Applied Research and Innovation Branch

Winter Maintenance Performance Measure

Colin Walsh, Vaisala Inc.

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16. Abstract

The Winter Performance Index is a method of quantifying winter storm events and the DOT's response to them. It is a valuable tool for evaluating the State's maintenance practices, performing post-storm analysis, training maintenance personnel, and identifying potential areas of cost savings and improved performance.

Implementation

The Winter Performance Index will be available for continued use in Region 4 through the end of the 2015-16 winter season. If the Index is determined to be a valuable tool, CDOT can choose to expand access statewide beyond the 2015-16 season.

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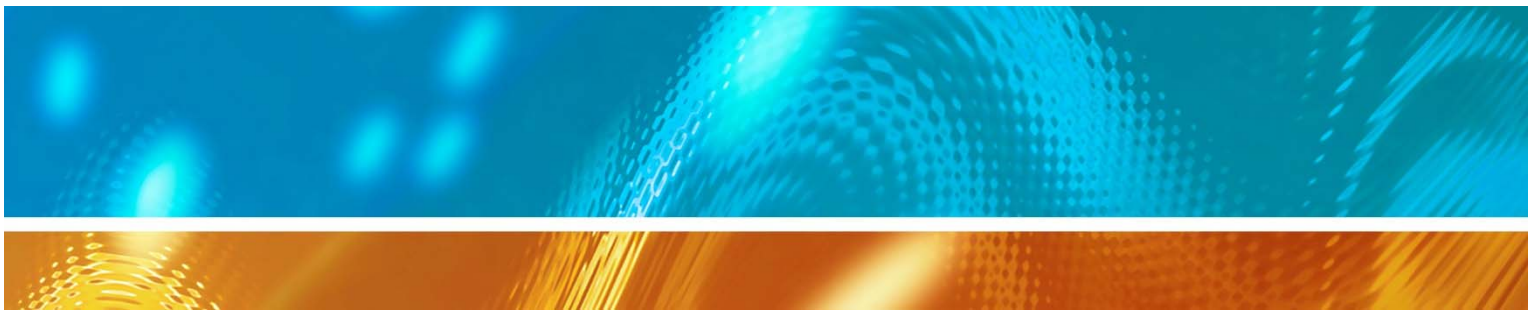
CDOT WINTER MAINTENANCE PERFORMANCE MEASURE



Study No. 314.02

Colin Walsh, Vaisala Inc.

Table of Contents

Winter Maintenance Performance Measure

The Winter Performance Index is a method of quantifying winter storm events and the DOT's response to them. It is a valuable tool for evaluating the State's maintenance practices, performing post-storm analysis, training maintenance personnel, and identifying potential areas of cost savings and improved performance.

The Winter Performance Index is derived using the Storm Severity Index, which rates the severity of a winter storm event based on key atmospheric measurements such as wind speed, precipitation, and surface temperature. The Storm Severity Index allows us to compare performance across different geographic areas which have their own unique climate conditions. The Storm Severity Index normalizes the different storm events because it quantifies and compensates for variation in the severity and duration of storms. The Storm Severity Index is then combined with pavement grip measurements to calculate the Winter Performance Index, with the Winter Performance Index showing the total amount of time roads were compromised by winter weather.

The Winter Performance Index is a tool that can be used to manage day-to-day operations. However, in the following report we have applied the Index to an entire winter season to demonstrate the potential value of the tool and to highlight differences in performance within the studied region.

Vaisala would like to acknowledge and thank the following CDOT study panel members: David Reeves, Kyle Lester, Isaac Lopez, Ed Gentry, Thomas Aguilar, and Wesley Templeton.

Executive Summary

Data analysis of treatment effectiveness utilizing the Idaho Transportation Department (ITD)'s Winter Performance Index has been possible for an extended winter period (November to March inclusive) for the purpose of this Research Project. This report summarizes that data which is available routinely through the Vaisala RoadDSS service as a weekly report but views it from a seasonal and monthly perspective.

Figure 1 shows the locations of the 11 road weather stations (RWIS) analyzed in this study, which have been chosen to represent different climatic areas. There are two situated on the main I25 corridor (Berthoud and Natural Fort), one situated on US36 (Baseline) and eight in total on I70 (Genesse, Floyd Hill, Bakerville Exit, Hermans Gulch Exit, Loveland Pass Exit, EJT West Portal, Lower Runaway Truck Ramp and Silverthorne).

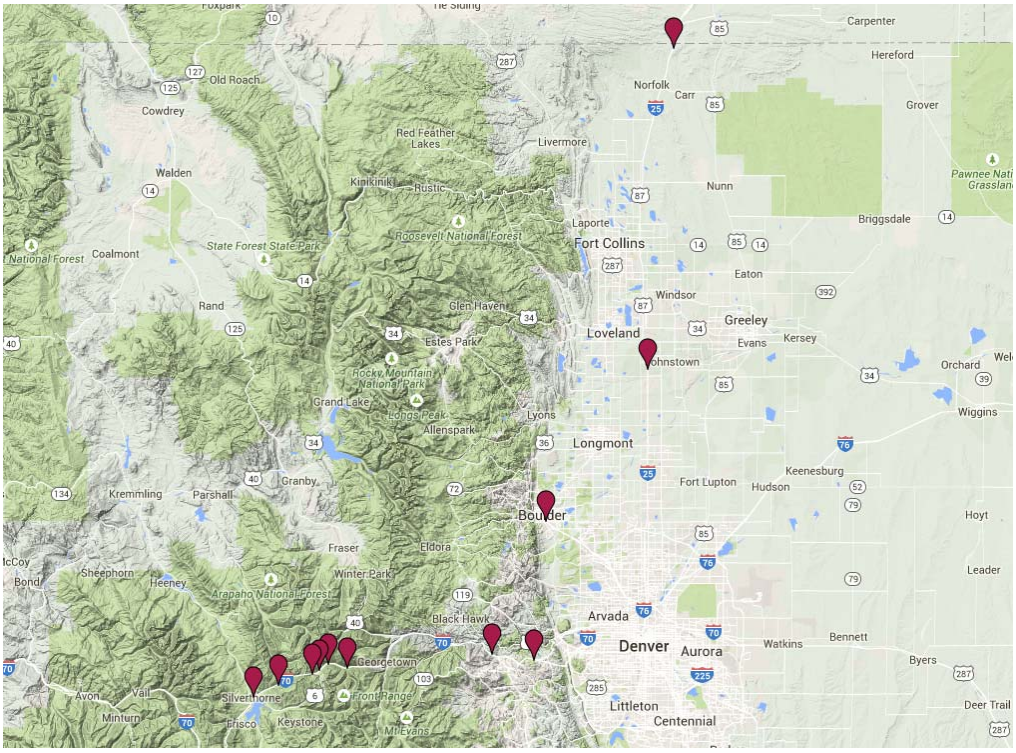


Figure 1: Locations of the 11 RWIS analyzed in this study

The results presented within this report show that the algorithms contained within the ITD Winter Performance Index can be utilized statewide in Colorado. The results show that the Storm Severity Index enables realistic comparison between different sites, and will allow CDOT to identify areas of concern and improve Performance Index ratings through maintenance operations evaluation. They show how difficult the I70 corridor is to maintain, with ice/snow-forming weather seven times more prevalent on the western section of I70 than at the other locations.

1 Results

Data was analyzed for all sites between November 2014 and April 2015.

1.1 Hours of GRIP < 0.6 and Mobility Index

The Mobility Index describes without a value judgment the percentage of time that an event was maintained with GRIP above 0.6. It is formally defined as:

$$MobilityIndex = \frac{Grip >= 0.60\, Duration(hours)}{CombinedEventsDuration(hours)}\%$$

	Total Duration of events	Hours of GRIP < 0.6	Total Winter Mobility Index	Overall % lost	Hours of disruption saved
I25 Berthoud	221.9	73.1	67%	33%	148.8
I25 Natural Fort	89.4	42.9	52%	48%	46.5
US36 Baseline	470.1	275.2	41%	59%	194.9
I70 Loveland Pass Exit	1011.5	593.0	41%	59%	418.5
I70 Silverthorne	1008.9	721.2	29%	71%	287.7
I70 Lower Runaway Truck Ramp	890.4	721.8	19%	81%	168.6
I70 EJT West Portal	1121.5	948.5	15%	85%	173.0
I70 Hermans Gulch Exit	1033.7	735.9	29%	71%	297.8
I70 Bakerville Exit	992.9	905.8	9%	91%	87.1
I70 Floyd Hill	351.6	235.1	33%	67%	116.5
I70 Genesse	394.3	135.3	66%	34%	259.0

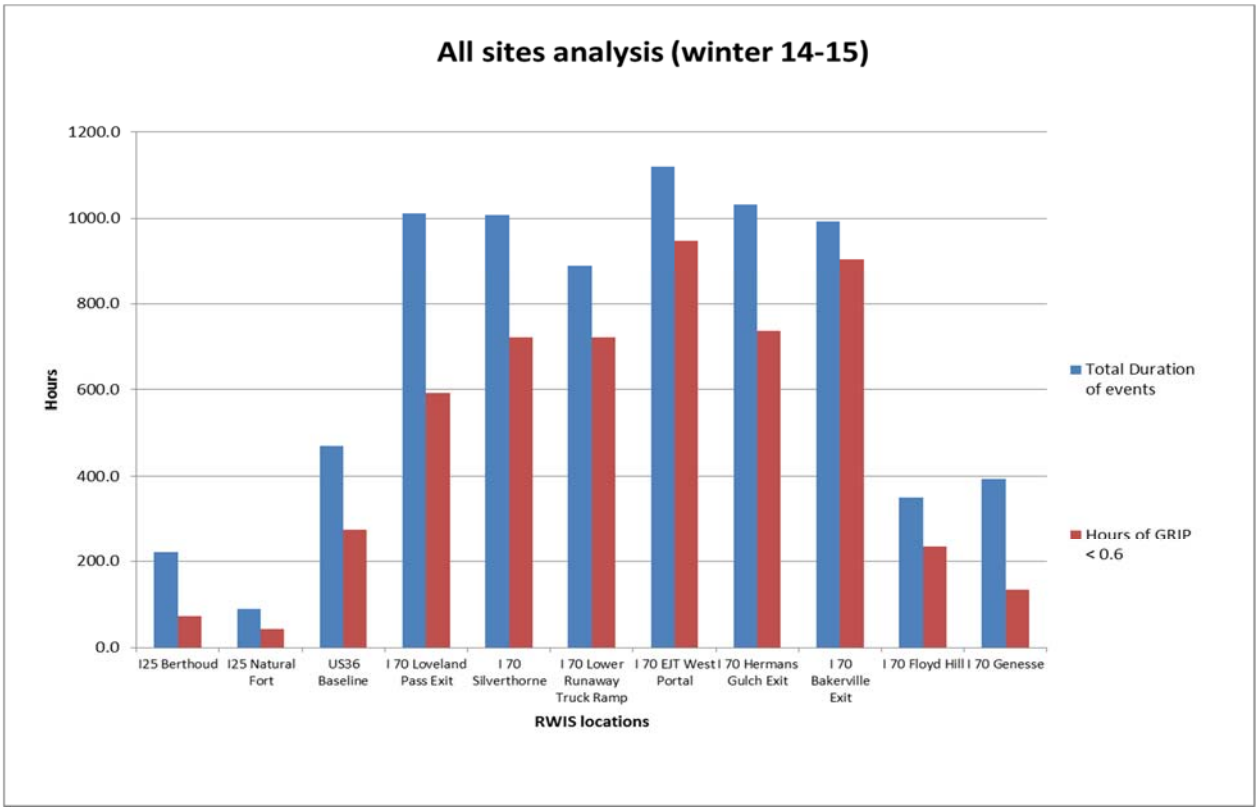
Table 1: Main GRIP and event assessment for Winter 14/15

Column 1, Table 1 shows the total hours that, if left untreated, some form of ice or snow would have been present on the road surface at each RWIS site. This means that the road surface temperature was below freezing, and the DSC111 was reporting some form of layer thickness, i.e. not a DRY surface state.

- The first clear result is that in terms of hours of event it was approximately 4 times more likely to see icing/snow events on the western side of I70 than at any of the other RWIS locations.
- The average Mobility Index (the percentage of event where GRIP was maintained above 0.6) ranges from 67% at I25 Berthoud down to 9% at Bakerville Exit. This value is calculated from the winter totals.
- The site with the highest number of hours of event that needed treatment was the EJT West Portal site with 1121.5 hours.
- The site reporting the lowest number of hours that required treatment was I25 Natural Fort with only 89.4 hours throughout the entire winter.
- In quantitative terms it was the treatments at I70 EJT West Portal that appear to have suffered most from the weather in terms of keeping roads above a GRIP value of 0.6, as defined in Annex A of GRIP < 0.6, for a total of 948.5 hours. For clarity that means that GRIP may have been

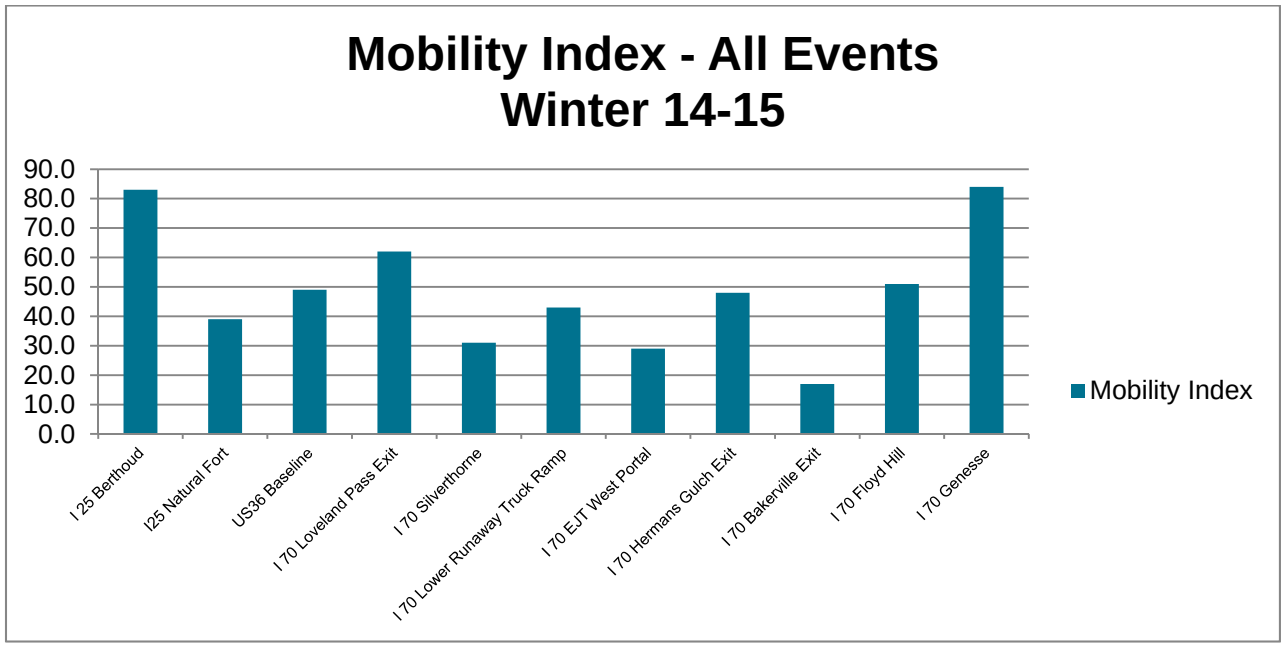
recovered for a short time during these events but was not sustained for 120 minutes, hence continuing the event.

- The last column of the table shows the number of hours where GRIP was maintained due to the efforts of the winter maintenance operation. This reaching a significant 418.5 hours at I70 Loveland Pass Exit and 297.8 at I70 Hermans Gulch Exit.
- It can be stated from these figures that on I70, winter operations kept the road free flowing for 1808 hours more than would have happened if nothing had been done. For US36 this equated to more than 154 hours. For I25 this equated to more than 195 hours. It is an interesting debate as to which of these figures offers the highest return on investment given the catchment and traffic densities.

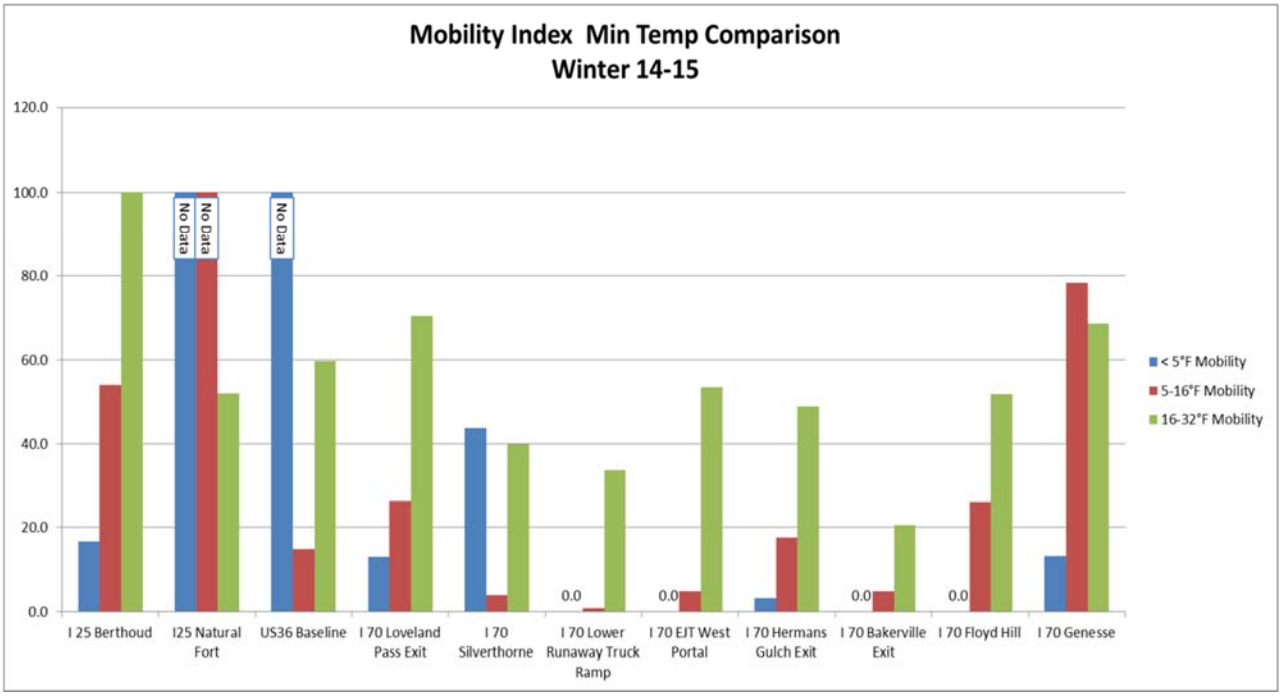


Graph 1: Event duration versus time of event categorized as GRIP below 0.6

Total Winter Mobility was calculated in Table 1 and Graph 1 by using the full winter sums of Total Duration of Events and Hours of Grip < 0.6. However, within the ITD Winter Performance Index Mobility is usually calculated by looking at an entire single event. This is likely to include times when GRIP > 0.6. Graph 2 shows the Mobility Index calculated as the average Mobility per single event over the winter. We see slightly different results when compared to Table 1, with almost all RWIS showing a higher value due to the fact that for a large proportion of the events there were well-treated times, even if overall they suffered significant periods of GRIP < 0.6.



Graph 2: Average Mobility Index from all events at all sites – Winter 14/15



Graph 3: Average Mobility Index Minimum Temperature Comparison – Winter 14/15

Graph 3 looks at one of the critical factors (temperature) and how the variation affects the Mobility. As a general rule, it can be seen that higher Road Surface Temperatures during an event result in increased effectiveness of treatment. From the Graph above, maintenance actions on I25 show favorable results, while maintaining Mobility at the Bakerville exit on I70 proves problematic.

1.2 Storm Severity

The next table shows how the weather behaved at the same time as the events described above. The Storm Severity Index assesses the conditions that the winter operations teams faced at each site during the aforementioned events. This allows actual performance in each region to be normalized for storm conditions which will allow accurate comparison of winter maintenance effectiveness.

	Average Storm Severity	Maximum Storm Severity	Minimum Storm Severity
I25 Berthoud	40.6	316.9	14.8
I25 Natural Fort	28.1	45.9	16.8
US36 Baseline	21.5	59.3	12.5
I70 Loveland Pass Exit	42.0	320.2	12.7
I70 Silverthorne	43.9	312.0	13.0
I70 Lower Runaway Truck Ramp	24.7	311.9	10.1
I70 EJT West Portal	33.5	333.9	9.7
I70 Hermans Gulch Exit	43.8	321.6	11.7
I70 Bakerville Exit	38.7	321.6	14.0
I70 Floyd Hill	33.3	312.2	14.6
I70 Genesse	36.6	311.1	13.5
All Average	32.2	247.2	12.0
I25 Average	34.3	181.4	15.8
US36 Average	21.5	59.3	12.5
I70 Average	37.1	318.1	12.4

Table 2: Analyzing the conditions with respect to winter severity for each event

Within the standard ITD Winter Performance Index report each phase of each event is given a Storm Severity Index using the following formula:

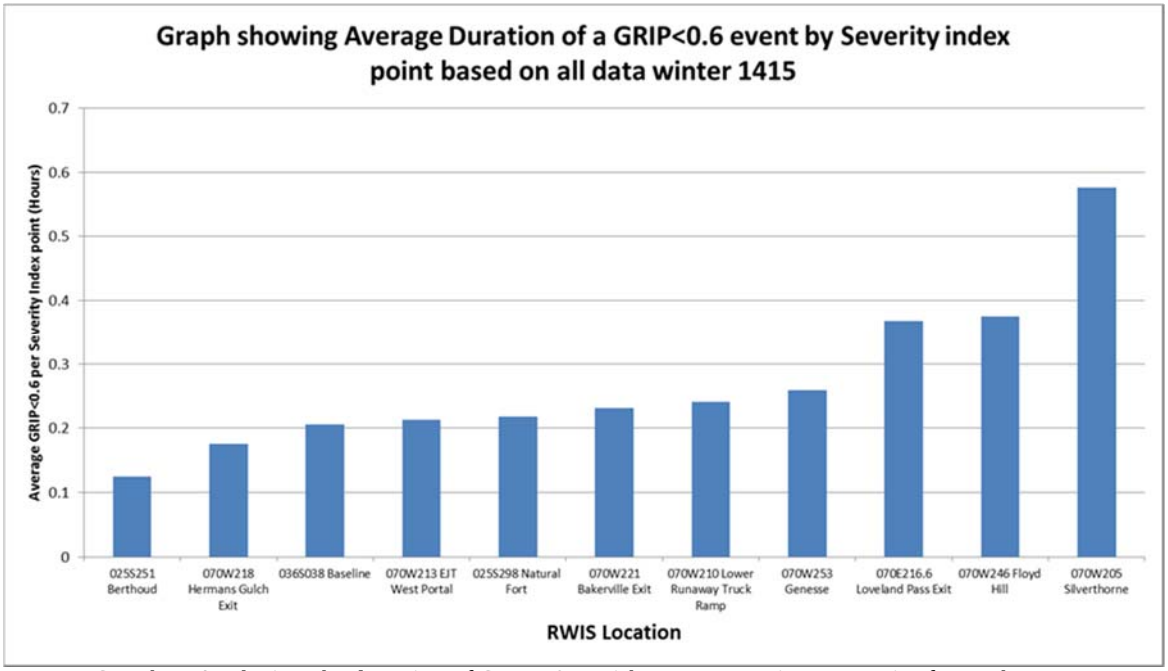
$$SeverityIndex = MaxWindSpeed(mph) + MaxLayerThickness(mm) + \left(\frac{300}{MinSurfaceTemp(^{\circ}F)}\right)$$

where $MaxLayerThickness(mm) = \max(IceLayer, SnowLayer, WaterLayer)$

The results from this part of the analysis are as follows:

- Storm Severity during the winter 2014 to 2015 season varied from a low of 9.7 to a maximum of 333.9. The max occurs when temperature falls to <1°F.
- Average severity for the I25 stations was 34.3, US36 was 21.5, and for the I70 stations it was 37.1.

As broad guideline, normal frost events (below freezing with a small amount of surface liquid) would be in the range of 10-20, normal snow events in the range of 20-80 and severe weather (very low temperatures, strong wind and snow) between 80 and 500.



Graph 4: Analyzing the duration of GRIP<0.6 with respect to winter severity for each event

Graph 4 illustrates how average duration (where GRIP is <0.6) at each site can be normalized taking Storm Severity into account. This calculation can be used to determine the effectiveness of winter maintenance operations under uniform conditions. Despite Bakerville and EJT West Portal having the worst Mobility figures earlier, both sites have favorable results when the Severity Index is applied.

For example, if we had a Storm Severity of 50 (temps around 10°F, snow layer at 10mm and wind at 10mph) then most stations would expect GRIP to remain <0.6 for between 7 and 12 hours. Loveland Pass and Floyd Hill would expect GRIP to remain <0.6 for 18-19 hours. Silverthorne, however, would potentially lose GRIP for almost 29 hours on average. It needs to be borne in mind that these are average figures and will vary depending on event. Consideration should also be given to the fact that some GRIP recovery expectations at some sites may differ due to current CDOT Levels of Service guidelines.

1.3 Winter Performance Index

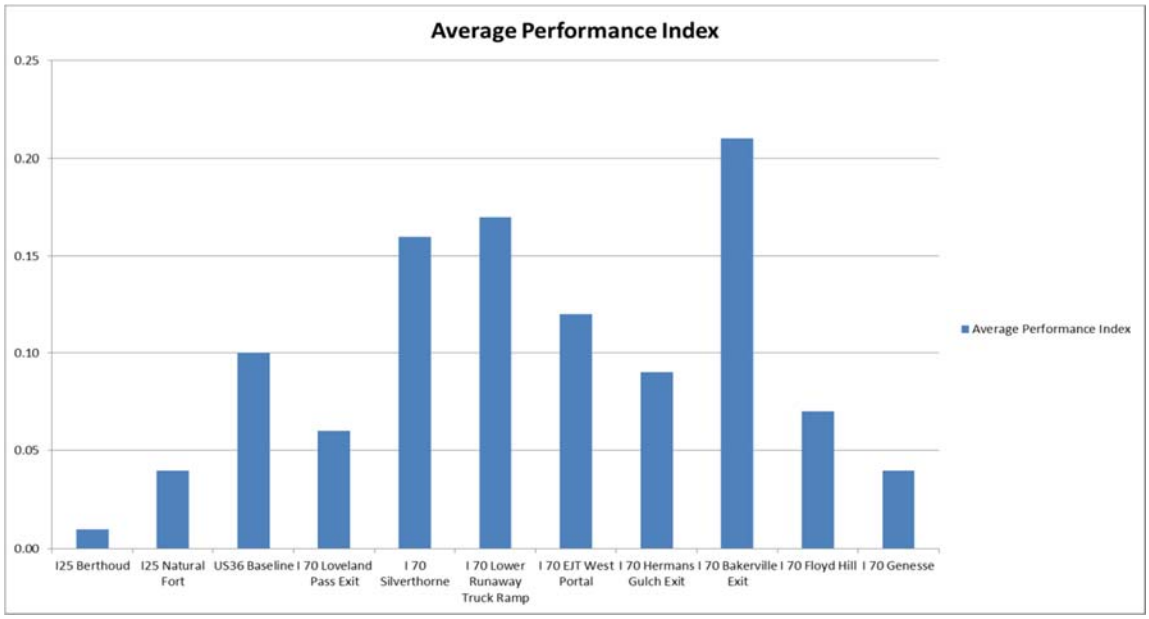
The Winter Performance Index combines the GRIP < 0.6 events and the Storm Severity Index as described above in the following way:

$$PerformanceIndex = \frac{Grip < .6 Duration(hours)}{SeverityIndex}$$

And then it categorizes the response effort as follows:

Winter Performance Index Legend	
0	Successfully treated
0.00 - 0.30	Significantly accelerated grip recovery
0.31 - 0.49	Some success at grip recovery
0.50 - 0.69	Very little success at deicing
0.70 -	Limited maintenance or no deicer success

Graph 5 outlines the average Winter Performance Index per site for Winter 14/15.



Graph 5: Average Performance Index from all events at all sites – Winter 14/15

Results from Graph 5 show clearly that, on average, I25 maintenance operations are very successful at maintaining GRIP while other sites managed to recover GRIP successfully as a general rule. However, the average values do not always reflect the actual situation at each site as the following table shows.

Table 3 outlines the winter performance at each RWIS location based on event type.

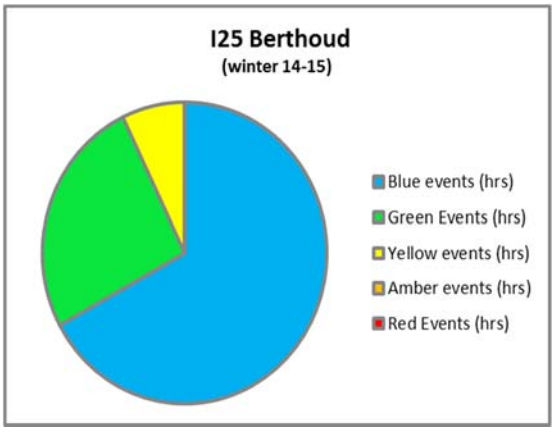
	Total Duration of events	Blue events (hrs)	Green Events (hrs)	Yellow events (hrs)	Amber events (hrs)	Red Events (hrs)
I 25 Berthoud	221.9	148.8	57.2	15.9	0.0	0.0
I25 Natural Fort	89.4	46.5	23.1	19.8	0.0	0.0
US36 Baseline	470.1	194.8	43.2	42.3	152.8	37.0
I 70 Loveland Pass Exit	1011.5	418.5	300.4	143.7	50.7	98.2
I 70 Silverthorne	1008.9	287.7	179.8	227.7	200.3	113.4
I 70 Lower Runaway Truck Ramp	890.4	168.6	88.6	113.3	218.2	301.7
I 70 EJT West Portal	1121.5	173.0	386.1	189.3	220.0	153.1
I 70 Hermans Gulch Exit	1033.7	297.8	223.1	218.1	101.7	193.0
I 70 Bakerville Exit	992.9	87.1	84.9	258.7	282.6	279.6
I 70 Floyd Hill	351.6	116.5	127.9	75.9	31.3	0.0
I 70 Genesse	394.3	259.0	77.6	43.5	14.2	0.0

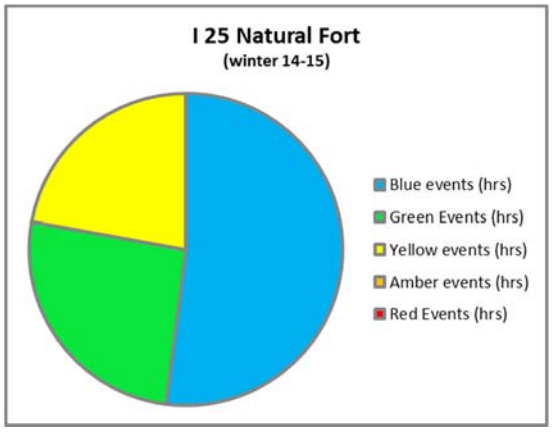
Table 3: Winter Performance Index results by event type for Winter 14/15

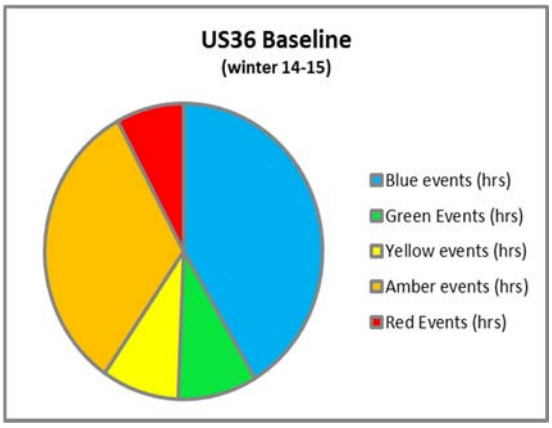
Results from Table 3 are fairly self-evident:

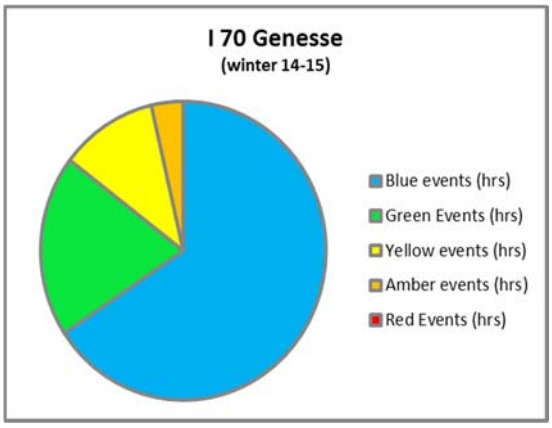
- The events on I25 were handled very well indeed, with a predominance of blue categorization of 'Successfully Treated' events and no amber or red events.
- On US36, the red event was one single occurrence which began on the morning of December 29th at 7:28 AM. Closer inspection suggests that it was a snow event coupled with very low temperatures that started at the beginning of rush hour; these factors combined may have had a serious impact on maintaining GRIP > 0.6. Such instances could be investigated by CDOT during the implementation phase and monitored by post-storm analysis to identify potential maintenance changes to minimize future issues.
- The I70 sites at Lower Runaway Truck Ramp and Bakerville each recorded more events in the amber and red categories than in any of the other categories. As a result, it is possible to conclude that current maintenance actions at these sites are not as effective in GRIP recovery compared to actions at other RWIS sites.

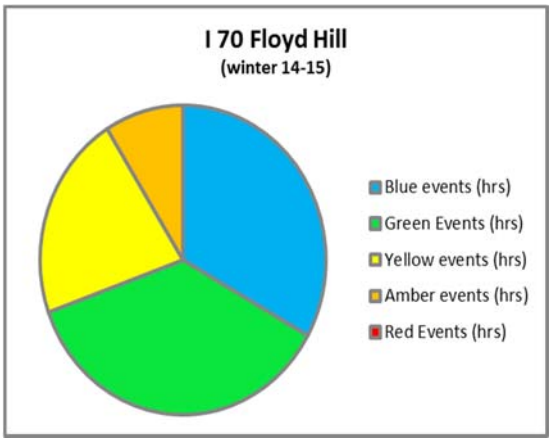
The following pie charts summarize each station's results.

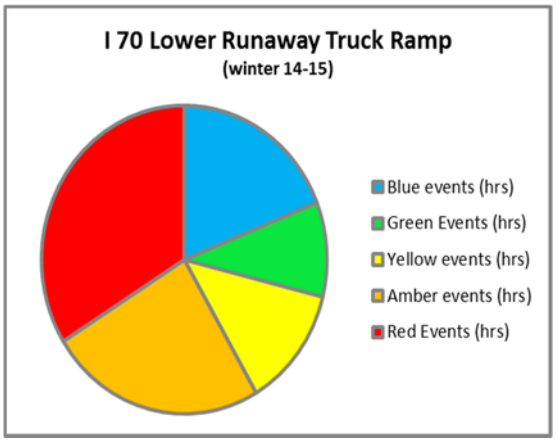


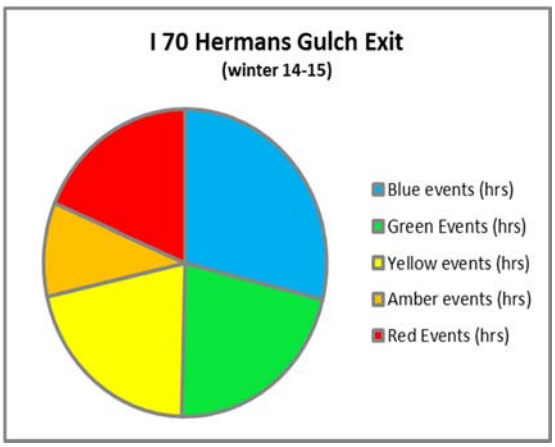


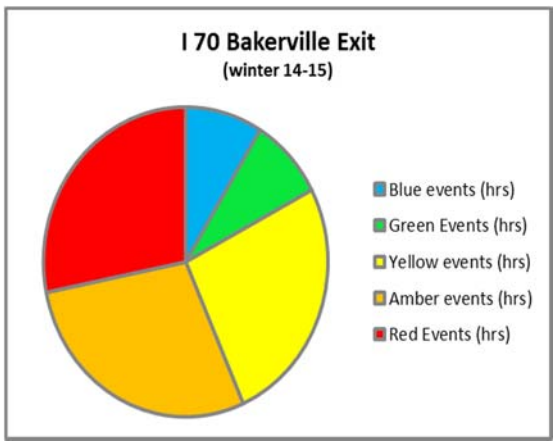

US36 Baseline
(winter 14-15)
Blue events (hrs)
Green Events (hrs)
Yellow events (hrs)
Amber events (hrs)
Red Events (hrs)

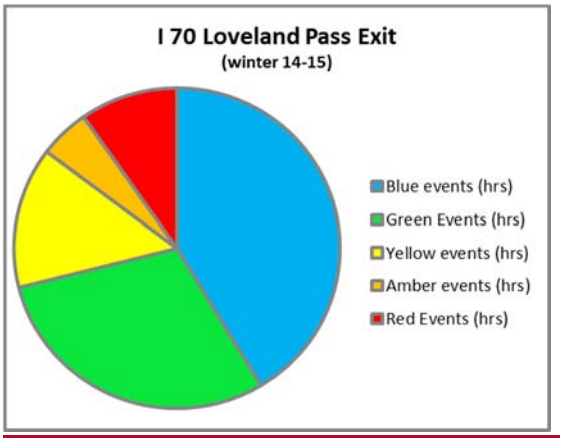

I 70 Genesse
(winter 14-15)
Blue events (hrs)
Green Events (hrs)
Yellow events (hrs)
Amber events (hrs)
Red Events (hrs)

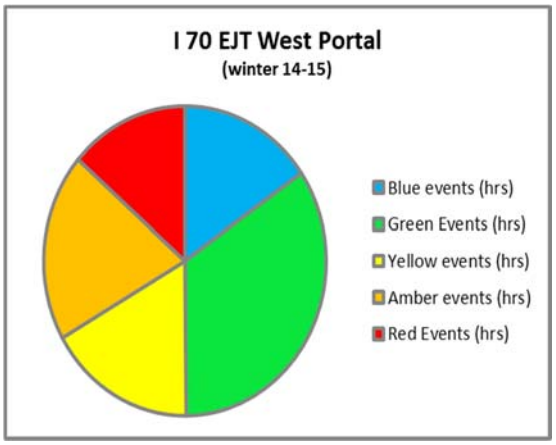

I 70 Floyd Hill
(winter 14-15)
Blue events (hrs)
Green Events (hrs)
Yellow events (hrs)
Amber events (hrs)
Red Events (hrs)

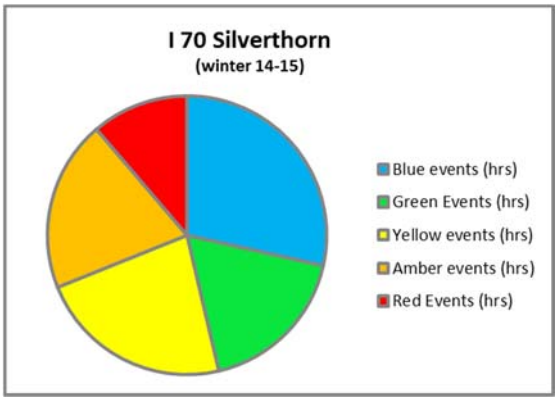

I 70 Lower Runaway Truck Ramp
(winter 14-15)
Blue events (hrs)
Green Events (hrs)
Yellow events (hrs)
Amber events (hrs)
Red Events (hrs)


I 70 Hermans Gulch Exit
(winter 14-15)
Blue events (hrs)
Green Events (hrs)
Yellow events (hrs)
Amber events (hrs)
Red Events (hrs)


I 70 Bakerville Exit
(winter 14-15)
Blue events (hrs)
Green Events (hrs)
Yellow events (hrs)
Amber events (hrs)
Red Events (hrs)







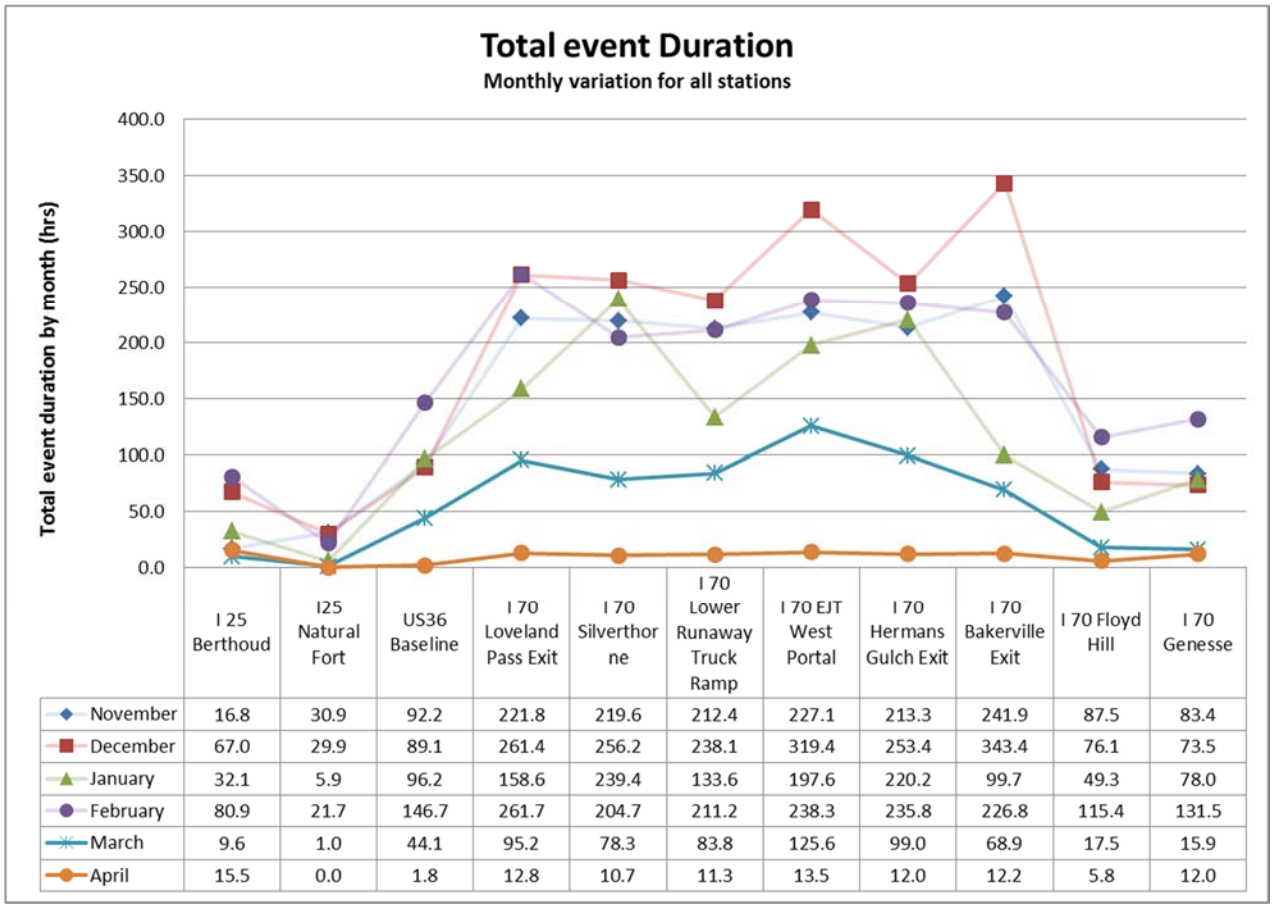
Pie charts of measured performance criteria

In summary, maintenance activities on I25, US36 and both eastern sites on I70 were relatively successful in maintaining Mobility throughout the winter. Mobility at the other sites was significantly hampered and would require further investigation. There are some potential reasons why the results on this section of I70 corridor are significantly worse than elsewhere including:

- Road prioritization based on the CDOT Level Of Service,
- Effectiveness of current chemical treatment,
- Current winter maintenance operations including available fleet.

1.4 Monthly Breakdown of Results

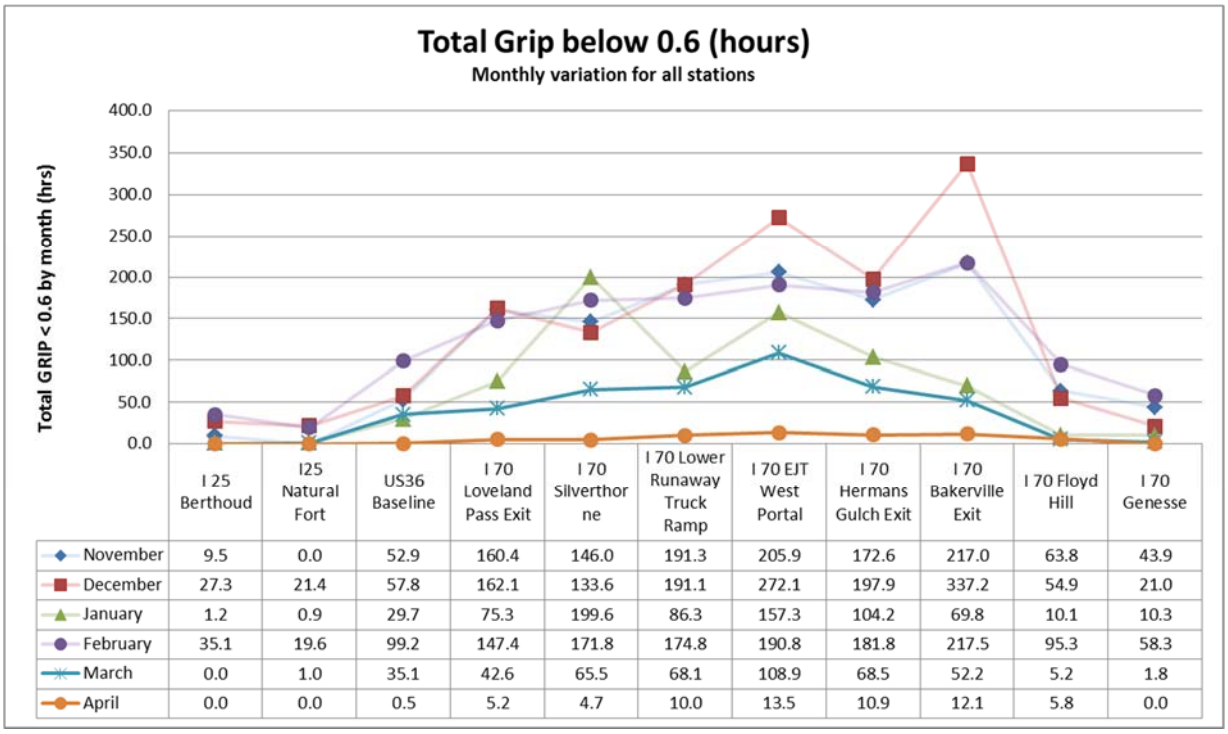
Graphs 6-8 show the monthly breakdown of the measures discussed above.



	I 25 Berthoud	I25 Natural Fort	US36 Baseline	I 70 Loveland Pass Exit	I 70 Silverthorne	I 70 Lower Runaway Truck Ramp	I 70 EJT West Portal	I 70 Hermans Gulch Exit	I 70 Bakerville Exit	I 70 Floyd Hill	I 70 Genesse
November	16.8	30.9	92.2	221.8	219.6	212.4	227.1	213.3	241.9	87.5	83.4
December	67.0	29.9	89.1	261.4	256.2	238.1	319.4	253.4	343.4	76.1	73.5
January	32.1	5.9	96.2	158.6	239.4	133.6	197.6	220.2	99.7	49.3	78.0
February	80.9	21.7	146.7	261.7	204.7	211.2	238.3	235.8	226.8	115.4	131.5
March	9.6	1.0	44.1	95.2	78.3	83.8	125.6	99.0	68.9	17.5	15.9
April	15.5	0.0	1.8	12.8	10.7	11.3	13.5	12.0	12.2	5.8	12.0

Graph 6: Monthly breakdown of the total events that took place at each RWIS location

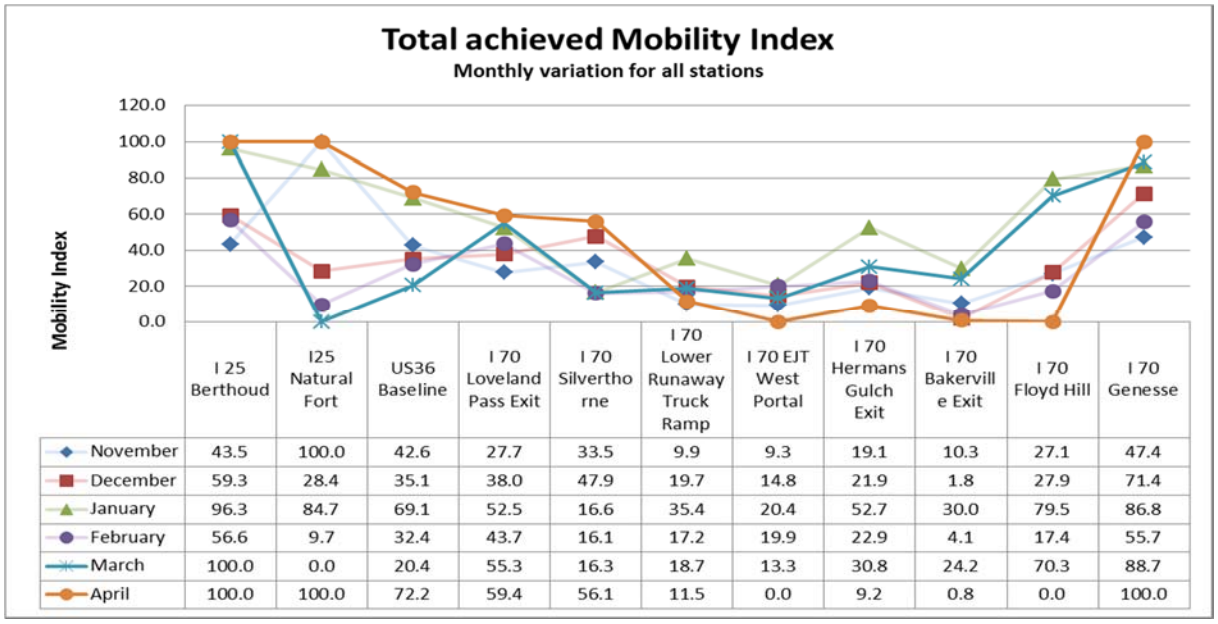
From Graph 6 we can see that the month of December had the most sustained poor weather across all sites, especially across the I70 western locations where the month was clearly the most significant in terms of actual events taking place.



	I 25 Berthoud	I25 Natural Fort	US36 Baseline	I 70 Loveland Pass Exit	I 70 Silverthorne	I 70 Lower Runaway Truck Ramp	I 70 EJT West Portal	I 70 Hermans Gulch Exit	I 70 Bakerville Exit	I 70 Floyd Hill	I 70 Genesse
November	9.5	0.0	52.9	160.4	146.0	191.3	205.9	172.6	217.0	63.8	43.9
December	27.3	21.4	57.8	162.1	133.6	191.1	272.1	197.9	337.2	54.9	21.0
January	1.2	0.9	29.7	75.3	199.6	86.3	157.3	104.2	69.8	10.1	10.3
February	35.1	19.6	99.2	147.4	171.8	174.8	190.8	181.8	217.5	95.3	58.3
March	0.0	1.0	35.1	42.6	65.5	68.1	108.9	68.5	52.2	5.2	1.8
April	0.0	0.0	0.5	5.2	4.7	10.0	13.5	10.9	12.1	5.8	0.0

Graph 7: Monthly breakdown of hours that RWIS measured GRIP falling to less than 0.6

Graph 7 continues with the theme of December being the most challenging month weather-wise, again with the six western I70 sites facing the greatest problems.



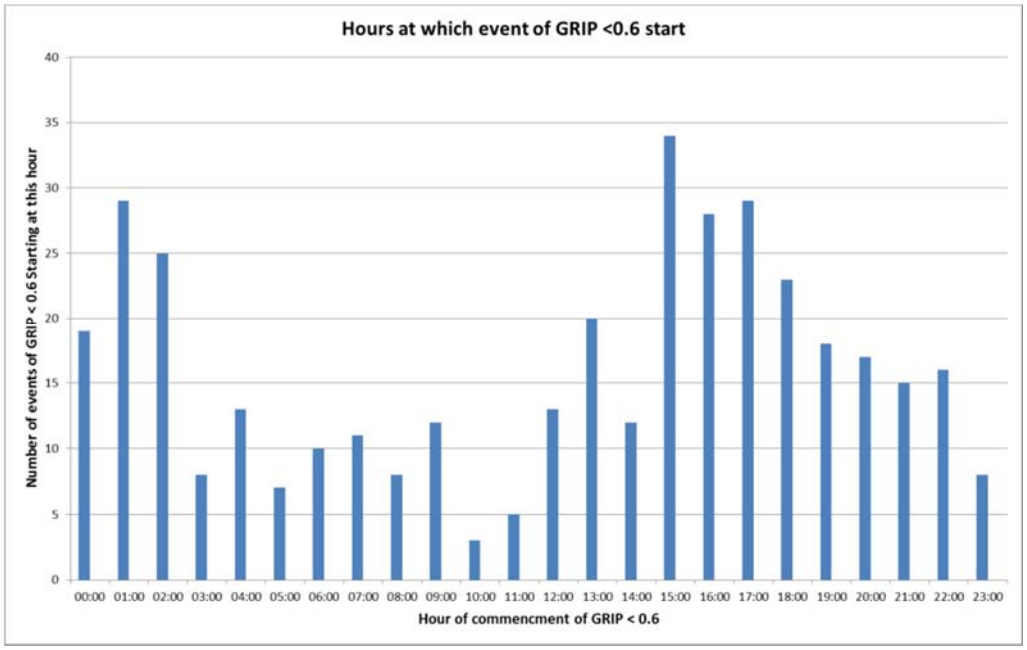
	I 25 Berthoud	I25 Natural Fort	US36 Baseline	I 70 Loveland Pass Exit	I 70 Silvertho rne	I 70 Lower Runaway Truck Ramp	I 70 EJT West Portal	I 70 Hermans Gulch Exit	I 70 Bakervill e Exit	I 70 Floyd Hill	I 70 Genesse
November	43.5	100.0	42.6	27.7	33.5	9.9	9.3	19.1	10.3	27.1	47.4
December	59.3	28.4	35.1	38.0	47.9	19.7	14.8	21.9	1.8	27.9	71.4
January	96.3	84.7	69.1	52.5	16.6	35.4	20.4	52.7	30.0	79.5	86.8
February	56.6	9.7	32.4	43.7	16.1	17.2	19.9	22.9	4.1	17.4	55.7
March	100.0	0.0	20.4	55.3	16.3	18.7	13.3	30.8	24.2	70.3	88.7
April	100.0	100.0	72.2	59.4	56.1	11.5	0.0	9.2	0.8	0.0	100.0

Graph 8: Achieved Mobility Index results for each station by month

Graph 8 shows that Mobility scores by month varied across the measured network. Month by month variability was relatively stable at Berthoud and Baseline but more variable at the other locations. Natural Fort has the most variability of all locations with February at 9% Mobility (the March figure of 0% relates to one event of 1 hour duration), while 100% Mobility was achieved for events in November and April.

1.5 Individual Event Analysis

The ITD Winter Performance Index gives us many ways to filter and analyze winter performance data. Graph 9 shows a view of the starting hour of registered periods of GRIP falling below the 0.6 threshold. This is interesting in that it shows the times throughout the 24 hour period when such events are happening.



Graph 9: Number of events where GRIP < 0.6, by starting time

Graph 9 shows there is an apparent favorite time period for the roads system to be affected by winter storm conditions, which stands out as 3:00 PM – 10:00 PM. One theory for this is that heavier volumes of traffic can affect operations and hence grip can be lost in this time frame. The other notable period is between 12:00 AM and 3:00 AM, which may be influenced by the rapid fall in temperatures during this time period. However this is open to further study and debate.

Station	Date	Time Range	Event	Duration (hours)
070W221 Bakerville Exit	27-Dec-2014	02:35 PM - 10:00 PM	GRIP<.6	187.4
070W213 EJT West Portal	21-Dec-2014	10:03 PM - 11:53 AM	GRIP<.6	85.8
070W218 Hermans Gulch Exit	28-Dec-2014	07:19 AM - 11:17 AM	GRIP<.6	76.0
070W221 Bakerville Exit	21-Dec-2014	09:46 AM - 10:00 AM	GRIP<.6	72.2
070W213 EJT West Portal	23-Nov-2014	12:16 PM - 08:50 AM	GRIP<.6	68.6
070E216.6 Loveland Pass Exit	28-Dec-2014	01:07 PM - 09:33 AM	GRIP<.6	68.4
070W210 Lower Runaway Truck Ramp	21-Dec-2014	02:26 PM - 10:30 AM	GRIP<.6	68.1
070W218 Hermans Gulch Exit	21-Dec-2014	09:20 AM - 03:42 AM	GRIP<.6	66.4
070W221 Bakerville Exit	15-Nov-2014	01:13 AM - 12:53 PM	GRIP<.6	59.7
070W221 Bakerville Exit	12-Nov-2014	01:47 AM - 09:03 AM	GRIP<.6	55.3

Table 4: Top ten events by duration

Table 4 shows the top ten events by duration as identified through the RWIS measurements throughout the winter of 2014-15. Bakerville suffered 40% of these events, showing again how difficult weather conditions can be at this location. The other events were spread between EJT West Portal, Loveland Pass Exit, Hermans Gulch Exit and Lower Runaway Truck Ramp.

As can be seen in Table 4, these events all occurred in November and December.

Station	Date	Duration (hours)
I25 Berthoud	25-Dec-14	38.3
I25 Natural Fort	25-Dec-14	23.6
US36 Baseline	29-Dec-14	51.2
I 70 Loveland Pass Exit	22-Nov-14	92.2
I 70 Silverthorne	25-Dec-14	139.1
I 70 Lower Runaway Truck Ramp	22-Nov-14	88.2
I 70 EJT West Portal	22-Nov-14	93.4
I 70 Hermans Gulch Exit	22-Nov-14	90.2
I 70 Bakerville Exit	25-Dec-14	241.7
I 70 Floyd Hill	21-Feb-15	45.3
I 70 Genesse	10-Nov-14	58.3

Table 5: Longest full events at each site

Table 5 shows the longest event at each site regardless of whether GRIP was >0.6 or not. The different weather conditions experienced between sites is clear with events on western I70 lasting up to 4 times longer than those on eastern I70, US36 and I25.

2 Summary

As can be seen from the data provided above, the information that can be elicited from the Winter Performance Index goes far enough to be able to understand both individual event performance as well as macro level network details. Treatment effectiveness can now be measured for analysis and improvement measures can be employed and then assessed.

There is clear evidence that the severity of winter storms across the region varies significantly and that performance cannot be measured effectively without taking this into account. Utilizing the Storm Severity Index to calculate actual Winter Performance Index gives a realistic picture of the effectiveness of winter maintenance operations across the region. It also needs to be considered that winter maintenance practices may vary due to Level of Service guidelines and therefore lower expectations of GRIP recovery may be acceptable at some sites

3 Proposed Next Steps for Implementation

- Evaluate the current CDOT network and prepare an RWIS network assessment. Recommend site modifications required to support the implementation of the Winter Performance Index.
- Schedule pre-winter training and arrange for ongoing support through the 2015/2016 winter season to ensure effective utilization of the Winter Performance Index.
- Evaluate in more detail the red and amber events, identified in the above report, with regard to the effectiveness of the CDOT treatment at those times. Determine if the data support further investigation into pre-treatment (anti-icing) scenarios.
- Retain continued support in refinement of the Winter Performance Index formula, as needed, as the Winter Performance Measures are integrated into CDOT's winter maintenance operations
- Upgrade existing CDOT software capabilities to best utilize Winter Performance Measures.

Annex A: Definitions

For clarity the following definitions apply to each of the categories reported.

Event name: GRIP<.6
Triggered when grip is below 0.6 for 30 minutes
Cleared when grip is above 0.6 for 120 minutes

Event name: FROST treated
Surface temperature < 32°F (0 °C)
AND water layer thickness > 0 and < 0.04 mm
AND snow & ice layer thickness 0 mm
Triggered when observation condition is met for 30 minutes
Cleared as soon as more water or ice or snow on the road – otherwise check observation condition next 120 minutes

Event name: TREATED
Surface temperature < 32°F (0 °C)
AND water layer thickness > 0 mm:
Triggered when observation condition is met for 30 minutes
Cleared when observation condition not met for 120 minutes

Annex B: Full Index report

This will be supplied in full as a separate Excel Document

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