Long Term Performance of Utility Trench Repairs in Low Traffic Residential Areas

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Paper prepared for presentation at the Innovations in Pavement Management, Engineering and Technologies Session

Of the 2019 TAC-ITS Canada Joint Conference, Halifax, NS

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Abstract

Trenching through existing asphalt pavements is a necessity for the installation and maintenance of critical utilities such as water and waste water services in most urban areas. The following will outline observed performance of a recent trench restoration program and provide strategies for decreasing wasted material and improving standards for trench restoration to minimize ground disturbance and material waste in urban residential areas. Drawing on historical information and collected data from pavement condition assessments performed on trenched pavement sections of different ages, the analysis looks to highlight performance characteristics from a lifecycle cost and environmental impact perspective, and relate these findings to pavement management strategies in low traffic, residential areas.

1 Introduction and Study Background

In August of 2017, WSP Canada's Pavement Engineering team worked jointly with the City of Mississauga and Region of Peel in Mississauga, Toronto, Ontario, Canada to assess the performance of a joint infrastructure trench repair for a utility replacement program and refine their restoration guidelines and timelines to better integrate with pavement asset management practices. The study area, Sheridan Homelands in Mississauga, Ontario, included 29 roads. These roads were constructed within a period from 1953 to 1969 and underwent similar maintenance efforts (sealing of severe cracks with epoxy, cold/hot patching of potholes) prior to the commencement of this study.

This group of roads was selected as a study candidate due to similar traffic volume and environmental characteristics such as subgrade type, climatic factors and construction methods. The roads of the study area resided on a spectrum of age and condition when a watermain trench and reinstatement was performed. This varied data set with multiple controls provided a useful basis for evaluation of pavement performance.

2 Data-sets and Provided Information

Historical data sets provided by the City of Mississauga and Region of Peel included:

2.1 - Construction History

The City of Mississauga presented documentation outlining the documented year of initial construction and the year that rehabilitation was performed on the road, as well as information on when the watermain replacement (time of trenching) had occurred. This data was used to provide context for the deterioration of the road over time.

In the study area, the road initial construction date, first rehabilitation date and year of trenching are as follows:

Table 1: Construction History - Sheridan Homelands

Road Name	**Registered Year**	**Rehabilitation Year**	**Year of Trenching**
Pyramid Crescent	1966	1998	2015
Corsica Court	1966	1998	2015
Woking Crescent	1966	1995	2015
Wadding Crescent	1966	1995	2015
Herridge Drive	1966	1997	2011
Altadena Court	1967	1998	2017
Westman Road	1965	1990	2017
Cleary Court	1965	1994	2017
Loanne Drive	1953	2002	2017
Liruma Road	1953	2000	2017
Renzoni Road	1965	1992	2008
Haygate Crescent	1965	1992	2008
Misener Crescent	1965	1991	2016
Waycross Crescent	1966	1991	2007
Delfiore Drive	1965	1989	2007
Vineland Road	1968	1988	2010
Frankfield Road	1968	1998	2010
Winthorpe Crescent	1965	1997	2010
Belfast Crescent	1965	1995	2008
Cushing Road	1965	1989	2008
Jenner Court	1965	1997	2008
Speyside Drive	1965	2001	2001
Barnstone Crescent	1968	1996	N/A
Merrington Crescent	1969	1996	N/A
Hornsgate Drive	1968	1996	N/A
Hayford Court	1969	1996	N/A
Pinkwell Drive	1969	1996	N/A
Kinnerton Crescent	1969	1996	N/A
Hollington Crescent	1967	1998	N/A

The above data indicates that roads in this study area were constructed on average in 1966, received their first rehabilitation at an average of 29.6 years of age (Standard Deviation of 5.98 years), and were trenched for watermain replacement an average of 17.6 years after the initial rehabilitation was completed.

2.2 - Geotechnical Data

Existing geotechnical reports were provided to WSP in an effort to provide supplementary information to the condition assessments and to better understand the site conditions. These reports are summarized below:

2.2.1 - Existing Subgrade

Subgrade soils in this area were found to be silty clay, with varying quantities of sand. SPT N-Values measured in the soil indicated firm to hard consistency. Firm to hard clayey soils provide good structural capacity but may drain slowly.

2.2.2 - Existing Pavement Structure

The average asphalt thickness encountered in the study area was 140mm, ranging from 132mm to 180mm. Average thickness of granular material in the area was found to be 395mm, ranging from 327mm to 458mm. The average total pavement thickness in the area was 530mm.

2.2.3 - Subdrains

The existing roadways do not include subdrain installations, thus drainage issues and water-related damage was expected and encountered in the pavements during the study. The lack of subdrains are a probable contributing factor to the pavement edge alligator cracking encountered on some of the roads. Photo 1 below shows an example of pavement edge alligator cracking on Frankfield Avenue

Photo 1: Pavement Edge Alligator Cracking – Frankfield Ave

2.3 - Traffic Volumes

Roads in this study can be characterized as Local Residential (Average Annual Daily Traffic of less than 2,500 vehicles) and Local Collector (Average Annual Daily Traffic of less than 5,000 vehicles). Volume of heavy vehicles with axle loads greater than 3000kg is considered to be minimal.

2.4 - Condition Data

Road condition data collected in 2012 and 2017 in the form of PQI (Pavement Quality Index) was provided by the City of Mississauga. This method of condition evaluation operates on a scale of 0 (failed) to 100 (newly constructed and defect free). The following Table 2 shows the PQI ratings obtained in the study area in 2012 and 2017:

Table 2: Historical Condition Data

Road Name	**PQI 2012**	**PQI 2017**	**Reduction over 5 Years**
Pyramid Crescent	92	85	7
Corsica Court	88	82	6
Woking Crescent	90	83	7
Wadding Crescent	85	79	6
Herridge Drive	66	44	22
Altadena Court	81	75	6
Westman Road	75	59	16
Cleary Court	77	64	13
Loanne Drive	91	84	7
Liruma Road	85	79	6
Renzoni Road	68	47	21
Haygate Crescent	70	50	20
Misener Crescent	75	59	16
Waycross Crescent	69	50	19
Delfiore Drive	74	59	15
Vineland Road	47	28	19
Frankfield Road	83	78	5
Winthorpe Crescent	64	44	20
Belfast Crescent	80	73	7
Cushing Road	69	50	19
Jenner Court	73	56	17
Speyside Drive	94	86	8
Barnstone Crescent	90	83	7
Merrington Crescent	87	81	6
Hornsgate Drive	88	82	6

Hayford Court	88	82	6
Pinkwell Drive	89	82	7
Kinnerton Crescent	91	84	7
Hollington Crescent	86	80	6

The above data indicates that an average of 11 PQI points were lost over the five-year period of evaluation. Interestingly, pavements with initial PQI scores of less than or equal to 70 (7 roads) averaged a per-year loss of PQI of 4 points, with the remaining 22 roads losing an average of 1.7 PQI points per year. This supports the hypothesis that acceleration of deterioration occurs near the end of the asset lifecycle.

A limitation of this provided data arose in the fact that the surveyor did not take into account the presence of two different ages of pavement surface (and structure) present in roads that had undergone watermain replacement. These two distinct surfaces of different ages were combined and may reflect in some scores that are weighed higher than reality. Value may still be gained from assessing the “rate of change” of PQI over the timeframe taking into account the initial PQI. The following graph shows the PQI at initial sampling plotted against the change in PQI (Delta PQI) over a five-year period. A linear trendline which provides some support to the claim that the rate of change of PQI increases as the pavement condition deteriorates:

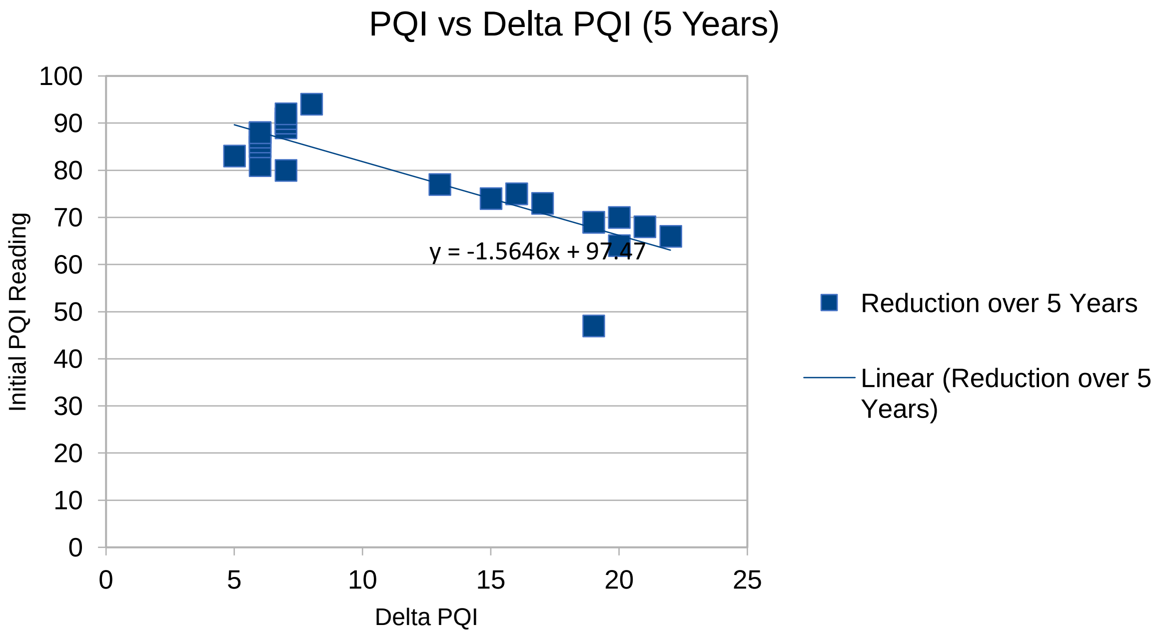

Figure 1: PQI vs Delta PQI (5 Years)

WSP's evaluation summarized later in this study expanded on this preliminary data set, with the added specificity of differentiating the newer and older sections of pavement on roads that had undergone trench replacement, due to the governing condition in terms of pavement management which is most often the section with more severe distresses.

2.5 - Repair Methodologies

The methodology one uses to excavate and restore a trench depends heavily on the depth and type of service that will be performed within the trench, as well as the characteristics of the soil at the trench wall. Trench restorations in the study area generally followed the guideline presented in Figure 2 below:

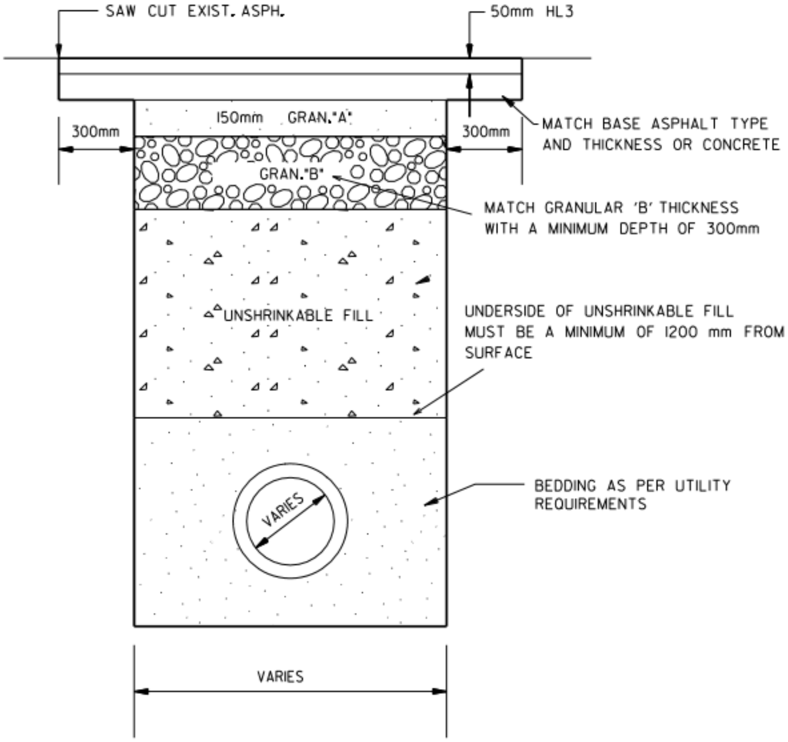

Figure 2: Trench Restoration Standard Drawing, City of Mississauga (Rev 2018)

Trench restorations with three (3) meters wide asphalt replacement were the most common (20 roads of 29). These three meter restorations were performed with screed-width in mind, as the asphalt was saw-cut at three meters in width from the curb edge, which enabled the contractor to include the backfilled and compacted trench and approximately 0.3 m on either side while both full width eight (8) meter asphalt replacement and one (1) meter wide of asphalt replacement was isolated to one (1) location (one road) each. Photos of the Typical 3m and 1m trench restoration are presented below:

Photo 2: Typical 3m Trench Restoration, Sheridan Homelands

Photo 3: 1m Trench Restoration (Hand Laid), Altadena Court

The focus of this paper will be on the performance of the dominant restoration width of three (3) meters, with the condition of the single case of full width and one (1) meter restorations discussed separately. The remaining roads were not yet trenched.

3 Data Collection Methods

This study necessitated a robust, standardized data collection method. Field Engineers from WSP utilized methods outlined in the Ministry of Transportation of Ontario’s SP-024 Manual for the Condition Rating Flexible Pavements (2014) to rate the condition of the roads' trenched and non-trenched pavements.

3.1 - Pavement Condition Index

PCI, or Pavement Condition Index, is a methodology used to evaluate the condition of a road based on the density and severity of different types of distresses visible on the surface of a pavement structure. Briefly, PCI is an index determined from a combination of the International Roughness Rating (IRI) and Distress Manifestation Index (DMI) of a road section.

In WSP's Sheridan Homelands study, the aforementioned factors were logged for each road on the trenched pavement (if applicable) and the un-trenched pavement along with an overall Ride Condition Rating (RCR) out of ten (10) points based on the comfort level of riding on the road at the posted speed limit.

PCI was developed by the Army Corps of Engineers, and the Ministry of Transportation of Ontario (MTO) has summarized a method outlined in their publications “Pavement Design and Rehabilitation Manual” (MTO, 2013) and “SP-024 Manual for Condition Rating of Flexible Pavements” (MTO, 2016). Additional information and detail may be found at those resources.

3.2 - Tiers of Pavement Condition

For the purpose of pavement management, it is common to assign PCI ranges to common condition identifiers. The identifiers chosen for this study were as follows:

- **Excellent (PCI 80+)**: Road is defect free
- **Good (PCI 66- 80)**: Road is mostly defect free, with minor distresses
- **Fair (PCI 46- 65):** Distresses are more common, with higher severity distresses starting to develop
- **Poor (PCI 36- 45)**: Higher severity distresses are intermittent to frequent
- **Very Poor (PCI < 35)**: Severe Distressing in the pavement with high frequency

These condition categories can be used in conjunction with guidelines presented in “Pavement Condition 101” published by the Ontario Good Roads Association (2009) for timing of rehabilitation.

3.3 - Pavement Condition Over Time

Research has been done on the typical deterioration rates of pavements over time. Author A. Shafaghat presented in his technical paper “Investigation of Aggregate and binder types effects on the microsurfacing rutting properties” (2015) the following visualization of PCI rating over time for a typical section of road:

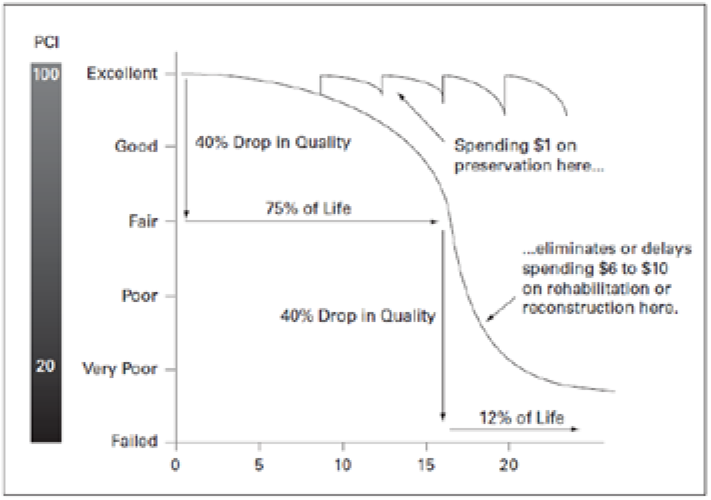

Figure 3: PCI over Time (Shafaghat, 2015)

The above Figure 3 clearly indicates the acceleration of pavement degradation over time, and thus the quickly closing window for rehabilitation activities that occurs near the end of the asset lifecycle for pavements.

3.4 - Common Failures - Local Roads

Local roads with relatively low truck traffic (non-industrial routes) are less likely to see deterioration based on excessive loadings, and more likely to see deterioration caused by environmental factors. Environmental factors include behavior of the subgrade soils, oxidization, thermal considerations, and the presence of water from either precipitation, run-off, or groundwater. The following Table 3 shows types of failures and their associated environmental factor.

Table 3: Common Failures - Local Roads

Distress Type	**Cause**
Thermal Cracking	Exposure to Varying Temperatures
Oxidation/Volatilization of Asphalt	Exposure to Oxygen and Sunlight. Dries the asphalt and may cause loss of coarse aggregate
Differential Heaving	Frost Action in the Subgrade
Settlement/Depression	Compaction of Subgrade Elements
Alligator Cracking	Failure of Pavement structure due to poor drainage or soft subgrade elements

3.5 - Common Failures – Trenches:

Cutting into a “whole” road may introduce new failure modes to a pavement. The following Table 4 describes some of these failures:

Table 4: Common Failures in Trench Restored Pavement

Distress Type	**Cause**
Joint Separation/ Joint Cracking	May be caused by improper mix design, deficient paving technique, or the deterioration/absence of asphalt joint sealant
Overall/Localized Settlement	Improper compaction of subgrade elements, trench backfill, or pavement structural elements (granular material/asphalt) may cause widespread or localized settlement, depending on the consistency of compaction methods and subgrade type.
Undermining of Asphalt	Common in soils with low cohesion (e.g Sand, Dry Granular Material), unintended removal of the pavement structure or subgrade under the existing asphalt makes re-compaction difficult or impossible depending on site conditions.
Coarse Aggregate Loss	The reinstatement of asphalt to final grade with a coarser grade asphalt (HL8 equivalent mix) may increase surface area of exposed aggregate and cause premature ravelling.
Loss of Crossfall	Reinstated trenches may adversely affect drainage of the road if the original grading is not maintained, potentially causing ponding.

For the most part, the above failures may be avoided by ensuring that paving is taking place in close to optimal conditions (dry, warm) and that the paving process is controlled with strict standards and specifications, as well as quality control measures taken on site during operations. Within the study area, the most common failure mode was pavement edge alligator cracking as reflected in the Photo 1 of this paper.

4 Pavement Condition Results

For the 29 Local Roads evaluated in this specific study, 22 of those roads were subject to watermain replacements and associated trench rehabilitation activities originated in 2001 (16 years prior to this study). Results are presented in Table 5 below:

Table 5: Pavement Condition Results, WSP 2017

Road Name	Year of Construction	Year of Rehab	Restoration Type	Pavement Age	PCI (non-trenched)	Age of Trench	PCI (trenched)
Pyramid Crescent	1966	1998	3m	20	71	3	88
Corsica Court	1966	1998	3m	20	76	3	87
Woking Crescent	1966	1995	3m	23	72	3	87
Wadding Crescent	1966	1995	3m	23	68	3	85
Herridge Drive	1966	1997	3m	21	55	7	81
Altadena Court	1967	1998	1m	20	58	1	N/A
Westman Road	1965	1990	3m	28	41	1	91
Cleary Court	1965	1994	3m	24	71	1	95
Loanne Drive	1953	2002	3m	16	76	1	94
Liruma Road	1953	2000	3m	18	61	1	91
Renzoni Road	1965	1992	3m	26	55	10	75
Haygate Crescent	1965	1992	3m	26	50	10	83
Misener Crescent	1965	1991	3m	27	40	2	75
Waycross Crescent	1966	1991	3m	27	47	11	78
Delfiore Drive	1965	1989	3m	29	60	11	83
Vineland Road	1968	1988	3m	30	34	8	76
Frankfield Road	1968	1998	3m	20	62	8	72
Winthorpe Crescent	1965	1997	3m	21	39	8	72
Belfast Crescent	1965	1995	3m	23	63	10	75
Cushing Road	1965	1989	3m	29	46	10	74
Jenner Court	1965	1997	3m	21	52	18	74
Speyside Drive	1965	2001	Full Width	17	80	17	N/A
Barnstone Crescent	1968	1996	N/A	22	70	N/A	N/A
Merrington Crescent	1969	1996	N/A	22	70	N/A	N/A
Hornsgate Drive	1968	1996	N/A	22	63	N/A	N/A
Hayford Court	1969	1996	N/A	22	69	N/A	N/A

Road Name	Year of Construction	Year of Rehab	Restoration Type	Pavement Age	PCI (non-trenched)	Age of Trench	PCI (trenched)
Pinkwell Drive	1969	1996	N/A	22	69	N/A	N/A
Kinnerton Crescent	1969	1996	N/A	22	70	N/A	N/A
Hollington Crescent	1967	1998	N/A	20	70	N/A	N/A

The condition of the non-trenched section of each road and the trenched section of each road was evaluated separately and compared over the road network with the age of the section. Figure 4 shows the results of this evaluation for Non-Trenched Pavement.

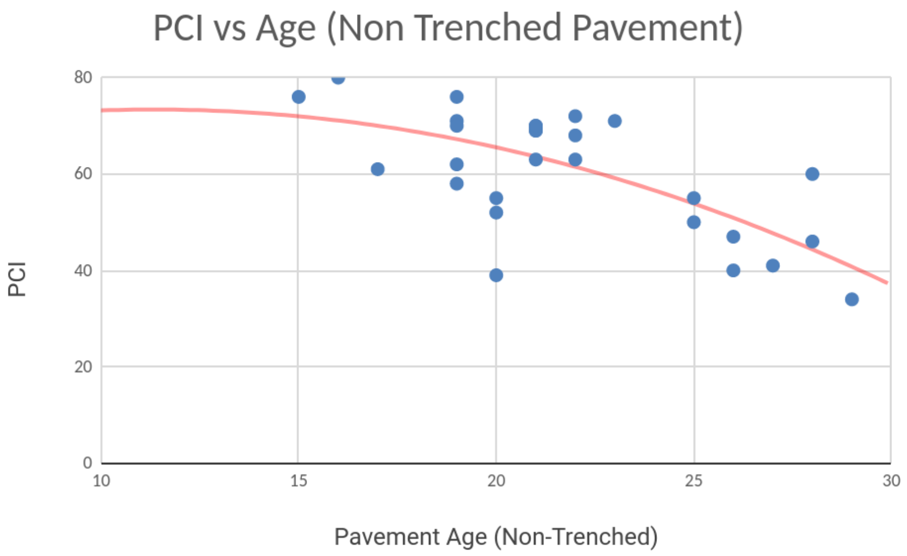

Figure 4: PCI of Non-Trenched Road Sections vs Age

The non-trenched portion of each road deteriorated at an average of 1.9 PCI points per year, with the rate of deterioration accelerating toward the end of the lifecycle. This rapid deterioration is expected, as road distresses tend to compound and accelerate over time if not treated.

The condition of the non-trenched road portions was compared to the seven (7) control roads in the study (road that were not trenched) to determine if the process of trenching caused a notable effect on the rate of deterioration in the adjacent pavement. Control roads saw an average PCI loss per year of 1.6 PCI, which is slightly lower than the average PCI loss of 1.9 points per year shown in the trenched pavements but is within the standard deviation of condition loss for trenched roads (0.46), so a small influence is probable, but not certain.

All three types of pavement (Trenched, Non-Trenched, and Control Roads) were plotted for PCI vs. Age of Pavement. Figure 5 shows the results of this data:

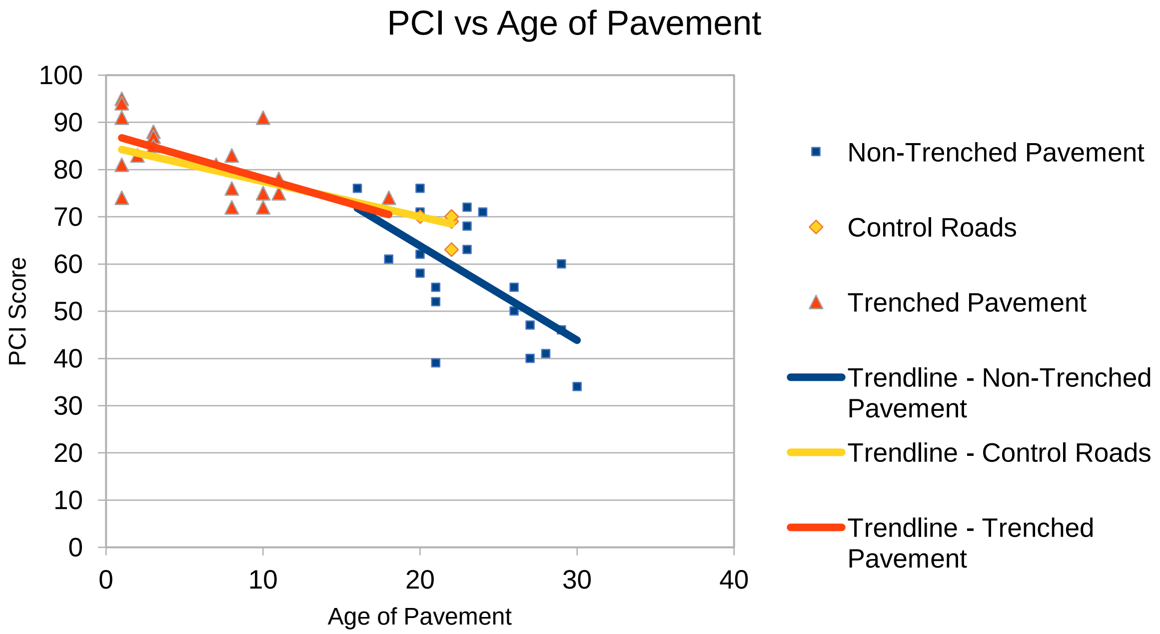

Figure 5: Pavement PCI vs Age

The above condition data indicates that the degradation rate of the trenched pavement is slightly lower when compared to the non-trenched roads and control roads when evaluating by the slope of the best fit lines. It should be noted that a significant drop in PCI (6.6 Per Year according to data from WSP's condition survey assuming an initial PCI of 100) is encountered in the first 1-3 years of pavement life, before significantly flattening over time, this lowers the intercept of the trendline and skews the year-by-year PCI change data. This may be caused by initial settlements of the pavement, or baseline defects present immediately after paving that are flagged during the Condition Survey.

The above Figure 5 reflects a similar trend to that in Figure 1, with the trendlines increasing in slope (rate of degradation) as the pavement ages. This supports the conclusions presented by A. Shafagat in Figure 3. The Rate of PCI loss per year should be lower near the start of the pavement lifecycle, with a steep acceleration occurring near the end of pavement life.

5 Discussion and Analysis

The results presented above indicate these main conclusions:

- The trenched pavement is degrading at a similar rate to the Control Roads, indicating that the trench is performing well.

- Under the conditions in the study area, the existing pavement's degradation rate was negligibly affected by the cutting and reinstatement of the 3m trenches. (1.5 PCI loss per year for Control Roads vs 1.9 PCI loss per year for Non-Trenched Roads)
- As pavement age increases, the rate that which the pavement condition deteriorates increases, as is evident in the City's collected PQI data and the data collected by WSP shown in Figures 1 and 5. This increased degradation is apparent in the Non-Trenched pavement trendline where the older pavements (25 years +) rapidly drop off in PCI score

The above conclusions generally support the Pavement Degradation Model widely used in the industry. A longer-term evaluation with more data points would eliminate noise and refine trends, though the reluctance of municipalities to advance trench cuts into newer pavement makes this data more difficult to obtain. The initial PCI drop of 6.6 points per year over the first three years is worth noting. This information may be useful for the development of Pavement Management Systems to predict the rate of degradation of pavement in the mentioned conditions.

6 Lifecycle Cost Analysis

6.1 - Lifecycle Cost Methods

Beyond the results of the condition assessment, the study was designed to assess the impact that trench replacements had on the lifecycle cost of the asset. This analysis used the following methods of comparison:

- Age of Pavement When Trenched
- Width of Pavement Restoration

Lifecycle costing for different pavement rehabilitation options was completed using the Net Present Value Method at a discount rate of 5 Percent. The following formula was used:

$$NPV = \frac{AssetValue}{(1+r)^n}$$

Where:

r = the chosen discount rate
n = the number of years from present day
NPV = the present value of the asset in the analysis year

Inputs relied on a pavement lifecycle of 26 years between rehabilitation based on the condition survey in the area on a 100-meter-long section of 8-meter-wide road. It is assumed that pavement is rehabilitated on schedule (Year 26). Year 0 rehabilitation cost was assumed to be the constant.

Constant factors were used for the price of materials and construction unit rates and were scaled linearly by volume where necessary based on the width of restoration and the length of road. Salvaged material was included in the overall lifecycle cost as a net expenditure.

A high-level sample lifecycle cost analysis was presented below in Figure 6 to illustrate the methods used:

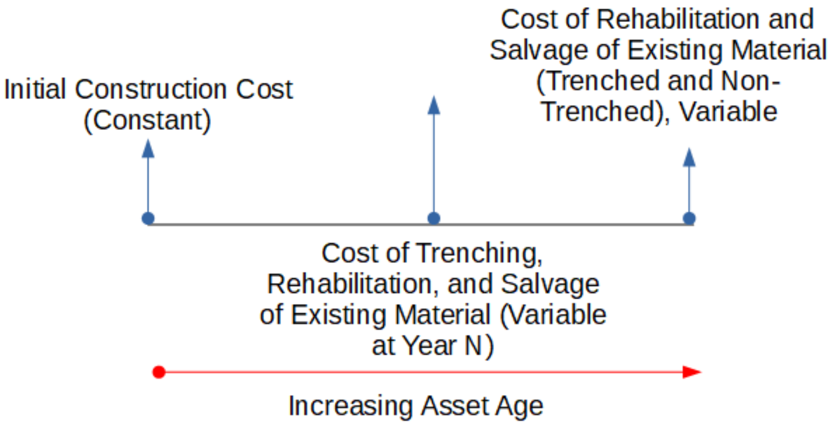

Figure 6: Sample Lifecycle Cost

The lifecycle costs in the above model can be broken down as follows:

- **Initial Construction Cost**: This is a sunk cost that exists, but is neglected in the analysis due to its constant nature and being un-useful for comparative purposes
- **Cost of Trenching, Rehabilitation and Salvage of Existing Material:** This cost summarizes the cost to remove the existing material and replace it with new material, while also taking into account the value remaining in the material that was removed from the existing road, and adding that value to the lifecycle cost for comparison purposes
- **Cost of Rehabilitation and Salvage of Existing Material (Trenched and Non-Trenched)**: This cost encompasses the rehabilitation cost (fixed), along with the value that remains in the newer trench asphalt and the existing asphalt.

The above approach is used to compare various situations, mainly the time at which the trenching and reinstatement occurs. The analysis compared the lifecycle cost impact of trenching at all different points in the pavement life, from Year 0 to Year 26.

Four sample scenarios were used to compare the lifecycle cost impact of the addition of a trench into previously intact pavement:

1. 3m Trench Cut into the Road followed by a 90mm Mill and Pave Rehabilitation
2. 1m Trench Cut into the Road followed by a 90mm Mill and Pave Rehabilitation
3. 3m Trench Cut into the Road followed by a 40mm Mill and Pave Rehabilitation
4. 1m Trench Cut into the Road followed by a 40mm Mill and Pave Rehabilitation

The above scenarios were chosen to compare and contrast different common rehab strategies and highlight effects of increased material usage/disposal. Each Figure 5 and 6 below indicates the lifecycle cost result and ultimate lifecycle cost difference of trenching the road at different times with differing strategies (3m vs 1m) within the 26-year lifecycle observed in the study area.

6.2 - LCCA - 90mm Mill and Pave Rehabilitation at End of Lifecycle per 0.1km

The following Figure 7 compares the lifecycle cost to the year of restoration on a 26-year lifecycle for a 90mm Mill and Pave Rehabilitation Strategy for both 1m and 3m trenches, including the value lost from removing material with remaining design life:

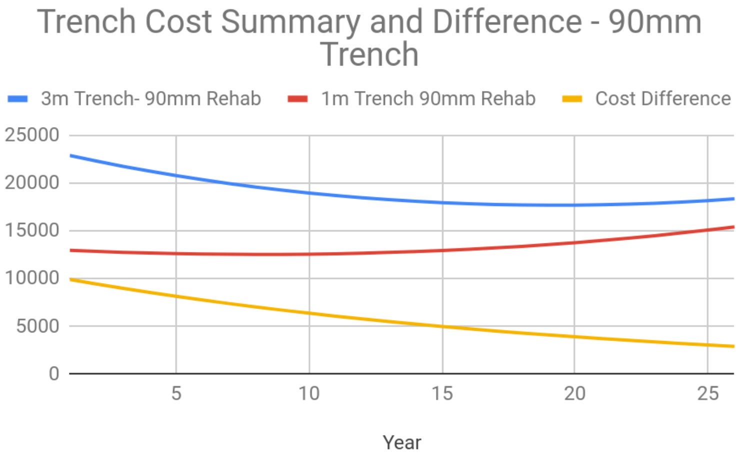

Figure 7: Lifecycle Cost for 1m and 3m Trenches considering a 90mm Mill and Pave Rehabilitation at end of lifecycle

The above Figure 7 indicates that the lifecycle cost savings of decreasing the trench width generally decrease as time goes on, as the existing pavement loses its value and the rehabilitation at Year 26 is removing a larger volume of new material. This data suggests that the trench restoration timeframe should differ depending on the width of the trench cut. For a 3m trench cut followed by a 90mm Mill and Pave rehabilitation, the local minimum lifecycle cost is near 20 years into the pavement lifecycle, with the 1m trench cut experiencing a local minima closer to 10 years from the initial rehab. It should be noted that the performance of 1m trenches is quite variable and the remaining 16 years of the pavement lifecycle may not be feasible.

6.3 - LCCA - 40mm Mill and Pave Rehabilitation at End of Lifecycle per 0.1 km

The following Figure 8 compares the lifecycle cost to the year of restoration on a 26 year lifecycle for a 40mm Mill and Pave Rehabilitation Strategy for both 1m and 3m trenches, including the value lost from removing material with remaining design life. The magnitude of cost savings from the differences is also plotted:

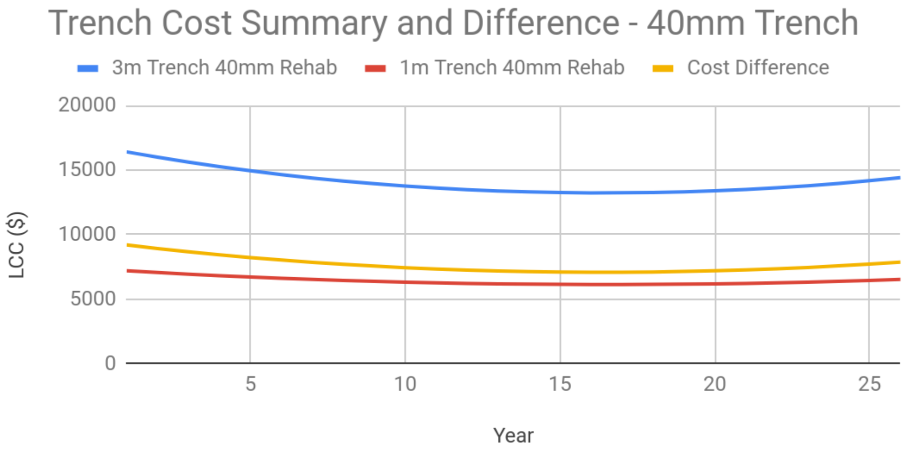

Figure 8: 1m and 3m Trench Restoration Sample Lifecycle Cost 40mm Mill and Pave Rehabilitation Strategy

The above Figure 8 indicates that cost differential between trench width variation is shallow and vaguely parabolic in nature, with a local minimum lifecycle cost for both strategies of approximately 15-16 years into the pavement lifecycle of 26 years. If a 40mm rehabilitation is planned, the model indicates that trench restoration near this time period is of the least lifecycle cost. The model also indicates that the 1m trench restoration is of a consistently lower cost throughout the pavement life.

Overall, the lifecycle cost as analyzed within the four different rehab strategies presents the expected result of a lower lifecycle cost for 1m trench restorations, but presents some interesting conclusions on the optimal timing of trenches to reduce the overall value of wasted material.

7 Performance Impacts

The performance of a trench over time is directly affected by the way in which it is reinstated. As indicated in this study, trenches with 3m width asphalt restorations have been performing on-par with their adjacent non-trenched roads and untouched control roads and have been having statistically little impact on the surrounding non-trenched part of the road.

Pavement restorations of one (1) meter in width encounter some limitations when placed, if properly sized laying and compacting equipment is not used. Hand-laid trenches are prone to break up and premature deformation and are susceptible to freeze-thaw cycles in cold climates. Studies to observe the long-term performance of 1-meter trenches may help to build a clearer picture as to whether, when properly implemented with specific equipment, these smaller trenches can withstand long-term use.

8 Environmental Impacts

Three main factors are key when discussing the environmental impact of pavement works: materials used, materials salvaged with remaining useful life, and materials recycled.

For the first category, the potential for impact mitigation is obvious: use the least amount of material possible. To expand, this means that restoration strategies should be minimized in scope while providing the necessary service level/design life. In this study, a reduction of trench width from three (3) meters to one (1) meter in width caused an average material and labour cost reduction which can be modelled and approximated using the following equations for this study area, focusing on asphalt volumes:

90mm Mill and Pave: $y = 6.6x^2 - 451.6x + 10277$

40mm Mill and Pave: $y = 8.8x^2 - 288.6x + 9458$

Where

y = cost savings for trench width reduction per linear 0.1km (100m)

x = the year of trench replacement (range of 0 to 26)

Salvaged materials are an inevitability, but the goal in any environmentally conscious pavement management system is to let the pavement structural materials deteriorate to their minimum service level before replacement. This is a more complex endeavor when the trench replacement is removing the in-place material, but is itself removed at secondary rehabilitation. The following Figure 9 summarizes the value of removed materials for all four trench cases examined during the study:

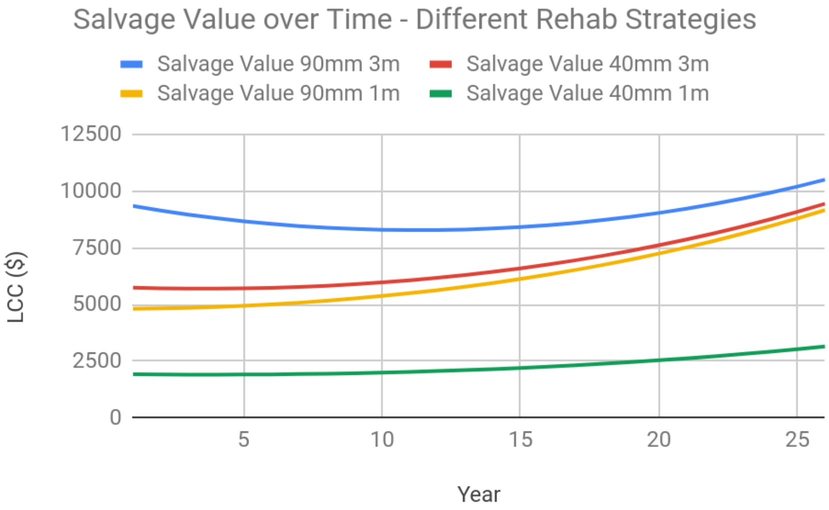

Figure 9: Value of Salvaged Material over time, 1m and 3m Trenches, 90mm and 40mm Rehab

It can be seen in the above figures that in most cases, the lifecycle cost (remaining value) in the salvaged material is higher as the trench occurs closer to rehabilitation, due to the quick removal of the new materials that must take place. The exception occurs with a 90mm rehabilitation and 3m trench replacement, with the lowest lost material value coming around year 12.

If remaining lifecycle cost is used to approximate the environmental impact of the material usage during trench restoration operations, the contents of this paper may be used to better inform Pavement Management Systems.

The reduced need for storage for the salvaged pavement materials and less overall material used creates a more environmentally sound pavement management plan.

The reuse of spent pavement materials and/or construction materials is an environmentally friendly way to reduce both salvaged and new materials used. Many modern pavement materials specifications such as the Ministry of Transportation of Ontario's OPSS 1010 (April 2013) provide guidelines for the re-use of salvaged materials.

Common practices include the reuse of asphalt pavement (RAP) in hot mix, the blending of existing aggregate with virgin aggregate to achieve a desired grain size distribution in the pavement base or subbase, and the use of recycled concrete material (RCM) in the granular layers. Though limitations to the reuse of materials exist, the following of guidelines such as provincial or municipal specification and organizations' publications such as the US Federal Highway Administration's "Reclaimed Asphalt Pavement in Asphalt Mixtures" (2011) may provide performant materials at a good price point that lower the environmental impact of paving operations.

9 Summary and Results

Weighing the performance characteristics, environmental impact and cost metrics for the study area resulted in the following guidelines adopted by the City of Mississauga/Region of Peel to improve their trench restoration program timing. These categories were loosely based on the original OGRA PCI condition scores, and adapted to fit Local Roads and increase accessibility and ease of use for program managers:

- **PCI Range 80+:** Avoid all but emergency trenches and repairs.
- **PCI Range 65 to 79:** Utility trenches should be restored in a manner that ensures long-term performance, such as the 3-meter-wide restorations in this study area.
- **PCI Range 45 to 64:** Utility trench width and restoration should be minimized to 1m or lowest possible for required work. This road is close to rehabilitation.
- **PCI Range 0 to 45:** Utility Trench Restoration should be paired with road rehabilitation to minimize wasted material and provide a smooth asphalt surface with minimal joints.

The above strategy can be implemented as closely as possible with public works projects to minimize wasted material and maximize service life of pavements. To implement this strategy, the municipality must keep track of its pavement condition. Data collection every 5 years is generally accepted to provide sufficient data to implement an effective Pavement Management System.

Future Improvements

In the future, the proliferation of specialized paving equipment designed to minimize trench impact is a must. The consistency of performance of trenched enables pavement management teams to have flexibility in their strategies and use less material during necessary repairs. Municipalities may play a role in the more widespread acquisition of smaller specialized pavers and rollers by requiring that contractors use this equipment when tendering.

As the performance of smaller width trenches improves, the minimization of used material will result in a large cost savings for municipalities and minimize the usage of raw materials, which, moving forward, may be critical in cost control for linear infrastructure projects such as the subject watermain replacement.

The improvement of material recycling methods will also enable a greater acceptance of the re-use of salvaged materials. Better (cheaper) trenchless installation and repair methods are also a step forward.

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