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Long-Term Study of the Cost Effectiveness of Stabilized and Untreated Aggregate-Surfaced Forest Service Roads

April 2017

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ABSTRACT

This report presents the findings from the fifth year of monitoring stabilized and annually dust treated test road sections on the Adams West Forest Service Road near Salmon Arm, B.C. This study is intended to provide FLNRO and the forest industry with guidance about the effectiveness and life cycle cost of various dust palliative treatment regimen.

ACKNOWLEDGEMENTS

This project was financially supported by British Columbia Ministry of Forests, Lands, and Natural Resource Operations (FLNRO).

The authors would like to thank Brian Chow, Chief Engineer, FLNRO, and Erik Kok, Operations Superintendent, Interfor Corporation for their direction and support.

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EXECUTIVE SUMMARY

Between 2012 and 2015, FPInnovations, Interfor Corporation, and the Ministry of Forests, Lands, and Natural Resource Operations (FLNRO) studied the performance of treated and untreated aggregate-surfaced road sections built on the Adams West Forest Service Road (FSR). The main objective of this long-term research project was to investigate the cost-effectiveness of conducting annual dust control treatments on FSRs surfaced with crushed aggregate. The hypothesis and belief is that annual dust control treatments with hygroscopic dust palliatives, such as calcium chloride or magnesium chloride, can prolong aggregate life by two-fold. Hygroscopic products attract moisture from the air and help keep the road surface moist, dense, and smooth. The anticipated benefits are reduced dust, reduced aggregate loss (via loss of fines, raveling, wear), improved transportation efficiency, and reduced grading requirements.

This report presents a summary of the results and conclusions found after four years of monitoring road performance and aggregate deterioration. Progress reports presented in 2013, 2014, 2015, and 2016 provide more detail on the study. The study area consisted of seven, 1 km-long sections located along two distinct (south and north) segments of the Adams West FSR. Traffic information related to volume, type, and speed was collected. Maintenance requirements were detailed. The road running surface condition in each test section was regularly surveyed for deterioration, and the surfacing aggregate was tested for changes in gradation that affect performance.

A survey of road users was conducted to determine whether the Adams West FSR was safer after the use of dust control treatment. 29 of the 33 participants (88%) agreed that the treated sections were safer now than without treatment—due to the substantial increase in visibility. On treated sections of the Adams West, it was found that dust settled within 4 seconds of a log truck passing whereas untreated sections took between 43 and 89 seconds to settle. The improved visibility and surface conditions have resulted in increased speeds of public traffic using the FSR and, because these vehicles do not carry radios, industrial road users must use more caution. Some survey respondents also claimed that the treated road segments became slippery after precipitation.

Surface aggregate samples from each test section were compared to the source pits' gradations and to FLNRO's specification for High Fines Surfacing Aggregate (HFSA). Some aggregate wear has occurred since construction of the sections in 2012 but no significant differences between treated and untreated section aggregate gradation were found. Materials sourced from the gravel pit at the south end of the road conformed more closely to the FLNRO specification, and offered better performance and slower deterioration than surfacing aggregate sourced from the north end of the test road. The source and quality of crushed aggregate appeared to have more impact on road aggregate performance than did dust control applications.

The regular surveys of road surface deterioration did not indicate any major performance differences between the treated and untreated sections. Despite higher traffic levels, the sections along the south end of the road had slightly better surface conditions, on average, than those at the north end. Grading interventions to the southern treatment sections were more frequent because of higher traffic levels, however, and this is likely to have increased surveyed condition ratings also. Aggregate wear and loss was monitored with regular surveys of road surface elevation. No differences were observed between

the treated and untreated sections, whereas the higher traffic, southern, treatment sections did show accelerated wear compared to the lower traffic, northern, treatment sections. Based on the findings of the surface condition surveys, aggregate gradation monitoring, and surface elevation surveying, dust control treatments were not found to substantially improve road surface conditions or prolong aggregate life.

An analysis of on-board GPS data revealed higher, average, truck travel speeds (by 1 to 5 km/h) on the treated versus untreated sections of the Adams West FSR. Truck travel speeds on relatively straight treated and upgraded sections of the Adams East FSR between KM 4 and KM 17 were also analysed. The average travel speeds increased by 6 to 15 km/h on the treated sections. Savings due to faster travel speeds and decreased haul cycle times can help off-set the cost of dust control treatment.

The cost-effectiveness of dust treatment applications was estimated through a life cycle cost analysis based on study cost data for road upgrading, log hauling, dust control application, and road maintenance. When the cost to dust treat and maintain the Adams West FSR was compared with historic maintenance costs prior to dust control applications, the dust control scenario was more expensive. However, when log hauling cost savings from increased travel speeds were included, small to moderate-sized savings resulted. Applying a life cycle cost analysis, it was found that, with the application of upgrading, dust control, and high quality aggregate, costs for road maintenance and hauling could be reduced by up to $115,000 per km over a 10-year period—generating a 139% internal rate of return.

In summary, dust control treatment along the Adams West FSR has improved road user safety, reduced haul cycle times, and led to overall transport savings for industrial operations using the FSR.

INTRODUCTION

British Columbia's Ministry of Forest, Lands, and Natural Resource Operations (FLNRO) has invested millions of dollars in road upgrades, stabilization, and maintenance over the past several years. Several forest service roads (FSRs) have had major upgrades by being resurfaced with crushed surfacing aggregate stabilized with hygroscopic additives. These treatments are believed to double the service life of the aggregate. While it is generally accepted that the treatments prolong aggregate life, no scientific work exists to support this belief. Tools for modelling aggregate deterioration on untreated road surfaces have been developed in other countries, but these models have limitations in a Canadian context.

In an effort to acquire more data and gain a clearer understanding of the value of road investments, FPInnovations (FPI), Interfor Corporation (Interfor), and FLNRO undertook a long-term study of road stabilization and dust control on the Adams West FSR. The FSR runs north–south along the west side of Adams Lake, which is located approximately 40 km northwest of the city of Salmon Arm in the southern interior of British Columbia. Interfor is the local licensee, and is responsible for maintaining the Adams West FSR.

Initiated in the summer of 2012 and monitored through 2016, the study focused on understanding the effectiveness of dust control treatment with respect to increased safety and traffic speeds, road performance, cost-effectiveness, and road user experience. Four progress reports were published in 2013, 2014, 2015, and 2016 (Légère and Beleznay, 2013; Légère, 2014; Légère *et al*., 2015; Field *et al.*, 2016). This report presents a summary of the trends and conclusions found during the study period.

METHODOLOGY

Treatment regimen

In 2012, seven tests sections were established along the Adams West FSR, between KM 3 and KM 42 (Table 1), for the purposes of long-term monitoring of the road. Prior to 2012, maintenance and upgrading of the road was conducted under the direction of Interfor, whereas from 2012 onward the road treatments and upgrading of the test sections were conducted under the joint direction of Interfor and FPInnovations in accordance with the study design. The dust treatment had an application rate of 1 litre per square metre, and the application occurred during late spring or early summer.

Table 1 describes the stabilization and dust control treatment used at different test sections along the Adams West. Traffic levels on the northern sections (2A, 2B, 3A, 3B, and 3C) were lower than those experienced by southern sections 1A, 1B, and 1C; the 'southern' sections, situated south of the Agate Bay Road intersection, received considerable public traffic utilizing this route to bypass Kamloops. For greater detail on the history of the aggregate and dust control treatment see Field *et al.*, 2016.

Table 1. Surface treatment regimen for test sections of the Adams West FSR from 2009 to 2016

	Test Section and Aggregate Source								
Year	South pit, near KM 0				North pit, near KM 39				
	1A: KM 3 to 4	1B: KM 4 to 5	1C:[b] KM 7 to 7.5		2A: KM 37 to 38	2B: KM 38 to 39	3A: KM 39 to 40	3B:[b] KM 40 to 41	3C: KM 41 to 42
Prior to the study									
2009	Two lifts, each 150 mm of crushed aggregate						No stabilization		
2010	No dust control								
2011	No dust control								
During the study									
2012	Dust control	Dust control	Dust control		Dust control	Dust control	Two lifts, each 75 mm of crushed aggregate, compacted (no dust control)[a]	Two lifts, each 75 mm of crushed aggregate, top lift stabilized[a]	Two lifts, each 75 mm of crushed aggregate, both stabilized[a]
2013	Dust control	No dust control	Dust control		Dust control	No dust control	Dust control	No dust control	Dust control
2014	Dust control	Dust control	No dust control		Dust control	Dust control	Dust control	No dust control	Dust control
2015	Dust control	No dust control	No dust control		Dust control	No dust control	Dust control	No dust control	Dust control
2016	Dust control	Dust control	No dust control		Dust control	Dust control	Dust control	No dust control	Dust control

[a] Crushed aggregate = High Fines Surfacing Aggregate (HFSA) specification (i.e., 19 mm (¾") minus).

[b] Control Section.

Note: Grey fill indicates dust treatment during the year.

Aggregate material: properties and performance

The aggregates used to upgrade the Adams West FSR were sourced from two gravel pits along the Adams West FSR. Gradation curves derived for these pit aggregates were compared with the high fines surfacing aggregate (HFSA) specification (British Columbia Ministry of Transportation and Infrastructure, 2011). The gradation curve of gravel sampled from the pit near KM 0 (the south pit) was comparable to the lower gradation limit of the HFSA, while the gravel from the north pit tracked closer to the upper gradation limit of the HFSA (Figure 1). Because fines increase with road use and wear, road surfaced with aggregate with more fines will tend to exceed the HFSA specification limits sooner.

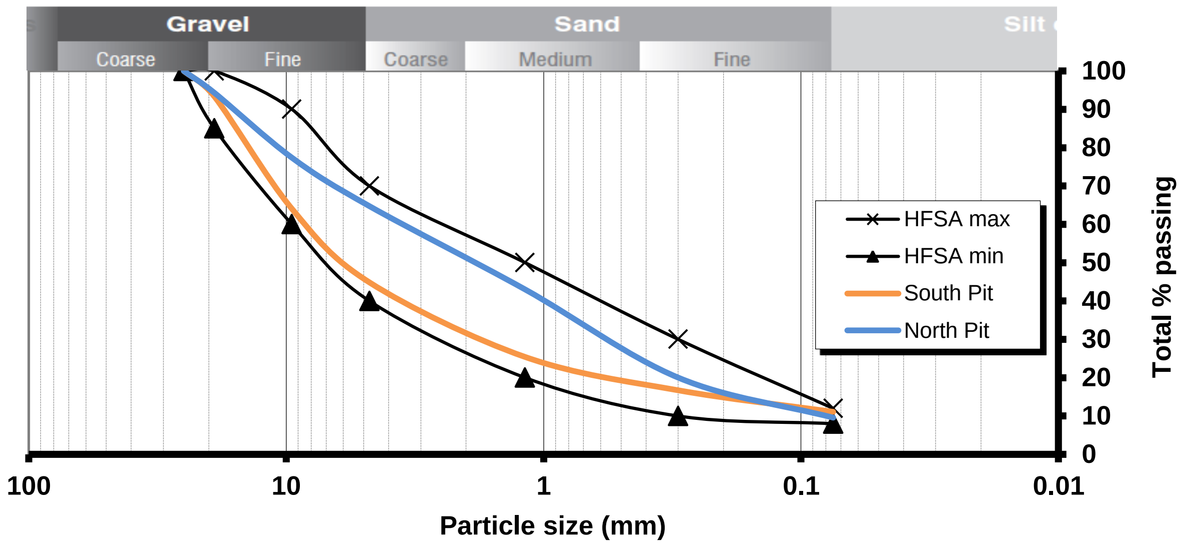

Figure 1. Average gradation of aggregates from the north and south pits on the Adams West FSR, at the time of crushing in 2009 (data source: FLNRO).

Table 2 lists the initial characteristics of the crushed aggregates used for the stabilization of the two test areas on the Adams West FSR that originated from the two different pits.

Table 2. Initial values for the aggregate used to construct the study road sections, compared by area

		Area	
		South	North
Initial gradation		Excellent	Good
% fines		11.1	9.6
% fine sand (passing 0.425 mm)		20	27
Plasticity index		9	30
Material performance	G_c	29	29
	S_p	90	400
Micro-Deval abrasion resistance (%)		9	15

As shown in Table 2, the south pit aggregate had slightly more fines but considerably less sand than the north pit aggregate. Despite similar fines contents, the south pit aggregate had a plasticity index of only 9 while the north pit had a plasticity index of 30. This would indicate a higher content of plastic clay in the north aggregate. For wearing course materials, Légère and Mercier (2003) recommended a fines content of between 4% and 15%, and that the fines have a plasticity index between 4 and 9. The results of a Micro-Deval abrasion test of the pit aggregates were 9.1% and 15.5%, for the south and north pit, respectively. The value for the north pit aggregate indicates there would likely be faster degradation than aggregate from the south pit.

As with plasticity index (PI) values, sieve analysis results can be used to understand the soil's material performance on unpaved road surfaces. The appropriate mix of coarse, intermediate, and fine particles can be evaluated using the grading coefficient (G_c). The shrinkage product (S_p), can be used to optimize the clay content of road materials (Légère, 2015).

The performance of aggregate roads has been extensively studied in South Africa where guidelines for optimum material gradation and plasticity have been adapted for North American use. Optimal performance of an unpaved road surface will usually be achieved when the wearing course materials have a grading coefficient between 15 and 35 and a shrinkage product between 100 and 365 (Jones, 2013). The south pit aggregate represents excellent quality material whereas the north pit aggregate, while still good, can be slippery and dusty (primarily due to its high PI that results in a high shrinkage product) (Légère and Mercier, 2003). Based on these test results and recommended specifications, the south pit offers an overall better surfacing material than the north pit.

Data collection

A number of tests and procedures were carried out to measure the performance of the Adams West FSR and to quantify the various factors influencing performance. Further detail on how the following data was collected can be reviewed in the previously cited progress reports:

- Average traffic volumes, types and travel speeds (collected with TrafX Vehicle Counters, JAMAR Radar Recorders and On-board computer data provided by Interfor).
- Road maintenance interventions (collected with an FPDat Grader datalogger, and through communications with Interfor and the road maintenance contractor).
- Road surface condition and performance (measured using the Unsurfaced Road Condition Index which rates the road's condition on a scale from 0 to 100).
- Road surface profile and aggregate wear (measured using a laser survey level to document road elevation and change over time).
- Baseline crushed aggregate properties from year 1 (determined from aggregate gradation curves, percent fines, Atterberg limits, Micro Deval tests, and recommended specifications for stockpiled crush in the source rock pits).
- Wearing course aggregate performance and deterioration (based on aggregate samples collected each year from the road surface compared to baseline properties from year 1).
- Survey data was obtained from willing participants responding to questions posed by FPInnovations concerning the safety and performance of the sections of road that were treated with dust control.

RESULTS AND DISCUSSION

Road User Safety

Road user survey

In order to better understand how the dust control treatment impacted the safety of road users on the Adams FSR, FPInnovations conducted a road user survey. The survey participants included twenty-two log haul truckers sampled on March 7th and 8th of 2017 as they entered the Interfor mill yard weight scale. Eight Interfor staff and three local residents who frequently use the Adams West were also surveyed. In total, 33 road users were consulted for the survey. 66% of road users surveyed reported that they had been driving on the road for more than 15 years, while 19% had been using the road for 10 to 15 years. Only 6% of those surveyed were relatively new to the road (0 to 5 years of experience). The long experience with the FSR of those road users surveyed lends credibility to their claims of improved safety along the Adams West. The survey questions and responses are summarized in Table 3.

Other comments from either individual or multiple survey participants included:

- Strong consensus that sections of treated road become slippery in rainy weather. (This finding also was noted by (RTAC 1987) and attributed to the presence of high fines content in road surface materials (i.e., more than 30% fines).
- When the dust control treated dust dries it becomes a sticky powder and can be difficult to remove from clothes and equipment. If not removed promptly it also can promote corrosion of vehicle wiring and other metal components, and may degrade clothing.
- Google Maps commonly directs people wishing to travel between the Shuswap area and northern Alberta to bypass Kamloops by taking the Agate Bay road and the Adams West FSR. As the Adams West FSR surface has become smoother and harder, it has supported increased speeds by public vehicles that Interfor and many truck drivers consider to be dangerous.
- The Adams West FSR was exceptionally dusty in the past, which created a health risk to drivers operating on the road because they would inhale large quantities when they stopped. Consensus is that, in this context, ‘the road is 100% better than it was 5 years ago’.

The results indicate that 88% of road users believe the safety of the Adams West FSR has improved since the use of the dust control treatment. This is largely due to an increase in visibility. Prior to the use of the dust control, many road users were unable to see traffic around them, significantly impeding traffic flow. Health risks posed by large quantities of road dust have decreased also.

Table 3. Results of survey conducted of Adams West FSR users in 2017

Survey Question	Survey Response	Survey Participant: Log Haul Driver	Survey Participant: Interfor Staff	Survey Participant: Public Road User	Total
Q.1 Compared to before or compared to untreated sections, has dust control treatment made the Adams West FSR safer to drive on?	Yes	19	8	2	29
	No	3	0	1	4
Q.2 If safer, why?	Improved visibility	19	8	2	29
	Smoother road surface	7	4	1	12
	Tighter surface	3	1	0	4
	Healthier for road users (less dust)	0	3	0	3
Q.3 Have you noticed safety concerns?	Slippery	15	1	3	19
	Increased public vehicle speed	3	1	2	6
	Sharp and deep potholes	1	3	0	4
Q.4 Have you noticed any other differences (+ and -) from the dust control?	Corrodes equipment	3	4	2	9
	Possible impact to environment	2	1	0	3
	Sticks to equipment	5	0	1	6

Dust settlement rates at treated sections

Visibility is a critical aspect of safe travel on resource roads and influences travel speed, sight distance, and following distance. Vehicles traveling in convoys or vehicles passing each other often create dust that impairs visibility; this reduces driver confidence and may cause them to slow down or increase following distance. Dust control treatments minimize the production of dust thereby facilitating faster safe travel speeds, longer sight distances, and denser, more productive, convoy spacing.

In order to quantify the effectiveness of the various dust control treatments studied, each was rated as to the initial dustiness after a log truck passed and the time for the dust cloud to settle to the point where visibility was no longer obscured (per RTAC 1987). Ratings were sampled on a dry, hot day in September 2015. Table 4 summarises the results of this sampling.

All sections that were treated with dust control in June 2015 had an initial dustiness rating of 4 (*i.e., thin dust cloud rising no more than 1 metre when a truck passes*) and visibility was restored within 4 seconds. Those sections without dust control in 2015, except for section 1B, had an initial dustiness rating of 2 (*i.e., thin-thick dust cloud drifting across roadway, visibility fair to poor*) and visibility was restored between 43 and 89 seconds after a log truck passed. Section 1B was an exception to this pattern and, despite not being dust treated in 2015, had an initial rating of 4 and visibility was restored only 3 seconds after a truck passed. In general, therefore, the dust control treatment appeared to be needed to mitigate dust and safeguard visibility for road users.

The findings of the dust settlement assessments were promising, although preliminary, and more intensive sampling is needed before making conclusions about treatment efficacy. It is recommended, therefore, that similar future studies conduct dust cloud settlement assessments more frequently and under a broader range of weather and traffic conditions.

Table 4. Sampling of summertime dust settlement rates on Adams West FSR test sections

Section	Treatment	Dustiness Rating[1]	Settlement Time (seconds)
1A	Annual dust control	4	3
1B	Dust control in alternating years (no treatment in 2015)	4	3
1C	No dust control	2	43
2A	Annual dust control	4	3
2B	Dust control in alternating years (no treatment in 2015)	2	89
3A	Annual dust control	4	2
3B	No dust control	2	81
3C	Annual dust control	4	4

1. Source: RTAC 1987

Treatment Impact on Road Performance

Overall road surface condition

Since 2012, assessments of road surface condition at each test section were conducted using the Unsurfaced Road Condition Index or URCI (Eaton et al. 1983). Annually treated section URCI values appeared to decrease at a comparable rate to those sections that were treated every second year and also to the untreated sections (Figure 2). Study sections in the south had a slightly slower deterioration rate than those sections in the north. Across all sections, the 2015 average URCI showed a decrease when compared with the 2012 average URCI. The southern sections (1A, 1B) dropped from an average of 95 to 76. The oldest of the northern treated sections (2A, 2B) dropped from 87 to 68, whereas the more recently treated northern sections (3A, 3B, and 3C) decreased from over 94 to 73.

From 2015 to 2016, the URCI increased for every road segment regardless of dust control treatment application, with an average increase from 73 to 80. However, it seems that those segments that received treatment in 2016 had a larger increase in URCI than those that did not receive treatment. For example, the URCI for segment 1B increased from 74 to 82 and the URCI for segment 2B increased from 67 to 78. Comparing with the untreated sections, the largest URCI increases were 77 to 81 and 72 to 76 on segments 1C and 3C, respectively. The largest URCI shifts were caused by improvements to corrugations, potholes, and ruts. The improvements were consistent throughout the summer.

No significant differences in URCI scores between treated and untreated surfaces were noted. That is, section 2A and 2B were quite similar in each year of the study, as were 3A, 3B, and 3C. The same can be said about 1A, 1B, and 1C for 2014-15. The other finding from the URCI data, a slight difference in average surface condition observed between the south and north, is believed to be caused by differences in the quality of aggregate.

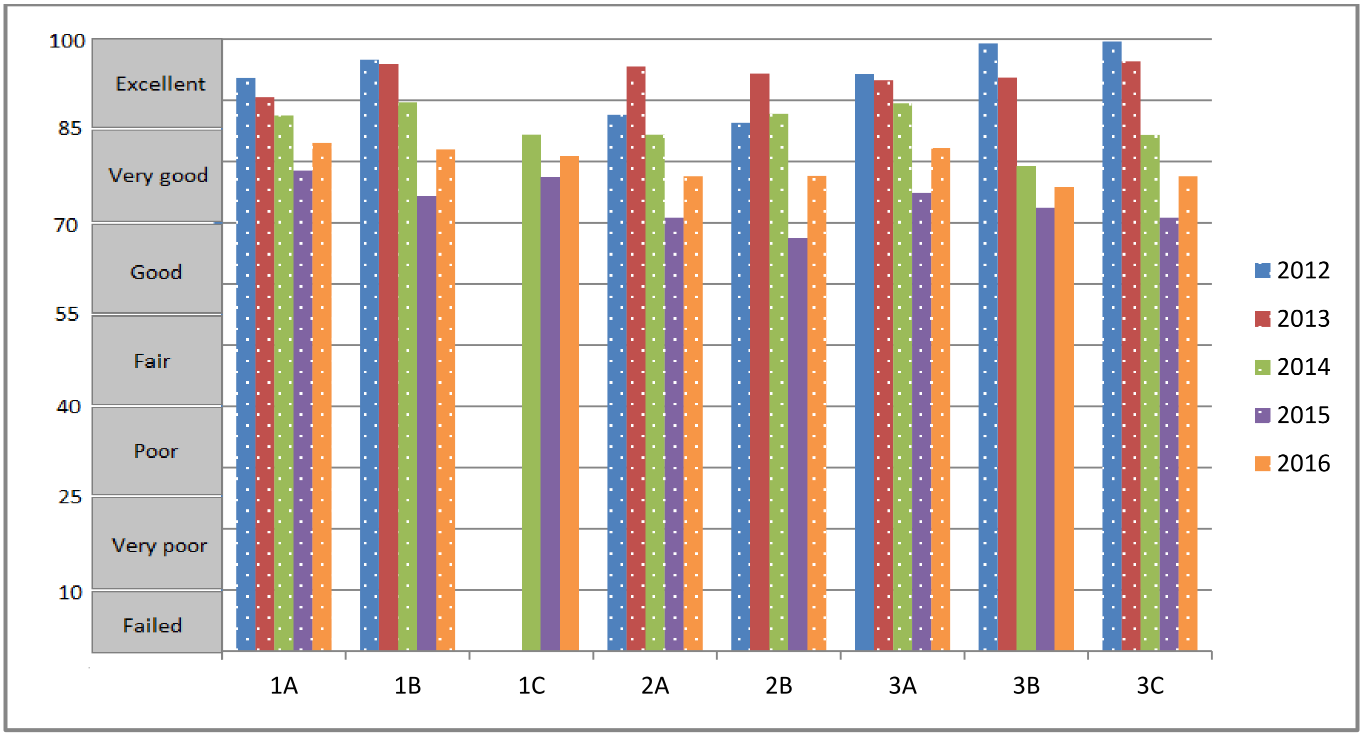

Figure 2. URCI data along the Adams West from 2012 to 2016. Note: speckled pattern indicates dust treatment that year.

It must be noted that the URCI ratings were collected relatively infrequently (only 2 to 4 times per summer haul period). Had it been economically and logistically feasible to gather ratings on a weekly basis, avoiding both rain and grading interventions, greater confidence could be attributed to the results from this method. To address this constraint, treatment performance on the test road was assessed in several ways and overall trends were described in previously cited reports.

Gravel loss (as indicated by decreasing road surface elevation)

A decrease in road surface elevation may indicate aggregate loss caused by vehicle traffic but the decrease may also be caused, in part, by grading efforts to change the cross-sectional shape. The southern sections on the road that were dust control treated each year experienced, on average, a 4 cm decrease per year in road surface elevation. In comparison, the northern sections treated each year experienced no net loss over the three years of monitoring (i.e., a 0.1 cm per year increase) and the untreated sections experienced only a slight decrease on average (i.e., a 0.2 cm per year decrease). (There was no data for an untreated regimen in the south of the test road because no control section was originally established in this section.) Unexpectedly, greater surface elevation losses were observed in the years when alternating regimen sections received dust control treatment. In summary, no consistent trends were observed between treated and untreated sections. Changes in surface profile, caused by aggregate loss and wear, varied between treatment regimen, study area, and time period (Table 5).

Table 5. Average loss of aggregate for each study area and regimen

	Average change in elevation (cm)				
	South		North		
	2012-13	2013-14	2012-13	2013-14	2014-15
Treated	-3.5	-4.5	-1.4	1.7	0.1
Treated in alternating years	-2.6	-5.9	-1.1	-1.5	-0.9
Not Treated	n.a.	n.a.	0.9	-1.3	n.a.

Note: Grey fill indicates dust treatment during the year.

Gravel loss (as indicated by gradation changes)

Aggregate from the road surface of each test section was gathered during each year and analysed for gradation characteristics. Each year's results were plotted with the initial gradation from the source pit and the HFSA max and min gradation envelop (Figure 3 to Figure 6).

The test sections in the south appear to change gradation in the same manner, regardless of their treatment regimen (e.g. Figure 3 & Figure 4). The surfacing aggregate is generally becoming finer since the initial testing on the pit material. In each case, the percent passing the fine sand mark is beyond the HFSA maximum.

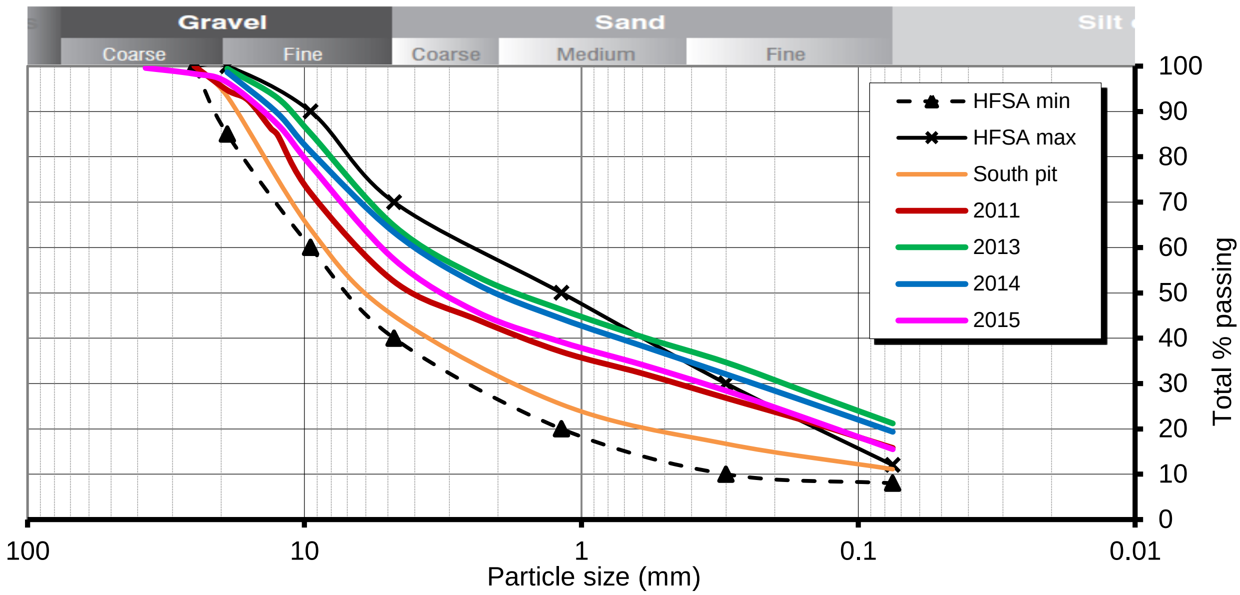

Figure 3. Average gradation of surfacing aggregates for Test Section 1A (yearly treatment).

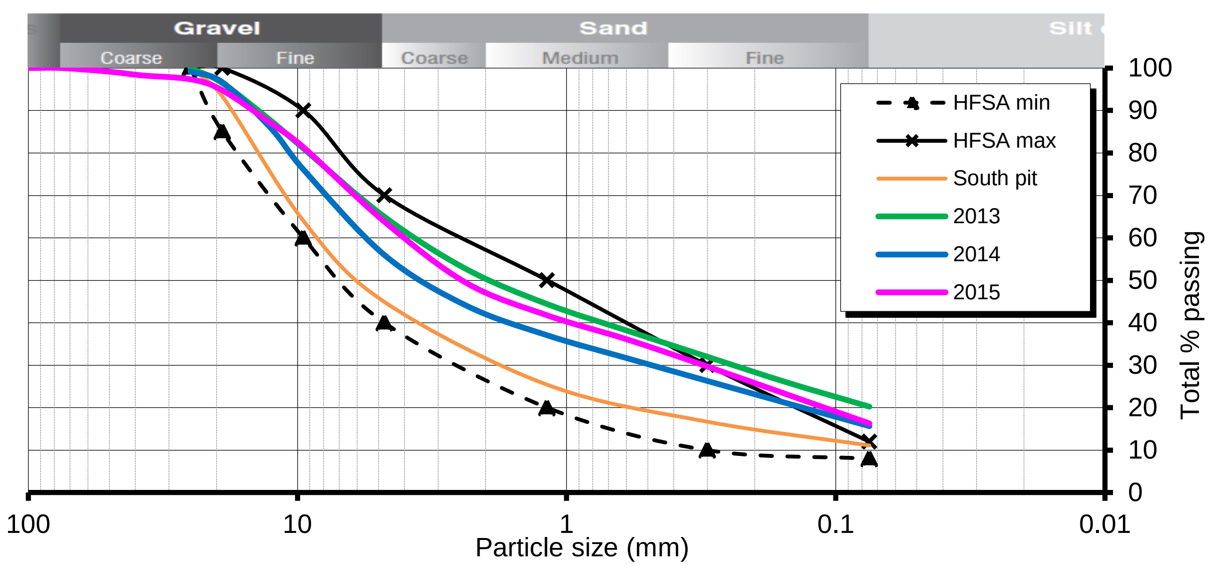

Figure 4. Average gradation of surfacing aggregates for Test Section 1B (alternating treatment).

The result of sampling surfacing aggregate in the north test sections appears to indicate a finding similar to that of the south test sections when comparing treatment regimen (e.g. Figure 5 & Figure 6). Fine contents increase with time and thus road use. However, comparing the results against the south sections, the curves for the north sections appear flatter and go beyond the HFSA max more frequently, further validating the observation that the south pit material was superior to the north.

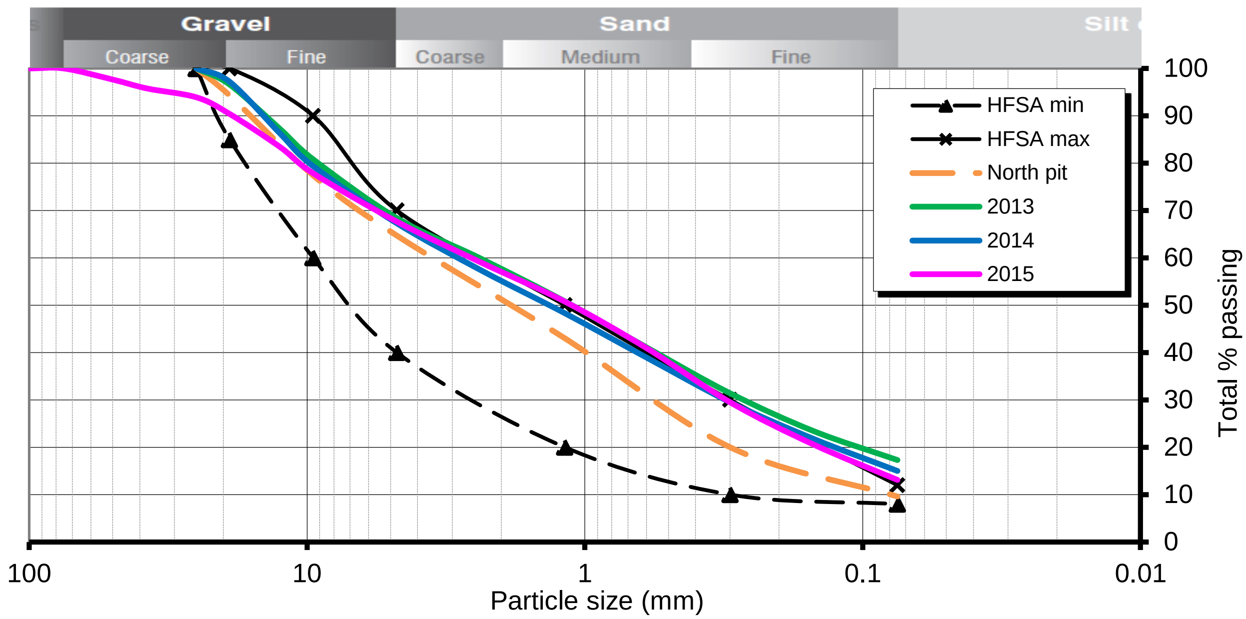

Figure 5. Average gradation of surfacing aggregates for Test Section 3A (yearly treatment)

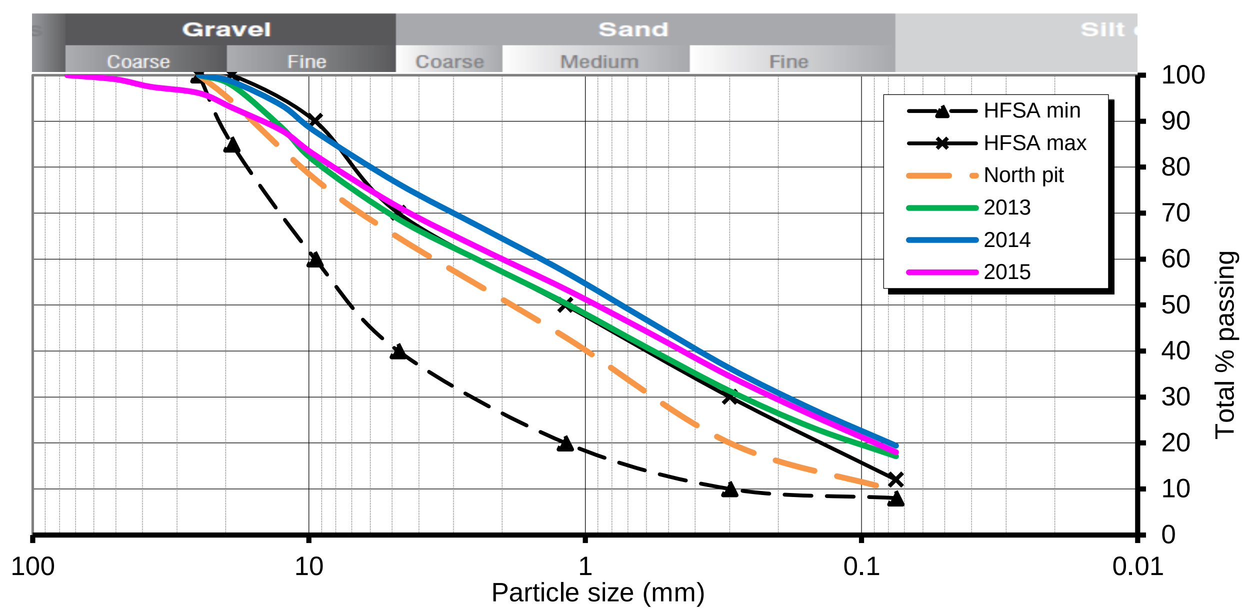

Figure 6. Average gradation of surfacing aggregates for Test Section 3B (untreated)

According to the gradation curves above, it appears that the treatment regimen does not have a substantial impact on gradation of surfacing aggregate. While the HFSA maximum is exceeded in each scenario as a result of typical wear by vehicle use, the HFSA is exceeded in coarse to fine sand from the north pit whereas the HFSA is only exceeded for fine sand in aggregate from the south pit.

Grading frequency

Grading usually is triggered by the presence of surface distress (potholes, corrugations, rutting, and loose gravel deposits) that can negatively impact travel speeds and vehicle safety. In this study, surface distress was quantified using the unsurfaced road condition index or URCI (Eaton 1988). There was a strong correlation between traffic volume and grading—the south section had over double the traffic of the north section and, on average, 1.7 times more grading than the north section in 2013 and 2014. URCI scores did not reveal, however, major differences in surface condition between the treated and non-treated sections. Possible reasons for this are a) grading was initiated only when a substantial length (e.g., over 3 km) of road was degraded, and would result in the 1 km-long test sections degrading to different levels of distress before maintenance, and b) the URCI was not measured at regular time intervals so readings would be strongly affected by recent rain events and grading interventions.

Prior to stabilization of the Adams West FSR, Interfor reported that the frequency of grading was much higher during the summer, with the entire road typically receiving five interventions plus spot grading when necessary. After stabilization in 2009, Interfor reported that summer grading frequency was reduced to two or three interventions, plus spot grading when necessary. The historical two to three interventions per summer agrees with study findings for the northern treated sections; however, the southern treated sections required more frequent grading (about 5 interventions per summer). The difference in frequency may be due to extra spot grading and (or) increased traffic levels on the southern sections since the 2009 road improvements.

Interfor believes that, since the start of the dust treatments in 2012, the treated road surface has taken longer to freeze in the late fall and thawed more quickly in the early spring. Potholes may develop when the road surface becomes saturated by rains or spring thaw; deep grading to cut out the potholes in the spring can be difficult if materials just under the surface are still frozen. Interfor estimated that the additional late fall and early spring grading on the Adams West FSR was comparable to that saved during summer due to the stabilization/ dust control treatment. It should be noted that the currently contracted grader operator responsible for the Adams West FSR has not noticed a difference in road freeze and thaw times on the treated sections.

Road Use and Productivity

Traffic volumes on the Adams West FSR

Traffic volume on the Adams West FSR has increased during the study period by an average of 8% for the south portion (KM 0 to 18) and by 28% for the north section (KM 18 to 42) (Figure 7). Traffic volume on the south section reached 336 vehicles per day in 2015 as compared to 144 on the north section. Traffic was comprised of both industrial and public vehicles.

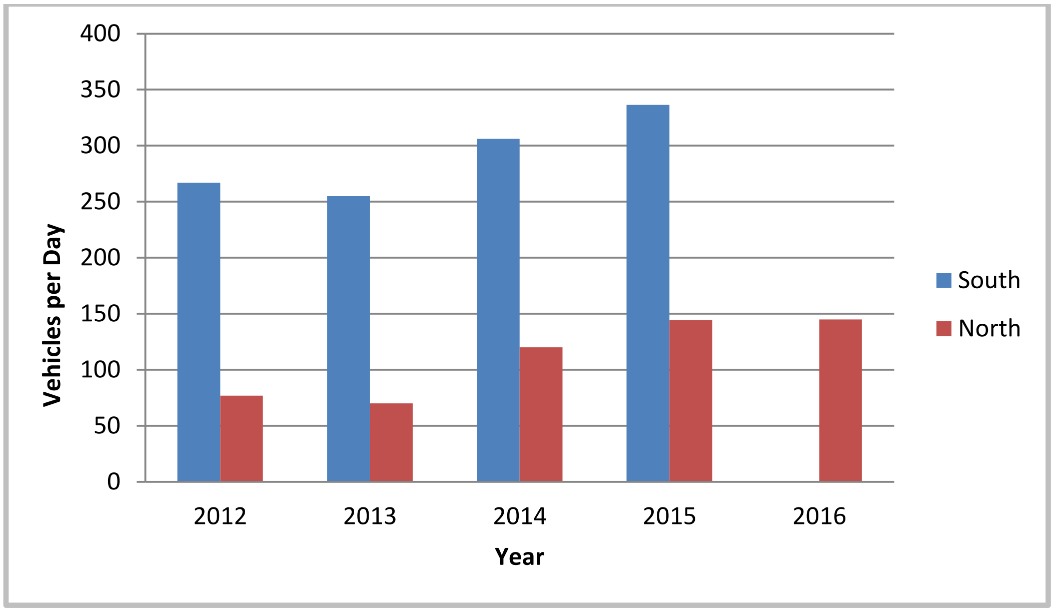

Figure 7. Vehicles per day travelling on the south and north study sections of the Adams West FSR (data spans May to November of each year).

Travel speed comparisons

Adams East FSR

In June 2015, KM 4 to 17 of the Adams East FSR was upgraded (curves repaired, and the base course re-graveled and stabilized with magnesium chloride). Surface dust control treatments were applied annually in the following years. This maintenance regimen was similar to that received by test section 3C (KM 41 to 42) on the Adams West FSR. FPInnovations reviewed available travel speeds for Interfor contractor log hauling trucks travelling on sections of the Adams East FSR from before and after the upgrade, and used this information to infer travel speed changes attributable to the combined impact of resurfacing and dust control treatment. Speed data from both August and October were considered in order to capture differences due to annual weather variation during the summer log hauling season (e.g., hot, dry conditions in August versus cool, damp conditions in October). Log hauling is anticipated to be subject to the greatest amounts of dust in August.

Loaded and unloaded log hauling trucks typically navigate resource roads differently. Unloaded trucks are substantially lighter and may travel at faster speeds than loaded trucks. Loaded trucks have the right-of-way along the road, however, and this force unloaded trucks to slow down or pull over and wait for loaded trucks to pass. Due to a limited amount of data, the analysis of how surface treatment influenced travel speeds on the Adams East FSR was based only on unloaded truck data, and some of the averages were based on very few data points.

Tables 6 and 7 present the average differences in unloaded truck speeds obtained on road segments KM 4 to 6 and KM 9.5 to 13 of the Adams East FSR. The two sections were selected for the analysis because they were relatively straight and the observed changes in travel speed from 2014 to 2015-16 could be attributed to dust control rather than to curve repairs and alignment upgrades.

Table 6. Unloaded travel speeds on two sections of the Adams East FSR in August and October

	Average travel speed of unloaded log hauling trucks (km/h)		
Section	Before upgrade (August 2014)	After upgrade and dust control (August 2015 and August 2016)	Difference
KM 4 to 6	36	43	7
KM 9.5 to 13	40	52	12
Section	Before upgrade (October 2014)	After upgrade and dust control (October 2015 and October 2016)	Difference
KM 4 to 6	34	49	15
KM 9.5 to 13	41	47	6

During August, unloaded travel speeds were 7 to 12 km/h faster, on average, after the upgrade and dust control treatment was applied. Faster travel speeds typically translate into shorter haul times; the respective changes in travel time on these sections were -16% and -23%, expressed as a percentage of the untreated condition. During October, unloaded travel speeds were 6 to 15 km/h faster, on average, after the upgrade and dust control treatment was applied. The changes in travel time on these sections were -31% and -13%, expressed as a percentage of the untreated condition. There appears to be a strong relation between unloaded truck speeds and upgraded/dust control treatment, however, the results also indicate a large variation in speed improvement.

Adams West FSR

Speeds of log hauling trucks were spot sampled both north and south of the intersection of the Adams West FSR and the Agate Bay Road, and are reported in Table 7 by surface maintenance regimen and sampling period.

Table 7. Average truck travel speeds by dust control treatment regimen

	Average travel speeds of unloaded and loaded trucks (km/h)			
	Southern Treatment Sections		Northern Treatment Sections	
	Summer 2014	Summer 2015	Summer 2014	Summer 2015
Treated each year	59	60	47	52
Treated in alternating years	54	52	N/A	N/A
Not treated	57	55	46	49

Note: Grey shading indicates dust control treatment that year

Northern sections treated every year showed consistently higher travel speeds than untreated sections (ranging from 1 to 5 km/h faster). Average travel speeds on the sections south of the Agate Bay Road intersection were approximately 10 km/h higher than north of the intersection. Differences in travel speed between the south and north study sections are, likely, because of better road geometry and alignment in the south (17% wider road surface, better site lines, and fewer curves). Although the effects of improved road geometry are not the focus of this study, this reaffirms their benefit to road use. For an unknown reason, the treatment in alternating years in the southern sections resulted in slower travel speeds, possibly due to the road geometry. As the alternating treatment section in the north (section 2B) does not have the same treatment and upgrading history (Table 1) as the other northern treatment sections, it is not comparable and is labelled as not applicable within Table 7.

Cost Effectiveness of Dust Control

Life-cycle costing analyses can be used to determine the cost-effectiveness of different road upgrade and maintenance decisions over a given road's service life. Costs such as initial base course upgrading, regular grading, annual dust control, and log transportation costs can be accounted for in the exercise.

Through discussions with Interfor and the contractor who completed the road upgrades for the Adams West FSR, it was learned that applying dust control treatment was expected to be approximately cost neutral and the main reason to treat was to increase road safety for both industrial operations and the growing numbers of public vehicles using the portion of the FSR south of the intersection with Agate Bay Road (KM 18). Table 8 summarizes the road maintenance and dust control costs by general road section, and the required savings in haul costs for the dust control treatment to be cost neutral. Interfor estimated there were five gradings and $4,500 per km spent on maintenance per year on the Adams West FSR in the era prior to when regular dust treatment was instituted. After dust control treatments were instituted, the number and cost of grading interventions remained the same for the southern portion of the Adams West FSR. Including approximately $2,100 per km for dust control treatments, the total maintenance cost of the southern sections was $6,600 per km. To attain cost neutrality, therefore, the dust treatment would have had to generate a savings of $2,100 per km in log hauling costs. The northern portion of the FSR experienced a $1,350 per km reduction in required maintenance after dust control treatment and, therefore, would have had to generate a savings of $750 per km in log hauling costs to attain cost neutrality.

Table 8. Typical grading maintenance and dust control costs for the Adams West FSR

Road section	Dust control cost ($/km)	Maintenance cost ($/km)	Required haul savings to be cost-neutral ($/km)
KM 0 – 18 (South)	2,100	4,500	2,100
KM 18 – 42 (North)	2,100	3,150	750

The savings in log hauling costs from the dust control treatments was estimated using an assumed haul rate of $155/hr, and this study's findings for yearly logging truck traffic and average speed differences between treatment sections. Figure 8 shows the estimated cost savings due to increased haul speeds for a range of traffic volumes. Given the 2015 traffic levels and speed increases (5 km/hr on the southern treated sections and 3.5 km/hr on the northern treated sections), the hauling savings were approximately $4,100 and $950 per km for the southern and northern portions of the road, respectively. The untreated sections were only 1 km-long and it is likely that longer untreated, dusty, sections would impact travel speeds and driver behavior to a greater degree leading to greater speed differences.

On both the north and south portions of the FSR the break-even point was exceeded, indicating that dust treatment can be cost neutral on lower traffic roads and can lead to substantial savings on higher traffic roads. In the case of the test road, not only was there a net savings due to the stabilization and subsequent dust treatments but also improved safety for all road users.

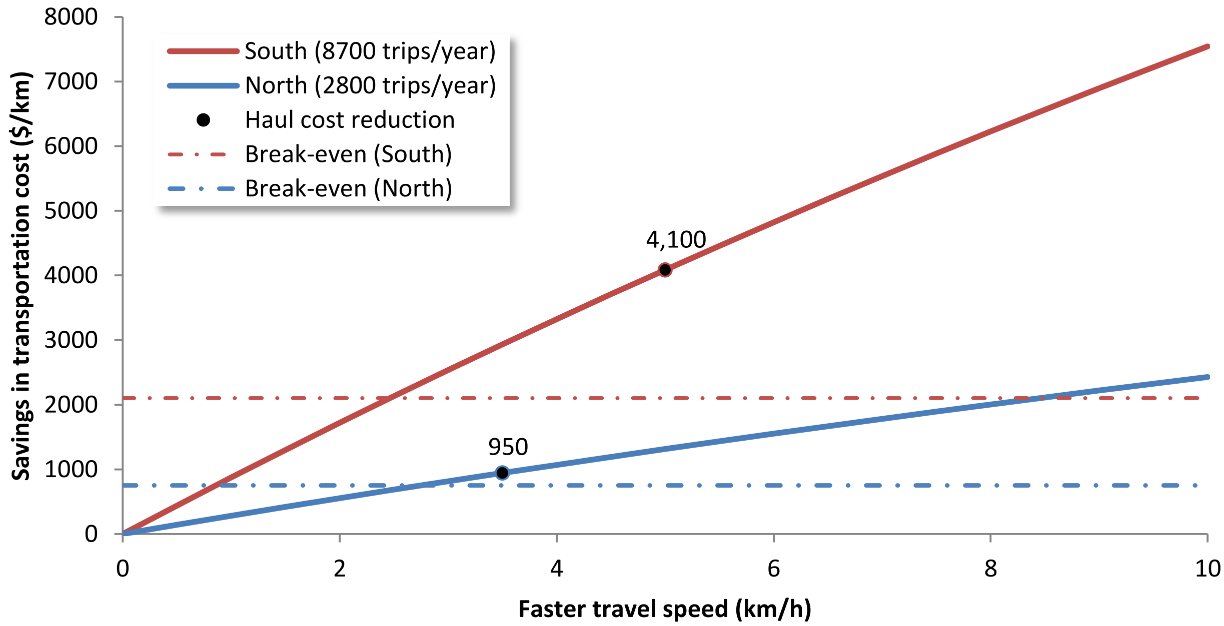

Figure 8. Estimated cost savings from dust treatment on south and north sections of the Adams West FSR.

Monthly road maintenance cost data (Appendix A) on the Adams West FSR, provided by Interfor, was correlated with grading cost data provided by Stillwater Grading, the principle grading contractor responsible for the Adams West FSR. This cost summary was used to support a 10 year-long cost analysis of transportation costs for the Adams West FSR.

A life cycle cost analysis was performed on several likely scenarios in order to provide a guide on the most cost-effective road treatment options over a 10-year service life. The scenarios were constructed with combinations of factors, such as road upgrading, dust control application, aggregate quality, truck travel speed, and grading cost. The scenario variables and total 10-year net present values (NPV) are summarized in Table 9. Note that the savings from Scenarios B, C, and D are calculated as differences from Scenario A (a baseline condition with no upgrade or dust control treatment).

To calculate the 10-year haul cost, FPI estimated 185 hauling days in a year, 25 trucks hauling each day, and approximately 2.5 trips per day for each truck. Based on information provided by Stillwater Grading and Interfor, the cost of grading the upgraded, dust control treated, high quality aggregate section of the Adams West FSR is approximately $5,000 per km per year (Scenario D). Based on this, therefore, the upgraded and dust control treated section with acceptable quality aggregate (Scenario C) was estimated to cost $7,500 per km per year to grade. Similarly, the upgraded section with acceptable quality aggregate (Scenario B) was estimated to cost $10,000 per km per year to grade. Finally, the section with acceptable quality aggregate but no upgrading or dust treatment (Scenario A) was estimated to cost $12,000 per km per year to grade.

Table 9. 10-year cost comparison of four road maintenance scenarios on the Adams West FSR

	Scenarios			
	A	B	C	D
Road upgrade cost (\$/km) (lasts 10 years)	-	\$25,000	\$25,000	\$25,000
Dust control cost (\$/km/year)	-	-	\$2,100	\$2,100
Aggregate quality	Good	Good	Good	Excellent
Average summer log hauling truck travel speed (km/h)	45	50	55	55
Annual road maintenance cost (\$/km/year)	\$8,000	\$6,000	\$6000	\$5,000
10-year total road maintenance cost (expressed as a net present value (NPV)) (\$/km)	\$109,331	\$116,109	\$112,465	\$89,687
10-year NPV total log hauling cost (\$/km)	\$674,206	\$612,915	\$561,839	\$561,839
10-year NPV transportation cost (includes only log hauling and road maintenance costs)	\$783,537	\$729,024	\$674,303	\$651,526
10-year NPV transportation cost difference (taking Scenario A as a baseline) (\$/km)	-	-\$69,434	-\$106,485	-\$115,596
Internal Rate of Return	-	61%	118%	139%
Benefit-Cost Ratio	-	2.78	2.41	2.62

In scenarios B, C, and D, despite the initial cost for upgrading the road, maintenance costs were reduced throughout the 10-year period. In addition to reduced maintenance requirements, road upgrading was assumed to increase summertime truck travel speeds by 5 km/h. Applying dust control treatment to the upgraded road surface was assumed to increase average summertime truck travel speeds by an additional 5 km/h. Quality of aggregate was assumed to affect maintenance requirements but not travel speeds. Gravel from the south pit on the Adams West FSR was representative of an excellent quality aggregate while material from the north pit was considered to be of good quality. Excellent quality aggregate may not be available for upgrading a road, however, if the source pit is too far away.

Scenario D, which included upgrading with excellent quality aggregate and annual dust control treatments, provided the most cost-effective road management approach, a high BCR, and the highest IRR evaluated in the 10-year cost analysis. A combined savings of over $115,000 in maintenance and haul costs was predicted with Scenario D, as compared to Scenario A, which did not include an initial upgrade or annual dust treatments.

CONCLUSIONS AND RECOMMENDATIONS

In order to conduct life-cycle cost analyses and make informed decisions on the most cost-effective regimen for maintaining resource roads, forest companies, and FLNRO need reliable data about road deterioration trends given various dust control and grading activities. In an effort to acquire road performance data and gain a clearer understanding of the value of road investments, FPInnovations, FLNRO, and Interfor's Adams Lake operation undertook a 5 year-long study of road stabilization and dust control on the Adams West FSR near the town of Adams Lake, in the interior of BC.

Progress reports were created in 2013, 2014, 2015, and 2016, whereas this report presents a summarization of the key findings and trends since the beginning of the project. Observations and recommendations are made about four key aspects of resource road management: cost-effectiveness, road user safety, road performance, and surface conditions of studied road segments.

Road user safety:

- 88% of survey participants claimed the segments of the Adams West subjected to treatment are safer now than they were without dust control due to increased visibility.
  - Many participants also claim that the dust control has created a smoother, tighter road surface which has led to increased travel speeds
- Dust levels were effectively controlled by the treatment. A sampling of dust settlement times revealed that visibility on treated surfaces was restored in 2 - 4 seconds, whereas visibility took up to 90 seconds to be restored on untreated surfaces. Visibility has a direct impact on road user safety, travel speed, sight distance and following distance.
- Safety concerns associated with the dust control treatment include:
  - Public traffic volume and speeds have increased. Since most, if not all of these vehicles, do not possess two-way radios, increased volumes and speed presents a safety concern for both public and industrial vehicles and demands a higher degree of caution from all road users.
  - Anecdotally, when the treated road is saturated from rain the surface becomes slippery. While this effect seems to be very noticeable while driving, log haulers have not mentioned any safety incidents or need for remediation efforts as a result of these conditions. Instead, drivers commented on the need to "drive to road conditions" as the road surface shifts from smooth to slippery.
- It may be prudent to monitor driving conditions after road segments with dust control have been saturated to ensure log haulers are not driving in unsafe conditions that could put themselves or others in danger. Further, it was reported that the dust control treatment "corrodes" equipment when treated mud sticks to vehicles and equipment. It was reported that this corrosion damages wiring boots, gloves, etc.

Treatment impact on road performance

- Road surface conditions were not found to be improved with surface stabilization. No substantial differences were found in terms of average road performance, as measured with the URCI methods (ruts, potholes, loose aggregate, corrugation), between treated and untreated surfaces. Some dust-controlled sections showed only moderately higher URCI scores.
- Regardless of treatment, there were URCI decreases comparably between test sections since the beginning of the study
- Since the beginning of this study in 2012, all test segments have reduced in URCI; however, the road condition remains ranked "very good" for all segments
- The slight difference in average surface condition observed between the south and north is likely caused by differences in the quality of aggregate.
- The southern sections on the road had a surface elevation change 3 times higher than the northern sections. Due to traffic volume on the south also being 3 times higher than the north, this is likely due to common traffic wear.
    - No differences were found in road elevation surveys (e.g., measure of aggregate surface wear/loss) between treated and untreated surfaces.
- Gravel wear was not found to be reduced with road stabilization and, as such, dust control **may** not prolong aggregate life.
- No differences were found in changes to gradation curves over time, between surface aggregate samples from treated and untreated road sections.
- Based on fines content, plasticity index, and Micro-Deval abrasion tests, material from the north pit would degrade faster than material from the south pit
    - The south pit offers better material overall

Road use and productivity

- Traffic volume on the Adams West FSR has increased during the study period by an average of 8% and 28%, for the south and north sections, respectively
    - As of 2015, traffic volume on the south 336 vehicles/day while the north only has 144 vehicles/day
- Travel times on the road were improved with surface treatment. Travel speeds on treated surfaces were moderately higher than on untreated surfaces: 5 and 3.5 km/h faster on the south sections and north treatment sections of the Adams West, respectively, whereas the Adams East has an average travel speed increase of 10 km/hr.

Cost-effectiveness:

- The estimated yearly savings in haul costs due to the observed speed increases on the Adams West were $4100 and $950 per km for the south and north sections, respectively.
- Employing road upgrading, dust control, and/or higher quality aggregate from the south pit will result in the larger cost savings by reducing road maintenance and reducing cycle-time haul costs.
    - Savings could reach up to approximately $132,000 per km per 10 years.

- The untreated sections were only 1 km-long and it is believed that longer untreated, dusty, sections would impact travel speeds and driver behavior to a greater degree.

Based on the findings presented, the source and quality of crushed aggregate may be more important for increasing road longevity than is dust control using a hygroscopic product. The hypothesis that yearly applications of a dust palliative can prolong aggregate life by twofold could not be confirmed in this study after 5 years of monitoring. The fact that hygroscopic dust palliatives, such as calcium chloride, are not true “stabilizers” (Jones, 2013; Beaulieu *et al*., 2011) may explain why the materials are deteriorating at a similar rate. They act primarily on the fines component of the aggregate, keeping the surface moist, dense, and dust free. They do not create cementitious or mechanical bonds between the larger particles.

The intention of the dust control treatment was to improve safety along the Adams road with the assumption that the cost of treatment would equal the savings in vehicle speed and road maintenance. FPInnovations has found data that suggests upgrading, applying dust control, and/or using a high quality aggregate will lead to increases in log truck hauling speed as well as reduced maintenance costs. This demonstrates that dust control may contribute to both improved road user safety as well as provide opportunities for Interfor in improved hauling and road maintenance savings.

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APPENDIX

Cost of road maintenance for the Adams West FSR (0 – 43 km) for 2016 provided by Interfor and Stillwater Grading

Month	Grading Cost	Compaction Cost	Watering/ Sanding Cost	Dust Control Treatment Cost ($)	Total ($)
January	$16,500		$16,500		$33,000
February	$23,100		$16,500		$39,600
March	$9,900		$8,250		$18,150
April	$1,650		$0		$1,650
May	$24,750	$13,500	$16,500	$95,000	$149,750
June	$24,750		$0		$24,750
July	$24,750		$16,500		$41,250
August	$24,750		$16,500		$41,250
September	$13,200		$16,500		$29,700
October	$6,600		$16,500		$23,100
November	$14,850		$16,500		$31,350
December	$21,450		$16,500		$37,950
Annual Total	$206,250	$13,500	$156,750	$95,000	$471,500

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