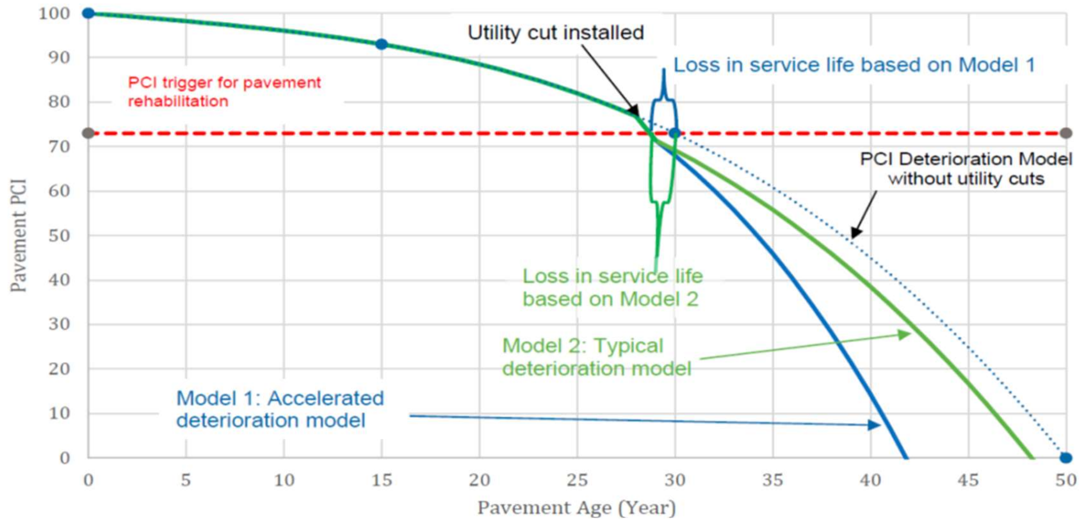
Table 5. Impact Cost of Utility Cut for Collectors

Utility Cut at PCI Condition	PCI (90 to 100)		PCI (80 to 90)		PCI (70 to 80)	
Pavement Age when cut	10		18		22	
Years to Rehabilitation without cut	15		7		3	
Rehabilitation cost - if no cut (Present Value $)	69,190		91,050		110,776	
PCI Deterioration Model	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Years to Rehabilitation with cut	8	11	5	6	2	2
Loss in Service Life (Years) due to Cut	7	4	2	1	1	1
Rehabilitation cost (Present Value $)	91,050	80,943	102,419	98,480	115,207	115,207
Difference of Cost (Compared to no-cut)	21,859	11,753	11,369	7,430	4,431	4,431
Impact Cost of Utility Cut ($/m^2)	503	270	261	171	102	102
Adjusted Impact Cost of Cut ($/m^2)	305		180		102	

Utility Cuts Impact for Local Roads

As an example, Figure 14 shows the pavement deterioration models for Local roads when a utility cut was conducted at a PCI between 70 and 80 (fair). A pavement service life loss of 1 year is determined based on both deterioration Model 1 and Model 2.

Figure 14. PCI Deterioration Model with Utility Cuts at PCI between 70 and 80 for Locals



The impact in terms of cost per utility cut per m^2 on roadway PCI conditions for Local roads is provided in Table 6. The adjusted impact cost is based on the impact cost from Model 2 plus 5% of the difference between the cost from Model 1 and Model 2.

Results

The resultant degradation impact costs, as presented in Table 7 and illustrated in Figure 15, for the installation of utility cuts for Arterial, Collector, and Local roads are finally determined by:

- PCI at time of utility cut is grouped by PCI range: 90-100, 80-90, 70-80, and below 70.
- The PCI deterioration models for each roadway classification provide the approximate age of the pavement at the time of utility cut installation.
- The potential impact cost is the adjusted impact coat as shown in Table 4, Table 5, and Table 6 for Arterials, Collectors, and Locals, respectively.

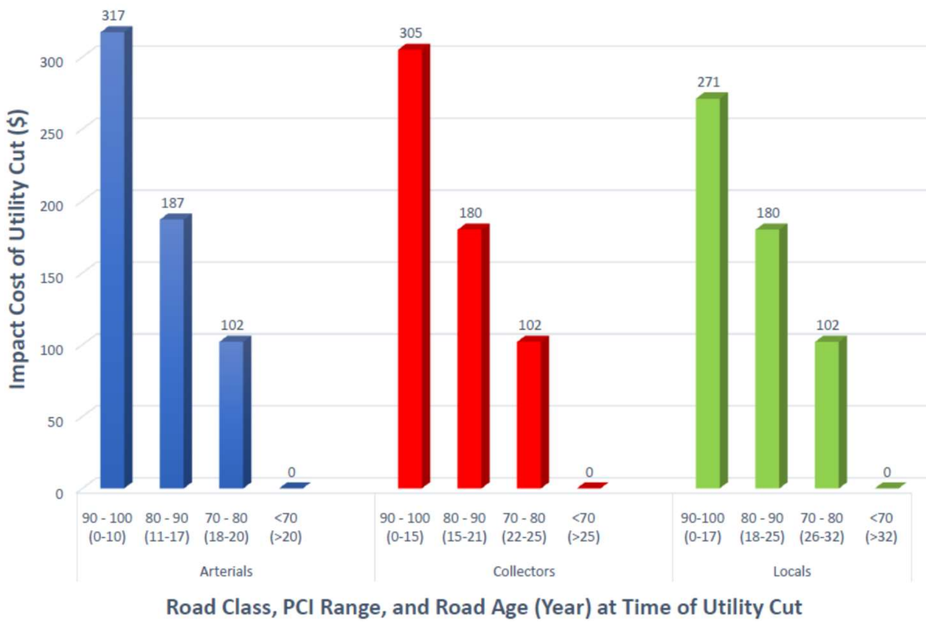
Table 6. Impact Cost of Utility Cut for Locals

Utility Cut at PCI Condition	PCI (90 to 100)		PCI (80 to 90)		PCI (70 to 80)	
Pavement Age when cut	11		22		27	
Years to Rehabilitation without cut	19		8		3	
Rehabilitation cost - if no cut (Present Value $)	59,144		91,050		110,776	
PCI Deterioration Model	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Years to Rehabilitation with cut	11	15	5	6	2	2
Loss in Service Life (Years) due to Cut	8	4	3	2	1	1
Rehabilitation cost (Present Value $)	80,943	69,190	102,419	98,480	115,207	115,207
Difference of Cost (Compared to no-cut)	21,799	10,046	11,369	7,430	4,431	4431
Impact Cost of Utility Cut ($/m^2)	501	231	261	171	102	102
Adjusted Impact Cost of Cut ($/m^2)	271		180		102	

Table 7. Potential Impact Costs of Utility Cut on Various Road Class

Road Class	PCI at Time of Utility Cut	Approximate Road Age at Time of Utility Cut (years)	Potential Impact Cost ($/m^2)
Arterials	90 - 100	0 - 10	317
	80 - 90	11-17	187
	70 - 80	18 - 20	102
	<70	>20	0
Collectors	90 - 100	0 -15	305
	80 - 90	15 - 21	180
	70 - 80	22-25	102
	<70	>25	0
Locals	90 - 100	0 - 17	271
	80 - 90	18 -25	180
	70 - 80	26 - 32	102
	<70	> 32	0

Figure 15. Potential Impact Costs of Utility Cut on Various Road Class



Conclusions

The City's pavement utility cuts database and the roadway network condition database were reviewed and analyzed in this study. The analysis approach employed statistical analysis, a KS-test, assessing the trend of PCI development, pavement PCI degradation models, as well as two types of pavement serviceability loss models were developed. It was found that the amount of pavement degradation, loss of pavement serviceably and pavement asset value can be quantified by using pavement surface condition indices of PCI by overcoming the challenges due to limit pavement condition database.

The primary objective of this impact analysis was to determine if the amount of pavement degradation and loss of pavement serviceably could be quantified using the City's available pavement utility cut database combined with the City's 2018 and 2020 roadway PCI databases. Review of the available PCI data combined with the City's utility cut database, notes changes in pavement PCI condition were observed, and increased rates of pavement deterioration resulting from utility cut installation were quantified. This analysis allowed for the development of PCI change (immediate at the time of the cut) and PCI deterioration (over times) models and provided a means for assessing the impact utility have on service life. This reduction in service life can be quantified in the costs associated with advancing future rehabilitation treatments to compensate for the utility cut installation.

Through the detailed technical analysis presented and ongoing consultation with key City personnel, the resultant costs relative to the loss in service life over the pavement life-cycle were developed for three City roadway classes: Arterials, Collectors and Locals. The information in this study may ultimately be used by the City to assist in determining the costs associated with the construction utility cuts on their overall roadway pavement network.

The analyses and their results of this study can be a useful reference to other agencies that may consider initiating utility cuts related pavement degradation fees with limit pavement condition data to begin with.

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