DEVELOPMENT OF A PAVEMENT MANAGEMENT AND PRIORITIZATION FRAMEWORK FOR THREE ACTIVE MUNICIPAL LANDFILLS

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ABSTRACT

Landfills are an essential component of a city's waste management strategy. Effective management and maintenance of the haul road network within an active landfill ensures efficient operations, level of service and overall effectiveness of the landfill. In early 2011, a study was carried out to assess the condition of the haul road networks within three major active landfills in a large Canadian city. The purpose of this study was to identify and document the road segments within each landfill, determine the condition and structure of each road, and develop maintenance, rehabilitation or reconstruction (M, R & R) strategies based on the collected data. The pavement structures within each landfill consisted of flexible pavements (asphalt concrete), gravel pavements and dirt roads.

To identify and document the road segments within each landfill, a unique roadway identification methodology was developed based on sound pavement management principles. The Route ID is a unique identifier which was used to develop a comprehensive pavement management database and to document all road segments within each landfill. The roads within each landfill were then sectioned using digital aerial images and site visits. Pavement attribute data was then collected for each unique identifier. To assess the condition of the pavements, condition surveys and deflection testing using a Falling Weight Deflectometer (FWD) were performed on all road segments. To identify the pavement structure, Ground Penetrating Radar (GPR) surveys and borings were advanced along each road segment. The collected data was then analyzed and used to develop M, R & R strategies for each roadway section. A prioritization methodology was also developed based on traffic levels, pavement thickness and structural condition. The pavement management methodology and prioritization strategy developed as a part of this study can be used by landfill operators to effectively manage their haul road networks and improve efficiency and operation.

INTRODUCTION

Landfills are an essential component of a City's waste management strategy. Most major City's rely on landfills as a site for the disposal of waste materials by burial and is the oldest form of waste management. A general operation of a landfill consists of using a confined area, compacting the waste material to reduce volume and burying the waste daily with layers of soil. For a typical City landfill, waste is hauled in by truck and the collection vehicles are typically weighed at a scale upon arrival. The trucks then use a designated haul route through the landfill property to dump their loads. The haul roads within the landfill property are typically not designed to sustain the heavy loaded garbage trucks. Furthermore, most landfills do not employ a traditional pavement management strategy or framework such as for municipal streets or provincial highways.

Effective management and maintenance of the haul road network and parking lots within an active landfill ensures efficient operations, level of service and overall effectiveness of the landfill. In early 2011, a study was carried out to assess the condition of the haul road networks within three major active landfills. The purpose of this study was to identify and document the road segments within each landfill, determine the condition and structure of each road, and develop maintenance, rehabilitation or reconstruction (M, R & R) strategies based on the collected data. The pavement structures within each landfill consisted of flexible pavements (asphalt concrete), gravel pavements and dirt roads.

PAVEMENT MANAGEMENT FRAMEWORK

In order to develop a pavement management strategy it was important to identify the length, type and structure of each road and parking lot within the three landfills. Using high resolution digital-aerial photography, each paved, gravel and trail road was identified and segmented using sectioning criteria.

A road identification methodology was required to develop an inventory of the haul roads and roadway assets within the landfill property. This methodology was used to develop a complete list of road segments within each landfill for inventory and management purposes. The proposed methodology was based on pavement management principles ensures data consistency and integrity of the collected pavement performance data.

Each section or Road ID consisted of the following parameters: Landfill ID, Route Number, and Pavement Sequence Number, with the following format:

Road_ID = [Landfill_ID] & [Route_No] & [Sequence_No]

Landfill Identification

This portion of the Road_ID refers to the unique City ID for each landfill. The following is the unique code for each City landfill:

- Fog Hill Landfill = FH
- East Foghill Landfill = EF
- Thomas Landfill = TH

Route Identification

This portion of the Road_ID refers to the route number for each road within the landfill. As an example, there could be 3 unique asphalt concrete roads, 8 gravel roads and 10 dirt/trail roads. The Route_ID is a unique two digit number ranging from 0 to 99.

Sequence Number

This portion of the Road_ID refers to the sequence number for each landfill road segment. The length of a landfill road may be "broken down" into a unique section based on pavement type, change in geometrics, whether it intersects with another landfill road, etc. The adjacent section increases in sequence number. The Sequence_No is a unique two digit number ranging from 0 to 99.

A conceptual example of this methodology is presented below in Figure 1 for Foghill Landfill which consists of two asphalt concrete roads, two gravel roads and one dirt/trail road. The proposed identification methodology produces 10 unique Landfill Road_IDs for Foghill Landfill in this conceptual example (Table 1).

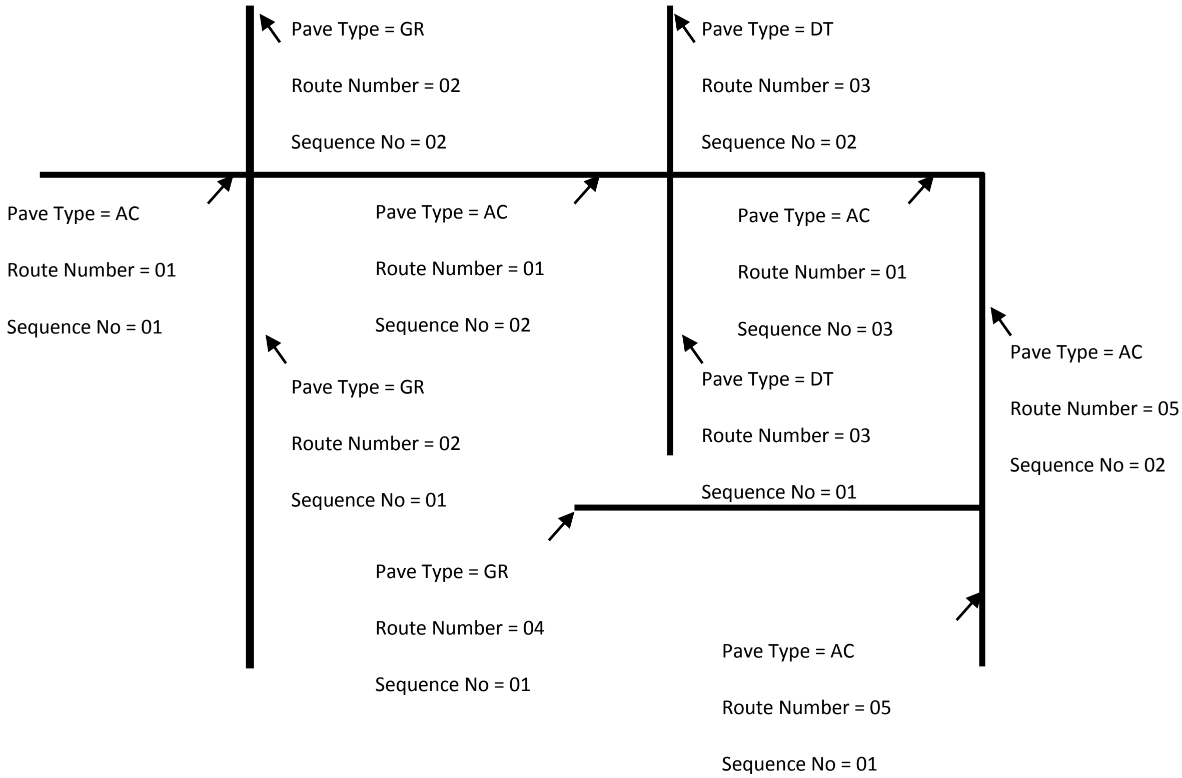

Figure 1: Example of Road Identification Methodology

Table 1: Unique Road_IDs Produced Using Proposed Identification Methodology

Road Number	Road ID	Landfill	Pavement Type	Route ID	Sequence Number
1	FH0101	Foghill	Asphalt Concrete	01	01
2	FH0102	Foghill	Asphalt Concrete	01	02
3	FH0103	Foghill	Asphalt Concrete	01	03
4	FH0201	Foghill	Gravel	02	01
5	FH0202	Foghill	Gravel	02	02
6	FH0301	Foghill	Dirt	03	01
7	FH0302	Foghill	Dirt	03	02
8	FH0401	Foghill	Gravel	04	01
9	FH0501	Foghill	Asphalt Concrete	05	01
10	FH0502	Foghill	Asphalt Concrete	05	02

PAVEMENT EVALUATIONS OF LANDFILL HAUL ROADS

The pavement evaluations consisted of a subsurface investigation, Ground Penetrating Radar (GPR) survey, Falling Weight Deflectometer (FWD) testing, and condition assessments. Cores and boreholes were drilled with a 100 mm diameter solid stem auger to confirm material types, layer thicknesses and for sampling. A continuous GPR survey using an air-launched horn antenna was performed to collect a continuous layer profile of the haul road pavements. FWD testing was performed to determine the insitu structural capacity of the pavement and subgrade strength. The following sections provide more details on the field investigation program.

Subsurface Investigation

The pavement investigation included advancing cores and boreholes through the existing asphalt and gravel pavements. Cores were drilled using a 150 mm diameter core barrel. The cores were taken from the paved roads and parking lots to establish the asphalt thickness and materials stratigraphy. Boreholes advanced on the existing roads and parking lots were drilled using a truck mounted auger equipped with 100 mm diameter solid stem augers. Grab samples from the auger were used to delineate soil stratigraphy.

The soil borings were located to document the characteristics of the granular materials in the pavement structure and the subgrade soils. The boreholes advanced on the existing pavement were generally advanced to an approximate depth of 1.5 m below the ground surface. Soil samples were characterized in the field, and representative samples were placed in labeled containers and transported to the laboratory for further examination and testing. Moisture content, grain size analysis, and Atterberg limit tests were carried out on selected samples.

All borehole and core locations were referenced to latitude and longitude coordinates established in the field using GPS. The offset locations of the core holes and soil borings advanced on the pavements were located with reference to the centerline of the existing roads.

Ground Penetrating Radar Survey

GPR data was collected on the asphalt surfaced roads. The testing was completed using a GPR system manufactured by Geophysical Survey Systems Inc. (GSSI). It consists of a SIR-20 data acquisition system with a Panasonic Toughbook Computer, a model 4105 2.0-GHz air coupled horn antenna, and a wheel-mounted distance measuring instrument (DMI). The vehicle is equipped with a Trimble GPS system which simultaneously collects GPS coordinates along the road sections. At the beginning of testing, the GPR antenna and DMI were calibrated. The start and end of all sections within the data file were “flagged” by the operator. To collect high resolution data for the asphalt concrete and granular layers, the antenna was set at 15 nanoseconds. The transmission rate for the GPR data collection was set to 100 kHz. Data was collected at a scan rate of 6 scans per metre.

It is important to note that several factors can influence signal penetration and the quality of collected data. Pavements or base/subbase materials with high moisture contents will adversely affect signal penetration. To limit or eliminate this problem, data was not collected during or immediately after a rain event. The collected GPR data was checked for quality and processed using RADAN 6.5, data reduction software developed by GSSI. GPR data is processed by identifying reflections caused by changes in the electrical properties (dielectric, electrical conductivity, etc.) of a material. The reflections are digitized and the software converts the digitized reflection into layer thicknesses. Once the layers were identified with RADAN 6.5, the layer and thickness data was exported and was summarized. GPR layer statistics including the minimum, maximum, average and standard deviation were reported.

The GPR data was calibrated using ground truth information obtained from cores and boreholes extracted or advanced on the paved roads. To calibrate the data a known layer thickness (core and borehole information) at a given point is input into the RADAN software to allow it to calculate the electrical properties for the specific material. By default, the RADAN software uses an assumed average value for the electrical properties of the materials if no ground truth information such as core and borehole is available. The layer depths are translated from nanoseconds to millimeter by the RADAN software using a backcalculated dielectric constant derived from inputted core and/or borehole information.

Falling Weight Deflectometer Testing

FWD testing was completed during July 2011 on each of the asphalt paved roads and parking lots. The deflection testing was completed using a Stantec LTPP-SHRP calibrated Dynatest FWD equipped with a differential GPS. This FWD unit passed its annual FWD calibration (load cell and geophones) at the Harrisburg, Pennsylvania SHRP FWD Calibration Center in December, 2010. A relative sensor calibration was completed prior to the start of testing.

FWD testing was completed in the outer right wheel path at an approximate 150 m interval in each direction and referenced linearly to an initial starting point on the road using a DMI, and spatially with GPS coordinates. A nine-sensor configuration was used to record the pavement deflections. The FWD sensor configuration is presented below in Table 2.

Table 2: FWD Sensor Configuration

FWD Sensor Number	1	2	3	4	5	6	7	8	9
Offset from FWD Load Plate (mm)	0	200	300	450	600	900	1,200	1,500	-300

The loading sequence consists of a seating drop at 40 kN followed by three load applications at three target heights. The three load levels were 25 kN, 40 kN and 55 kN (+/- 5%). The FWD used is equipped with thermo sensors that automatically monitor air and pavement surface temperature at each test location and store them in the FWD data file. Our FWDs are also equipped with a Trimble satellite receiver that is linked to the FWDwin software.

FWD Backcalculation Analysis

FWD Backcalculation analysis was completed using procedures provided and detailed in the 1993 AASHTO Guide for The Design of Pavement Structures to determine the effective structural number (pavement structural capacity) and the in-situ subgrade soil resilient modulus on both directions of the selected roads.

The maximum normalized deflection (D_o), measured at the center of the load plate, is a good indicator of the overall pavement strength. The deflection at this location is a function of the pavement layer stiffnesses, including the support capacity of the subgrade soil beneath the pavement structure. The normalization of the deflection under the load plate is a process that is completed to normalize the effect of the load variation during FWD testing between different test locations and to normalize the deflection values collected at different FWD load levels to a common standard load level of 40 kN (9,000 lbf) at a standard temperature of 20°C (68°F). The AASHTO 1993 temperature correction methodology was used to normalize the deflection to a standard temperature of 20°C.

The FWD measured deflections were used to determine the effective structural number and the in-situ subgrade resilient modulus. The structural number is a representation of the load carrying capacity of the pavement structure and the resilient modulus of the subgrade is a representation of the quality of the subgrade soil to resist permanent deformation under repeated traffic loading. Backcalculation uses analytical pavement response models to predict deflections based on a set of given layer thickness values and moduli. With pavement thickness held constant, based on GPR thickness scans, coring results and/or as-built construction records review, the response models identify the set of subgrade and pavement layer moduli that produce deflections that are very similar to those measured during FWD field testing. The backcalculated moduli are examined to draw some conclusions about the degree of structural deterioration in the pavement layers and the expected remaining life of the pavement structure. In addition, the backcalculated moduli can be used for the design of future structural overlays for the existing pavement (i.e. for rehabilitation design).

The outputs of the backcalculation and evaluation analysis are the modulus of elasticity of the pavement structure, or the effective pavement modulus (E_P), effective structural number (SN_{eff}) of the pavement layers, and subgrade soil resilient modulus (M_R).

Visual Distress Survey and Condition Assessment

The pavement condition of three landfill roads and parking lots were evaluated based on the type, severity and extent of the pavement defects or distresses in accordance to the methodology utilized by LTPP-SHRP. Severity is defined as how bad a defect or distress is, while extent is defined as how much of the defect or distress there is. A visual condition assessment of the pavements was performed to document condition and the distresses.

DEVELOPMENT OF PAVEMENT MANAGEMENT FRAMEWORK

To manage the existing asphalt, gravel and trail roads within the three landfills, a decision making matrix for each surface type was developed that considered the following factors:

- Existing pavement thickness at three levels for asphalt & gravel roads (Thick, Medium, Thin)
- Subgrade strength at two levels for asphalt roads (Strong, Weak)
- Pavement rating at various levels (Good, Fair, Poor)

Pavement Thickness

GPR and boreholes were used to determine the thickness of the existing pavement types for each survey section. GPR data was collected on the asphalt surface roads continuously in one pass in each lane and direction. The GPR profiles were reviewed to determine the optimum location of the boreholes.

Pavement Thickness Thresholds

Based on the pavement layer information obtained from the GPR surveys and the boreholes, the thickness thresholds were identified for the decision matrix. Summary statistics including the minimum, maximum, average, standard deviation and two percentile ranges (25% and 75%) were evaluated. The summary statistics for the various layers and total pavement thickness are presented below in Table 3.

Table 3: Summary Statistics for Pavement Layer Data

Summary Statistic	Asphalt Paved Roads			Gravel Roads
	Asphalt Layer (mm)	Granular Layer (mm)	Total Pavement Structure (mm)	Granular Layer (mm)
Minimum	35	25	229	110
Maximum	451	405	511	340
Average	158	167	301	190
25th Percentile	114	132	242	133
75th Percentile	197	230	363	213
Standard Deviation	56.9	62.8	94.3	102.9

Based on the results presented in Table 3, the following thickness thresholds measured in terms of total pavement thickness were assigned to each of the thickness levels for the asphalt and gravel surfaced roads:

Asphalt Surfaced Road (total thickness)

Thick: > 350 mm

Medium: 250 to 350 mm

Thin: < 250 mm

Gravel Surfaced Road

Thick: > 250 mm

Medium: 175 to 250 mm

Thin: < 175 mm

Subgrade Strength

FWD testing was completed to determine the insitu structural capacity and the subgrade strength of the asphalt paved roads. The Subgrade Resilient Modulus (M_R) was calculated for each road segment and is a function of the load, deflection, plate radius, and radial distance from the load plate to the measured deflection.

Subgrade Strength Thresholds

Based on the results of the FWD testing, the subgrade strength thresholds were identified for use in the decision matrix. Summary statistics including the minimum, maximum, average, standard deviation and two percentile ranges (25% and 75%) were evaluated. Presented in Table 4 are the summary statistics for the subgrade strength in terms of the Subgrade Resilient Modulus (M_R).

Table 4: Summary Statistics for Subgrade Resilient Modulus

M_R	Minimum (MPa)	Maximum (MPa)	Average (MPa)	Standard Deviation (MPa)	25th Percentile (MPa)	75th Percentile (MPa)
	5.8	179.7	49.3	27.0	31.3	62.3

Based on the results presented above in Table 4, the following subgrade strength thresholds, measured in terms of the Subgrade Resilient Modulus (M_R) were assigned.

- Strong Subgrade: $M_R \geq 21$ MPa
- Weak Subgrade: $M_R < 21$MPa

Pavement Ratings

Falling Weight Deflectometer testing to evaluate subgrade strength was not performed on the gravel or trail roads. Therefore, the pavement ratings developed during the visual distress survey were used as a measure of the serviceability of the roadway (evaluating surface drainage, rutting, washboarding, etc.). The numeric ratings are summarized as follows:

Asphalt Pavement Rating

5 – Excellent
4 – Good
3 – Fair
2 – Poor
1 – Failed

Gravel and Trail Pavement Rating
5 - Excellent Crown and Drainage, no maintenance
4 - Good Crown and Drainage, routine maintenance
3 - Needs re-grading, ditch maintenance, spot gravel application
2 - Needs additional aggregate layer, major drainage improvements
1 - Travel is difficult, requires complete rebuilding

The following pavement rating thresholds have been assigned:

Asphalt Roads	Gravel Roads	Trail Roads
Good: ≥ 3	Good: ≥ 3	Good: ≥ 3.5
Poor: < 3	Poor: < 3	Fair: 2 – 3.5
		Poor: < 2

Rehabilitation Strategies

It is understood that the City wished to maintain the existing asphalt roads and systematically convert the leachate access roads and gravel surfaced roads into asphalt surfaced roads and the trails into gravel surfaced roads. It is anticipated that the funding required to upgrade each of the existing surfaces for the full network of roads at the Foghill Landfill would be unreasonable to complete at one time, therefore, a three year phased upgrade was assumed. For each combination of surface type, thickness, subgrade strength, and pavement rating, a number of rehabilitation strategies were considered:

Asphalt Road Strategies (maintain and upgrade existing asphalt surfaced roads)

- Preventative Maintenance (crack seal)
- Minor Rehabilitation (chip seal)
- Minor Rehabilitation (40 -80 mm overlay)
- Major Rehabilitation (remove asphalt partial depth 40 mm and overlay 90 mm)
- Reconstruction (150 mm asphalt over 200 mm gravel)

Gravel Road Strategies (three-year phased conversion of gravel roads to asphalt surfaced roads)

- Preventative Maintenance (grading)
- Surface Treatment (apply gravel binding agent ‘Magnesium Chloride or emulsified asphalt’)
- Rehabilitation (Place 130 mm asphalt layer)

Trail Road Strategies (three-year phased conversion of trail roads to gravel roads)

- Preventative Maintenance (grading)
- Surface Treatment (apply dust suppressant)
- Rehabilitation (Place geogrid + 300 mm gravel)

ASPHALT ROAD AND PARKING LOT DECISION MATRIX

The developed Decision Matrix includes 12 unique scenarios resulting from the three thickness levels, two pavement rating levels, and two subgrade strength levels as investigated and summarized below in Table 5.

Table 5: Asphalt Road/Parking Lot Case Scenarios

Case	Thickness	Pavement Rating	Subgrade
1	Thick	Good	Strong
2	Thick	Good	Weak
3	Thick	Poor	Strong
4	Thick	Poor	Weak
5	Medium	Good	Strong
6	Medium	Good	Weak
7	Medium	Poor	Strong
8	Medium	Poor	Weak
9	Thin	Good	Strong
10	Thin	Good	Weak
11	Thin	Poor	Strong
12	Thin	Poor	Weak

The decision making framework for maintaining the existing asphalt is presented below in Table 6.

Table 6: Asphalt Roadway/Parking Lot Decision Matrix

Total Thickness	Pavement Rating (1-5)	Subgrade Strength (M_R)	
		Strong(> 20.7 MPa)	Weak(< 20.7 MPa)
Thick (> 350 mm)	Good (> 3)	Crack Seal	Chip Seal
	Poor (< 3)	Chip Seal	40 mm overlay
Medium (250-350 mm)	Good (> 3)	Slurry seal	40 mm Asphalt overlay
	Poor (< 3)	50 mm Asphalt overlay	80 mm Asphalt overlay
Thin (<250 mm)	Good (> 3)	50 mm Asphalt overlay	Remove 40 mm Asphalt + 90 mm Asphalt overlay
	Poor (< 3)	Remove 40 mm Asphalt + 90 mm Asphalt overlay	Reconstruct 150 mm Asphalt + 200 mm gravel

GRAVEL ROAD DECISION MATRIX

The Decision Matrix includes six unique scenarios resulting from the three thickness levels, and two pavement rating levels as shown in Table 7.

Table 7: Gravel Road Case Scenarios

Case	Thickness	Pvmt Rating
1	Thick	Good
2	Thick	Poor
3	Medium	Good
4	Medium	Poor
5	Thin	Good
6	Thin	Poor

It is assumed that the gravel roads will be systematically upgraded to asphalt surfaced roads over a three year period. The prioritization of the upgrade in surface type is based on the case scenarios presented in Table 7. The decision making framework for upgrading the existing gravel roads is presented below in Table 8.

Table 8: Gravel Roadway Decision Matrix

Total Thickness	Pavement Rating (1-5)	
	Good (≥ 3)	Poor (< 3)
Thick (> 250 mm)	Ongoing Maintenance (maintain grading/drainage) in Years 1 & 2	Place 130 mm Asphalt in Year 3
Medium (175-250 mm)	Apply gravel binding agent (Magnesium Chloride or emulsified asphalt) in Year 1	Place 130 mm Asphalt in Year 2
Thin (< 175 mm)	Place 130 mm Asphalt in Year 1	

TRAIL ROAD DECISION MATRIX

The Decision Matrix includes three unique scenarios for the unsurfaced trail roads resulting from the three pavement ratings as shown in Table 9.

Table 9: Trail Road Case Scenarios

Case	Pavement Rating
1	Good
2	Fair
3	Poor

It is assumed that the trail roads will be systematically upgraded to gravel surfaced roads over a three year period. The prioritization of the upgrade in surface type is based on the case scenarios presented in Table 9. The decision making framework for upgrading the existing trail roads is presented below in Table 10.

Table 10: Trail Roadway Decision Matrix

Pavement Rating (1-5)		
Good (≥ 3.5)	Fair (2 – 3.5)	Poor (< 2)
Ongoing Maintenance (maintain grading/drainage) in Years 1 & 2 + Place Geogrid & 300 mm gravel in Year 3	Surface Treatment (apply dust suppressant) in Year 1 + Place Geogrid & 300 mm gravel in Year 2	Place Geogrid + 300 mm gravel in Year 1

SELECTION OF PAVEMENT REHABILITATION STRATEGIES

Upon completion of the pavement evaluations, each road segment was classified based on its pavement thickness, subgrade strength, and pavement rating. The sections were then run through the Decision Matrices to determine the resulting rehabilitation treatment. The results are presented in Tables 11, 12 and 13. The Decision Matrices were created to be used as a network tool to evaluate conditions and future budget maintenance requirements. Treatment recommendations for individual roads may require individual assessment and engineering judgement to create maintenance recommendations that made sense for an individual roadway.

Table 11: Selected Rehabilitation Strategy for Asphalt Roads and Parking Lots

Section ID	From	To	Station From	Station To	Pavement Rating (1-5)	Thickness (mm)	M_R (psi)	Treatment per Section	Treatment per Road/ Parking Lot
FH0101	Main Gate	FH0102	0	100	3	508	6432	crack seal	crack seal
			100	200	3		9506	crack seal	
			200	300	3		9788	crack seal	
FH0102	FH0101	FH0103	0	100	3	330	6625	slurry seal	±50 mm variable asphalt overlay to level section
			100	200	3		4631	slurry seal	
			200	262	3		4563	slurry seal	
FH0103	F0102	FH0104	0	100	3	259	5680	slurry seal	±50 mm variable asphalt overlay to level section
			100	200	3		4499	slurry seal	
			200	300	3		7813	slurry seal	
			300	400	3		8152	slurry seal	
			400	445	3		8560	slurry seal	

Section ID	From	To	Station From	Station To	Pavement Rating (1-5)	Thickness (mm)	M_R (psi)	Treatment per Section	Treatment per Road/ Parking Lot
FH0104	FH0103	FH1305	0	100	1	225	12686	remove 40 mm asphalt + 90 mm asphalt overlay	remove 40 mm asphalt + 90 mm asphalt overlay
			100	200	1		9769	remove 40 mm asphalt + 90 mm asphalt overlay	
			200	215	1		7205	remove 40 mm asphalt + 90 mm asphalt overlay	
FH0201	South Gate	FH 0202	0	100	4	234	6638	50 mm asphalt overlay	50 mm asphalt overlay
			100	200	4		8213	50 mm asphalt overlay	
			200	300	4		5501	50 mm asphalt overlay	
			300	400	4		5511	50 mm asphalt overlay	
			400	462	4		6277	50 mm asphalt overlay	
FH0202	FH 0201	FH 0203	0	100	4	307	5835	slurry seal	slurry seal
			100	200	4		6577	slurry seal	
			200	212	4		8969	slurry seal	
FH0203	FH 0202	FH 0204	0	100	4	274	5621	slurry seal	slurry seal
			100	200	4		6745	slurry seal	
			200	230	4		6498	slurry seal	
FH0204	FH 0203	FH 1201	0	100	4	439	6023	crack seal	crack seal
			100	200	4		6097	crack seal	
			200	300	4		6955	crack seal	
			300	400	4		6869	crack seal	
			400	500	4		6934	crack seal	
			500	580	4		7272	crack seal	
FH0301	FHP101	FH0101	0	100	3	252	8895	slurry seal	slurry seal
			100	200	3		5668	slurry seal	
			200	265	3		4942	slurry seal	
FH0401	FH0501	FH0101	0	100	4	239	3974	50 mm asphalt overlay	50 mm asphalt overlay
FH0501	FH0301	FH0101	0	60	4	208	4345	50 mm asphalt overlay	50 mm asphalt overlay
FH2202	FH2201	FH0204	0	45	3	99	10008	50 mm asphalt overlay	50 mm asphalt overlay
FHP101a	NA				3	154	3859	50 mm asphalt overlay	50 mm asphalt overlay
FHP101b	NA				3	101	6110	50 mm asphalt overlay	50 mm asphalt overlay
FHP101c	NA				3	150	6236	50 mm asphalt overlay	50 mm asphalt overlay
FHP201	NA				3	158	4767	50 mm asphalt overlay	50 mm asphalt overlay

Summary of Treatments for Asphalt Roads and Parking Lots

Crack Seal

Crack sealing is completed on pavements that are in good to fair condition. It involves maintenance of longitudinal and transverse cracks in asphalt pavements. The cracks should be blown out with high pressure air to remove debris and sealed with an emulsified hot asphalt sealant. The crack sealant will help slow the migration of surface water into the pavement structure.

Chip Seal

Chip seals are placed on roads that are in good to fair condition with no structural distress. As asphalt ages, it oxidizes from ultraviolet radiation (e.g., sunlight) and becomes brittle and more susceptible to cracking. Placement of a slurry seal will help rejuvenate and protect the asphalt surface and provide a minor service life extension. The surface of the existing asphalt should be cleaned with a sweeper or vacuum truck and then the emulsified asphalt is applied and chip sized aggregates are spread on the emulsion and set into the emulsion with a roller. Application is typically with a truck mounted sprayer.

Slurry Seal

A slurry seal can be placed on existing asphalt that is in fair condition and is not exhibiting significant structural distress (e.g. alligator cracking). The chip seal will provide minimal structural strength gain and help restore the wearing surface of the asphalt. Placement of a slurry seal is an effective surface treatment especially on asphalt surfaces that are exhibiting ravelling. It can extend the service life of the asphalt several years (depending on volume and type of traffic). The surface of the existing asphalt should be cleaned with a sweeper or vacuum truck. An emulsified asphalt with aggregate chip mixed in is squeegeed onto the asphalt surface

40-50 mm Asphalt Overlay

An asphalt pavement in fair condition and is not exhibiting significant structural distress (e.g., alligator cracking) can be overlain with new asphalt to increase the structural capacity of the roadway and improve serviceability. The existing surface of the asphalt should be cleaned with a sweeper or vacuum truck and then a tack coat should be applied. The tack coat will help the new overlay section of asphalt bond to the existing pavement. The new overlay section of hot mix asphalt can then be placed and compacted. Note that cracks in the existing asphalt prior to placement of the overlay will migrate vertically into the new overlay section at a rate of approximately 25 mm per year.

Mill 40 mm Asphalt & 90 mm Overlay

Existing asphalt pavement that is in fair to poor condition and is exhibiting surface distress can be overlain directly if there are no grade restrictions or the existing asphalt can be milled to a depth of 40 mm to 50 mm prior to placement of an asphalt overlay. The placement of the overlay section will increase the structural capacity of the roadway and improve serviceability. A tack coat should be applied to the milled surface to help the new overlay section of asphalt bond to the existing pavement. The new overlay section of hot mix asphalt can then be placed and compacted. Note that cracks in the existing asphalt prior to placement of the overlay will migrate vertically into the new overlay section at a rate of approximately 25 mm per year.

Table 12: Selected Rehabilitation Strategy for Gravel Roads

Section ID	From	To	Pavement Rating (1-5)	Thickness	Treatment per Section	Treatment per Road
FH0601	Gate Entrance	FH0702	3	170	Place 130 mm asphalt in Year 1	Place 130 mm asphalt in Year 1
FH0701	West Gate	FH0702	3	340	Ongoing Maintenance (maintain grading/drainage in Years 1 &2)	Ongoing Maintenance (maintain
FH0702	FH0701	END	3	170	Place 130 mm asphalt in Year 1	Place 130 mm asphalt in Year 1
FH0801	FH0102	FH0702	3	125	Place 130 mm asphalt in Year 1	Place 130 mm asphalt in Year 1
FH0901	FH0103	FH0903	3	na	Place 130 mm asphalt in Year 1	Place 130 mm asphalt in Year 1
FH0902	FH0901	FH1001	2	na	Place 130 mm asphalt in Year 1	
FH0903	FH1001	FH0901	2.5	na	Place 130 mm asphalt in Year 1	
FH1001	FH1003	FH1002	2	50	Place 130 mm asphalt in Year 1	Place 130 mm asphalt in Year 1
FH1002	FH1001	END	2.5	150	Place 130 mm asphalt in Year 1	
FH1004	FH1003	FH1005	2	150	Place 130 mm asphalt in Year 1	

Section ID	From	To	Pavement Rating (1-5)	Thickness	Treatment per Section	Treatment per Road
FH1101	FH1002	FH1201	2.5	460	Place 130 mm asphalt in Year 3	Place 130 mm asphalt in Year 3
FH1102	FH1103	FH1201	2	460	Place 130 mm asphalt in Year 3	
FH1103	FH1102	FH1005	2.5	460	Place 130 mm asphalt in Year 3	
FH1104	FH1103	FH1105	2.5	460	Place 130 mm asphalt in Year 3	
FH1105	FH1104	END	2.5	460	Place 130 mm asphalt in Year 3	
FH1201	FH0204	FH1202	2.5	460	Place 130 mm asphalt in Year 3	Place 130 mm asphalt in Year 3
FH1202	FH1201	FH1301	2.5	460	Place 130 mm asphalt in Year 3	
FH1301	FH1202	FH1302	2.5	450	Place 130 mm asphalt in Year 3	Ongoing Maintenance (maintain grading/drainage in Years 1 &2) + Place 130 mm asphalt in Year 3
FH1302	FH1301	FH3202	2.5	450	Place 130 mm asphalt in Year 3	
FH1303	FH1302	FH1304	3	350	Ongoing Maintenance (maintain grading/drainage in Years 1 &2)	
FH1304	FH1303	FH1305	2.5	350	Place 130 mm asphalt in Year 3	
FH1305	FH1304	FH0104	3	350	Ongoing Maintenance (maintain grading/drainage in Years 1 &2)	
FH1401	FH1501	FH1305	3	180	Apply gravel binding agent (Magnesium Chloride or emulsified asphalt) in Year 1	Apply gravel binding agent (Magnesium Chloride or emulsified
FH1501	FH1002	FH1303	2.5	180	Place 130 mm asphalt in Year 2	Place 130 mm asphalt in Year 2
FH1601	FH0204	END of Section	3	180	Apply gravel binding agent (Magnesium Chloride or emulsified asphalt) in Year 1	Apply gravel binding agent (Magnesium Chloride or emulsified asphalt) in Year 1 + Place 130 mm asphalt Year 2
FH1602	FH1601	END of Section	2	180	Place 130 mm asphalt in Year 2	
FH1701	FH0202	Laydown Area	2	180	Place 130 mm asphalt in Year 2	Place 130 mm asphalt in Year 2
FH3102	FH1305	Dead End	3	180	Apply gravel binding agent (Magnesium Chloride or emulsified asphalt) in Year 1	Apply gravel binding agent (Magnesium Chloride or emulsified

Summary of Treatments for Gravel Roads

Ongoing Maintenance

Ongoing maintenance is recommended for existing gravel roads that are in good condition to maintain serviceability. Maintenance should include re-grading of the surface to eliminate rutting and maintain the crown and crossfall. The grading can be scheduled regularly (e.g., every month), as needed (based on the depth of the rutting and rideability) or during moisture events (e.g., rain or wet snow to aid in the grading process). Ongoing maintenance should also address surface drainage with attention paid to the crown of the road, the cross slope, localized low spots and roadside drainage ditches.

Gravel Binding Agent

A gravel binding agent should be placed on a gravel road that is in good to fair condition. Binding agents include magnesium chloride, calcium chloride or lignosulphonate based materials. The binding agent is typically sprayed onto the surface of the gravel roadway and provides two benefits, dust suppression and some binding of the loose aggregate to improve rideability and reduce material loss.

Asphalt Surfacing

Existing gravel roads that are in poor condition or have been identified to be upgraded to an asphalt surface should be surfaced with approximately 130mm of hot mix asphalt. Prior to construction of the new hot mix asphalt, the existing aggregate base material should be checked to confirm that the gradation is adequate to provide drainage and support for the proposed asphalt surfacing. A 130 mm asphalt overlay is used for this exercise based on the data collected for this assignment.

Table 13: Selected Rehabilitation Strategy for Trail Roads

Section ID	From	To	Pavement Rating	Treatment per Section	Treatment per Road
FH1003	FH1004	FH1001	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH1005	FH1004	FH1202	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	
SY1801	SY1005	SY1301	2.5	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
SY1901	SY1005	SY1801	3	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
SY2001	SY1801	Dead End	2.5	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2101	FH1005	Dead End	2.5	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2201	FH2202	FH1001	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2301	FH0801	Dead End	2.5	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2401	FH2301	Dead End	2.5	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2501	FH2903	FH2701	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2601	FH2602	FH2701	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2602	FH2904	FH2903	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	
FH2701	Dead End	FH2501	5	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH2801	Dead End	FH2501	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
SY2901	SY2902	SY2701	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Ongoing Maintenance (maintain grading/drainage) in Years 1 & 2 + Place geogrid & 300 mm gravel in Year 3
SY2902	SY2903	SY2901	5	Ongoing Maintenance (maintain grading/drainage) in Years 1 & 2 + Place geogrid & 300 mm gravel in	

Section ID	From	To	Pavement Rating	Treatment per Section	Treatment per Road
				Year 3	
SY2903	SY2902	SY2602	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	
SY2904	SY0102	SY2602	5	Ongoing Maintenance (maintain grading/drainage) in Years 1 & 2 + Place geogrid & 300 mm gravel in Year 3	
FH3001	Dead End	FH1401	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH3101	Dead End	FH3102	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH3201	FH0202	FH1301	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2
FH3202	FH3201	FH1302	2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	
FH3301	Dead End	FH1301	3	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2	Surface Treatment (apply dust suppressant) in Year 1 + Place geogrid & 300 mm gravel in Year 2

Summary of Treatments for Trail Roads

Ongoing Maintenance

Ongoing maintenance should be carried out on unsurfaced trail roads that are in good condition to maintain serviceability. Maintenance should include regrading the surface to maintain a crown and crossfall and to eliminate ruts and washboards. The grading can be scheduled at regular intervals (e.g., every month), or as needed (based on the loss of crossfall and/or the depth of rutting or washboarding and rideability) or during moisture events (e.g., rain or wet snow to aid in the grading process). Ongoing maintenance should also address the surface drainage of the trail paying attention to the crown of the road, the cross slope, localized low spots and roadside drainage ditches.

Dust Suppressant

Placement of a dust suppressant should be considered for unsurfaced trails that are in fair condition. Dust suppression agents include magnesium chloride, calcium chloride or lignosulphonate based materials. The dust suppressant is typically sprayed onto the surface of the road and provides two benefits, dust suppression and some binding of the surface materials to improve rideability and reduce material loss.

Gravel Surfacing

Existing unsurfaced trail roads that are in poor condition or have been identified to be upgraded to a gravel road should be reconstructed with approximately 300 mm of gravel placed over a geogrid. A biaxial or triaxial geogrid will provide additional structural support for the loose gravel and should be placed on the unsurfaced trail road prior to placement of the gravel. The existing trail road should be assessed at the time of surfacing to confirm the surfacing layers and reinforcement requirements.

SUMMARY AND CONCLUSIONS

The scope of this study was to investigate the current condition of the existing paved and un-surfaced roads at the three landfills, evaluate the collected data, and develop rehabilitation decision matrices to maintain and upgrade the network over a phased three year period. The study consisted of two phases.

The first phase consisted of field data collection including: Visual Distress Surveys, Falling Weight Deflectometer (FWD) testing, Ground Penetrating Radar (GPR) surveys and coring/boring to determine the appropriate thresholds for the thickness and subgrade levels.

The second phase involved developing a Rehabilitation Decision Matrix for asphalt of the three pavement surfaces (asphalt, gravel and unpaved trails), which included the evaluation of several rehabilitation strategies for multiple combinations of pavement thickness, pavement rating, and subgrade strength.

Each individual pavement section was then run through the appropriate Decision Matrix and the recommended treatment was identified. It is important to note that the Decision Matrix is intended to be used as a high level planning tool and the final decision on construction strategy should be based on detailed engineering analysis and design. The end result of this study was a network level planning budget which can aid the City in determining appropriate maintenance and upgrade financial needs over the next three years.

Upon development of the Decision Matrix and completion of this study, the following conclusions and recommendations are provided:

- The gravel roadways are in fair to poor condition and experience seasonal serviceability issues; however, the seasonal difficulties can be alleviated by designing and constructing for the spring thaw conditions. This may include the addition of the geogrid and additional granular materials.
- The City has suggested it would eventually like to upgrade gravel roads to asphalt roads in order to reduce annual maintenance costs and improve serviceability year round. While there is a significant initial capital cost investment to resurface the roads, the resulting annual maintenance costs to maintain an asphalt road is approximately 25% of the cost to maintain a gravel road.
- Similarly to upgrade the unsurfaced trail roads to gravel roads requires a significant capital investment and a phased upgrade. While travel and serviceability on the trails during inclement weather can be problematic, the result of a full upgrade may not be cost effective;
- The cost impacts to upgrade the gravel and trail network were reviewed and it may not be cost effective to budget for those upgrades. However, there are individual circumstances where it may not be practical to leave individual gravel or trail sections unpaved as they relate to the continuous operation of the landfill. Some roads which have higher traffic volume and must be fully accessible year round should be considered for hard surfacing as maintenance costs may be excessive on these facilities. Operations staff should identify the current critical unpaved roadways that must provide year round access and budget for reconstruction with an approximate 130 mm of hot mix asphalt. Prior to construction of the new hot mix asphalt pavement the existing aggregate base material should be checked to confirm that the gradation is adequate to provide drainage and support for the proposed asphalt surfacing. A 130 mm asphalt overlay is used for this exercise based on the data collected for this assignment.
- The framework developed as a part of this study could be extended to include other pavement types within the City by performing Life Cycle Cost Analysis and collecting pavement data; and
- Field testing should always be used to validate and confirm economic analysis and conceptual planning.S

REFERENCES

[Will be added for final copy]