Document: Confederation Line Wheel Flats report

Project: Confederation Line Performance Oversight

Version: 1.0

Date: June 4th, 2020

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Client: Rideau Transit Group

Document Ref: JBAUSA/RTM/023-04-04

File Name: JBA RTM wheel flats report Issue 1.0.docx

Document Management

Document Location

The source of the document will be retained at JBA Corporation head office. This document is only valid on the day it was printed.

Revision History

Ver.	Revision date	Author[s]	Summary of changes	Changes Marked
1.0	2020-06-04	P Perceval	First issue	No

Internal Approvals

Name	Signature	Title	Date of Issue	Version
J Boyle		Director, JBA	2020-06-04	1.0

Distribution

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CONTENTS

1 Abbreviations and Acronyms

Abbreviation	Meaning
ATC	Automatic Train Control – General term for single system automatic train protection, automatic train driving and automatic route setting
ATP	Automatic train protection - Electronic system to prevent overspeeds and signal overruns on railroads.
ATPM	ATP manual mode, train operator manually commands motor and braking within safe operation speed/distance envelope enforced by ATC system
CBTC	Communications-Based Train Control – ATC system using continuous data communication between trains and central computer
EB	Emergency Brake – Safe brake on train
EVR	Event Recorder (also known as Train Data Recorder/Incident recorder)
GEBR	Guaranteed Emergency Brake Rate
HVAC	Heating, Ventilation, Air Conditioning
IMIRS	Work order database used by RTM for logging maintenance and defects
JBA	JBA Change Management Corporation
LRV	Light Rail Vehicle
MDBF	Mean Distance Between Failures
M/S	Meters per second, unit of speed – 1m/s = 3.6km/h
M/S/S	Meters per second per second, or MS^{-2}, unit of acceleration
OBCU	Onboard Control Unit
OCS	Overhead Catenary System
OEM	Original Equipment Manufacturer
OLRT	Ottawa Light Rail Transport (Construction and vehicle procurement company)
PBEB	Pushbutton emergency brake – Combined friction and track brake
RTG	Rideau Transport Group

Abbreviation	Meaning
RTM	Rideau Transport Maintenance
WABTEC	Westinghouse Air Brake Technologies Corporation

Table 1 Abbreviations and acronyms

2 Executive Summary

RTG have asked JBA Change Management Corporation to compile this report detailing the background, investigation and solutions identified by the wheel flats task force convened to investigate wheel flats problems on the Confederation line LRV.

The Confederation line has experienced a high number of emergency brake applications over winter 2019-2020. The Emergency brake provides an extremely high reliability of brake application to meet the system safety requirements; this mode of braking sacrifices the software control of slides during braking.

The frequent emergency braking combined with lower adhesion caused by winter conditions and specific to selected locations Is likely to increase the risk of flats on the cars.

The task team had a twofold brief; to reduce both the causes of the emergency braking as well as the reasons the emergency braking causes wheel flats. This will give a higher level of availability and reduced delays in future winters.

The causes of the excessive emergency brake events were:

- The ATS/ATC system has some software issues that under specific but repeatable operating scenarios cause emergency brake events and platform overshoots,
    - This is reported to be corrected in the yet to be deployed in V6.1 of the ATC system software
- The GIDS system is prone to false detections due to ground snow accumulation, false triggers due to operation of its heater and due to false detection during snow events of intrusions.
    - These are being addressed by software changes, and readjustment of the height
- Rail adhesion, and the reaction of the train and ATC system when the train was being operated under service profiles that exceeded the available adhesion, leading to overspeed emergency brake events.
    - There are requirements to better use the different available operational profiles offered by the ATC system, notably the two different reduced acceleration and brake rates, and,
    - there is for the train a proposal to modify the braking controls, that would reduce the probability of an emergency brake event under bad adhesion conditions.

The causes of wheel flats caused by emergency braking were:

- The emergency brake has a very high adhesion demand on all axles, compared to the adhesion available in winter conditions. Trailer axles have the highest adhesion requirement and are most prone to slide. Reducing this adhesion requirement is likely to reduce the endemic tendency to flatten wheels during emergency braking.
    - There is a proposal to modify the emergency brake rate thereby reducing the adhesion requirement and the risk of wheel flats during emergency brake events, while still meeting the GEBR
- Defects on the vehicle braking equipment which intermittently caused cylinder pressure to drop to zero, leading to excessive braking at low temperature (observed only when daily

minimum was below -11C). These have been recreated on bench testing and the supplier, WABTEC is identifying a solution.

- There were faults on some LRV's in either load weigh sensing or brake valve setting that lead to incorrect (lower cylinder pressure and higher brake effort) on some axles than need to be corrected.
- There were issues with the ability to deliver sand to the vehicles due to moisture in the sand silos, which froze from time to time starting in mid-December.
- The sand purchased was incorrect in terms of size, particle size distribution, particle shape (ground with sharp corners vs. rolled with rounded edges) and led to clogging of the sanding system

The problems related to the Coronavirus Pandemic are likely to make progress slow over spring/summer 2020. Any local initiatives to improve adhesion or the condition of the cars along with reduction of the number of EB events should be progressed in case of delays to equipment changes or modifications.

To provide assurance of LRV availability under winter conditions it is vital to eliminate epidemic episodes of wheel flats. Therefore, it is recommended that identified actions are completed.

3 Background

The OC Transpo Confederation Line opened in passenger service in September 2019. The line is a fully automatically operated and signaled line running on dedicated new tracks. The rolling stock consists exclusively of Alstom Citadis Spirit LRV's running in multiples of 2 articulated cars. Each car has 5 bogies (trucks), 3 of which are motored and 2 trailers. One of the trailer trucks is fitted with tachometers to provide tachometry (speed measurement) and odometry (distance measurement) for the signaling system.

The train supply and maintenance are undertaken by Alstom, under separate contracts to Rideau Transport Group, which in turn provides the maintenance of the trains and tracks to the operator, OC Transpo.

During winter 2019-2020 there were many incidents involving flatted wheels on the LRV's (see Figure 1). These resulted in noise in the car, requiring the trains to be stopped for tire turning. This caused a loss of availability and concern on the part of the train operator.

Figure 1 - Example of wheel flat

The investigation into issues with the wheel flats has involved a cross-functional task team consisting of the train manufacturer/maintainer Alstom, the signal supplier Thales, the project body OLRT, and the maintenance body RTM. Additional input was provided from consultants JBA and SNC Lavalin.

Name	Company	Expertise
Robillard, James	RTM	Rolling stock Specialist
Stepka, Allan	Thales	Signaling integration and testing
FRANCE, Richard	Alstom	Project Manager
GOUDGE, Lowell	Alstom	Train systems design engineer
MILLIEN, Frederic	Alstom	Project Engineer
L'HOMME, Alexandre	Alstom	Project Manager
MATTHIOPOULOS, Michail	Alstom	Customer Director
Nadon, Steven	OLRT	Testing and Commissioning, infrastructure
Catlow Richard	SNC Lavalin	Senior Consultant
Pate, Tom	RTM	Maintenance Director
Perceval, Peter	JBA Change Management	Train systems performance
Marconi, Joseph	OLRT	Director, Systems and Integration

Initial discussions revealed some known issues identified with OLRT, RTM and Alstom staff:

1. GIDS system (Guideway Intrusion Detection System). This detects the presence of people stepping off the end of the platforms onto the Guideway. This system had been identified as tripping when no persons were present, resulting in the loss of movement authority and an emergency brake application.
2. Flats are mostly on trailer axles.
3. Emergency braking was occurring because of overspeed's at speed limit reductions. Slippery conditions were preventing the speed from reducing fast enough to prevent emergency brake intervention.
4. Poor sand quality – the sanders had been identified as being filled with sand which was finer than called for in the Alstom specification – this increased risk of clogging.

To achieve a more thorough and balanced investigation a task team was set up to evaluate incidents of wheel flats and emergency braking using a structured evidence-based approach.

Meetings were undertaken weekly with members of the team. Actions were taken at each meeting to gather data and specifications. Team members performed analysis on the data and presented the result to the group meetings.

JBA Change Management Corporation have been involved in the process as follows:

1. Analysis of failure data provided by RTM.
2. Analysis of event recorder data provided by Alstom.
3. Participation in the wheel flats cross-functional group meetings in February and March 2020. This was to facilitate the meeting and challenge participants to obtain information and conclusions.
4. Provision of general technical advice relating to rolling stock braking, based on global experience of railroad braking. Note that this is not specific to the hydraulic braking systems as used on the LRV.

The information provided to compile this report is as follows:

1. Technical specifications regarding the operation of the LRV service and emergency braking systems.
2. Additional functional information provided by Alstom by email.
3. Event recorder downloads from select cars from the times from the end of January to mid-February 2020.
4. Work order details from the IMIRS system identifying cars with flats. Limited context information.
5. Selected wheel truing data, which has not included many cars found with flats.
6. Other data provided during meetings from the signaling system and other EVR's not disclosed to JBA, this was unverified by JBA but the conclusion of investigations by other parties in the meeting.

4 Citadis Spirit braking system

4.1 Hydraulic/Electrodynamic service braking system

The braking system consists of spring-applied, hydraulically released calipers applying friction pads to ventilated disks mounted to the axle ends. The motored trucks also use Electrodynamic brake from motors & gearboxes mounted on one end of each motor truck axle. These brakes provide a controlled 'brake effort' which is the force pushing the train to a stop. There are 3 motored trucks and 2 trailer trucks on each car.

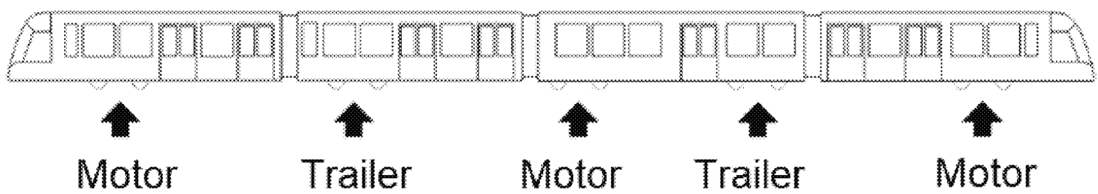


Figure 2 - Trucks on LRV

The motor & gearbox is in the place of a brake disk because of space constraints, therefore the motored axles have only 1 brake disk as opposed to 2 on the trailer axles. The single brake disk axle requires twice the caliper (pad) force to apply the same brake effort as an axle with two disks.

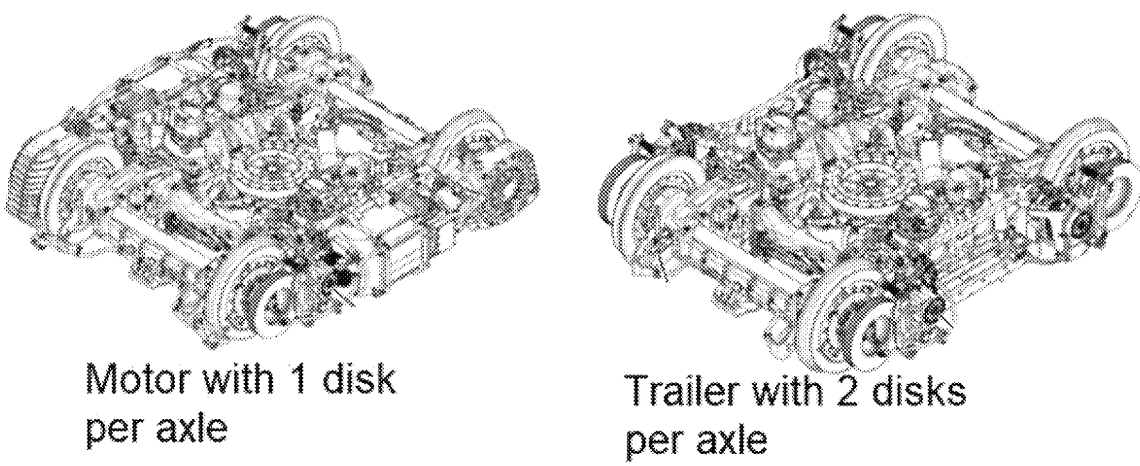


Figure 3 - Motor and trailer truck design

The caliper and disks are the same for motor and trailer trucks, so to get the same braking effort on a motor and trailer axle the motor axle pressure needs to be half the trailer axle pressure (the hydraulic pressure releases the spring force on the pads so the lower the pressure, the higher the force).

Although the static braking effort on both types of axles can be the same by using double the pad pressure, the ability of the axle to dissipate kinetic energy during braking is halved with a single disk. The kinetic energy of a moving train represents a huge amount of energy to be dissipated as heat in the disks when braked. In emergency the friction brake disks must dissipate a high proportion of the braking power of the vehicle. The remainder of the braking power is dissipated by the electromagnetic track brakes. The power of the braking system is related to effort as the product of the speed (in meters per second) and the effort (in N or KN). So 50KN brake application at 20m/s (72 km/h) is 1000KW (1MW) of braking power converted to heat in the disks.

These disks are ventilated to help dissipate the energy. Exceeding the power rating of the disks will soften the friction material and reduce braking effort.

4.2 Management of the braking system

The train management system converts the braking demand from the CBTC system into necessary braking effort for the measured load on the train and shares the braking effort between trucks to maximize the electrical efficiency of the train as required by the specification. The system is designed to apply a deceleration of 1.34 m/s/s when a 100% service brake is demanded by the CBTC system, though normal service operation does not use more than 0.89m/s/s or 66.4% of the maximum available brake. The CBTC monitors the deceleration of the unit, increasing braking demand if the train is too far forward to stop at the current brake rate.

The system is designed to use the Electrodynamic service brake up to a level of 24% adhesion coefficient (the ratio of brake effort to downward force from train weight). This electrodynamic brake is also limited by the maximum power rating of the motors and converters (725KW per truck). The braking energy is either regenerated into the Overhead Catenary to power another train or is dissipated in the rooftop brake resistor which is sufficient to brake the train under routine service operation without use of friction brakes.

If high braking power is demanded, in excess of 725KW/truck at high speeds or high loads, the mechanical brake disks are also used. The hydraulic power unit (HPU) releases some pressure on the calipers to allow the spring within the caliper to apply force to the brake pad on the disk, creating brake effort to 'top up' the electrodynamic brake. This is known as 'blending' the brake.

If a defect occurs in the electrodynamic brakes the service brake can be achieved using the mechanical brake system to supply the shortfall. The TCMS will balance out the braking ability of the whole LRV (all 5 trucks) to compensate for loss of braking on a single truck. The application of disk brakes is applied uniformly across all disks, up to the maximum of 0.24 adhesion coefficient, with the remainder being spread across the remaining trucks not yet at the maximum adhesion limit.

4.3 Emergency brake

The emergency brake is known as EB or PBEB. It is a fail-safe brake which has a very high theoretical reliability. The brake is irrevocable, the train must stop for this brake to be released.

If the CBTC detects a potentially unsafe condition the emergency brake is applied by de-energizing a continuous train loop. This de-energizes electro-hydraulic valves within the HPU's to disconnect the service brake and connect a regulator which releases brake pressure from the calipers, which is then maintained at a fixed level of around 12 bar for motor trucks and around 30-45 bar for trailer trucks depending on the load weight on the truck. A magnetic track brake is also applied which acts directly on the rails. The resulting deceleration of 1.95m/s/s (at 48km/h) is applied to the car.

The regulator connected to the brake system can only reduce the hydraulic pressure in the cylinders (increasing the sprung brake effort) once the emergency brake is applied:

1. The emergency brake effort will always be the same or higher than the friction service brake effort on the truck at the time the emergency brake is applied. There are some theoretical cases when there is crush loading on the car, and the propulsion system has multiple defects, where the service brake pressure may be higher than the emergency brake.
2. The design is not compatible with the use of wheel slide protection, which would require increasing the hydraulic pressure on the truck to reduce brake effort on that truck to control the slide.
3. If a fault such as a hydraulic leak in the circuit causes the pressure to drop more than is required (effort is too high on a truck), this cannot be corrected so the truck will over-brake.

Because the emergency brake rate has to be met when the train is fully laden with passengers and empty, the trailer trucks have a load weight function which increases the emergency brake force on the trailer trucks once the passenger density is approaching the AW2 level. This helps reduce the worst-case adhesion requirement as well as reducing the empty train maximum brake rate, and thus the possibility of slides when at low train loading. This load weigh function is performed on the trailer trucks, because the 2 disks per axle on these trucks can dissipate the additional energy from the loaded train. The resulting adhesion on the trailer trucks steps up at around 100 tons train weight (see Figure 4)

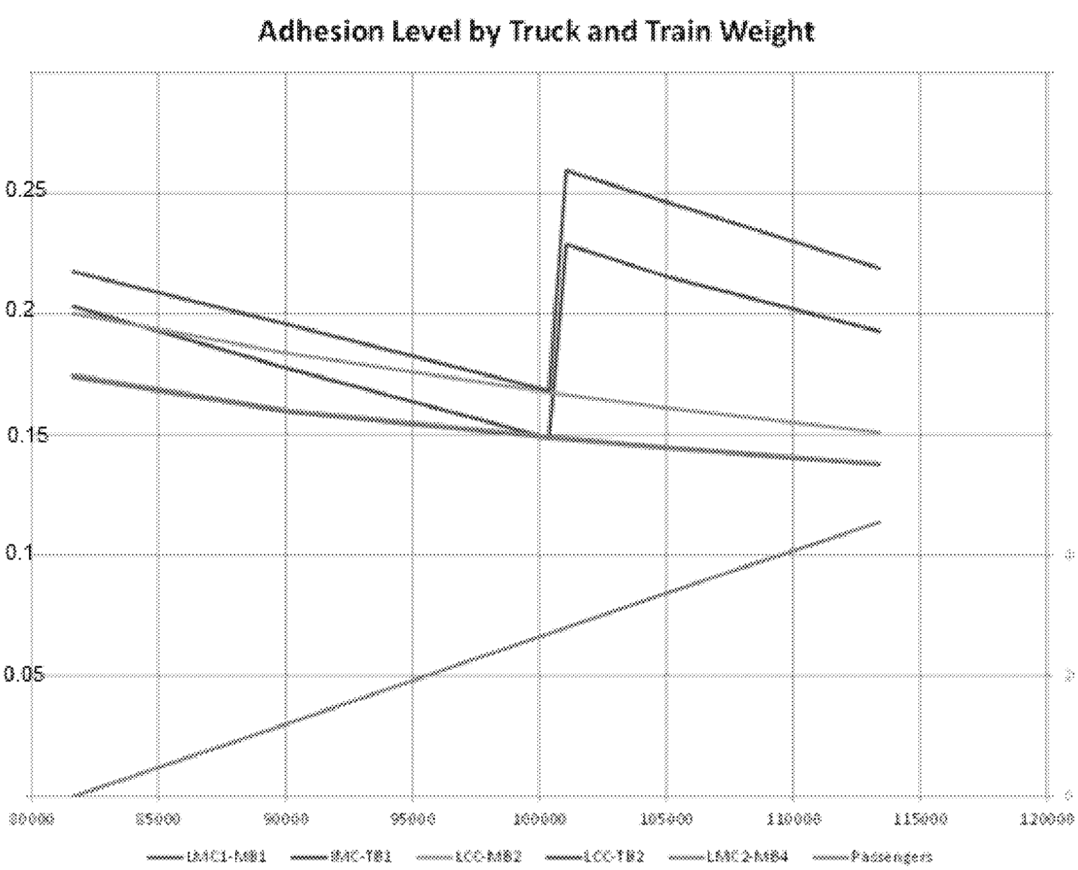


Figure 4 - Emergency brake adhesion requirement for each truck based against passenger load

Because of the high increase in adhesion requirement when the car goes over AW2 load level the train is more susceptible to sliding when full. When the train is empty the motor truck and trailer truck have more convergent adhesion requirements; any wheel slide will not affect trailer axles especially unless other factors (e.g. sanding) affect adhesion levels on the train. This step up in the brake effort takes place at a passenger load level consistent with the maximum system design capacity and was very infrequent in the events reviewed.

Figure 5 shows a typical table of adhesion expected in different generic rail conditions. The actual adhesion experienced depends on speed (higher speed gives lower adhesion), wheel diameter & type of braking used. Adhesion levels lower than 0.10 are not uncommon globally during rail contamination.

Rail conditions	Adhesion coefficient	Rail conditions	Adhesion coefficient
Dry and clean	0.25–0.3	Moisture	0.09–0.15
Dry with sand	0.25–0.33	Light snow	0.10
Wet and clean	0.18–0.20	Light snow with sand	0.15
Wet with sand	0.22–0.25	Wet leaves	0.07
Greasy	0.15–0.18		

Figure 5 – Realistic railroad adhesion levels.

4.4 Sanding

Wheel sanding is used successfully globally in mitigating poor adhesion conditions. The LRV is fitted with 4 air-operated sanders distributed down the car as shown in Figure 6. They are fitted with heating for operation under severe conditions.

Sanding is applied under the leading wheels only of the nearest fitted trucks ahead of a truck where the wheels are detected as slipping in motoring or sliding in service brake. Sand is applied automatically under the leading wheels of each train during emergency brake, whether slide is occurring or not.

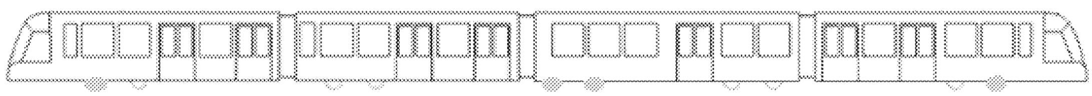


Figure 6 - Axles fitted with sanders

The sand is expected to improve the adhesion level of leading trucks and the intermediate motor truck. However, the effect of sanding dissipates rapidly with the number of axles from the sander. The trailing motor truck is the most distant truck from any sander, being 4-5 axles away from an active sander.

The LRV has had problems with clogged nozzles and insufficient sanding being applied during winter 2019-2020. This is partially related to maintenance of the sanding system and the incorrect sand grade being loaded to the sand hoppers on the train.

Alstom are modifying the sanding system to apply all sanders in emergency brake to increase the amount of sand on the track. Maintenance of the sanding system has been updated to check for blockages and for correct heater function. They are also resolving problems with sand procurement to achieve the correct grade which is not being used at present.

4.5 Track brake

Each truck is fitted with a magnetic track brake which applies a friction material between the truck body and the rail head. It is applied electrically from the train battery when the emergency brake is applied, or when the penalty brake (service brake and track brake) is manually applied.

Track Brake Data - PBEB (TB Applied to 8 kph)					
Track Brake Data Calculated Using S70 Salt Lake City Dynamic Testing Results					
Track Brake Normal Force (N) X 10	693000 +/- 5%	Average Brake Rate From Track Brake only			
Entry Speed	**Average Braking force / car for entire stop**	**AW0**	**AW1**	**AW2**	**AW3**
100	55678	0.66	0.60	0.51	0.48
90	56300	0.66	0.60	0.52	0.48
80	57073	0.67	0.61	0.53	0.49
48	61538	0.72	0.66	0.56	0.53
24	70822	0.81	0.74	0.64	0.60

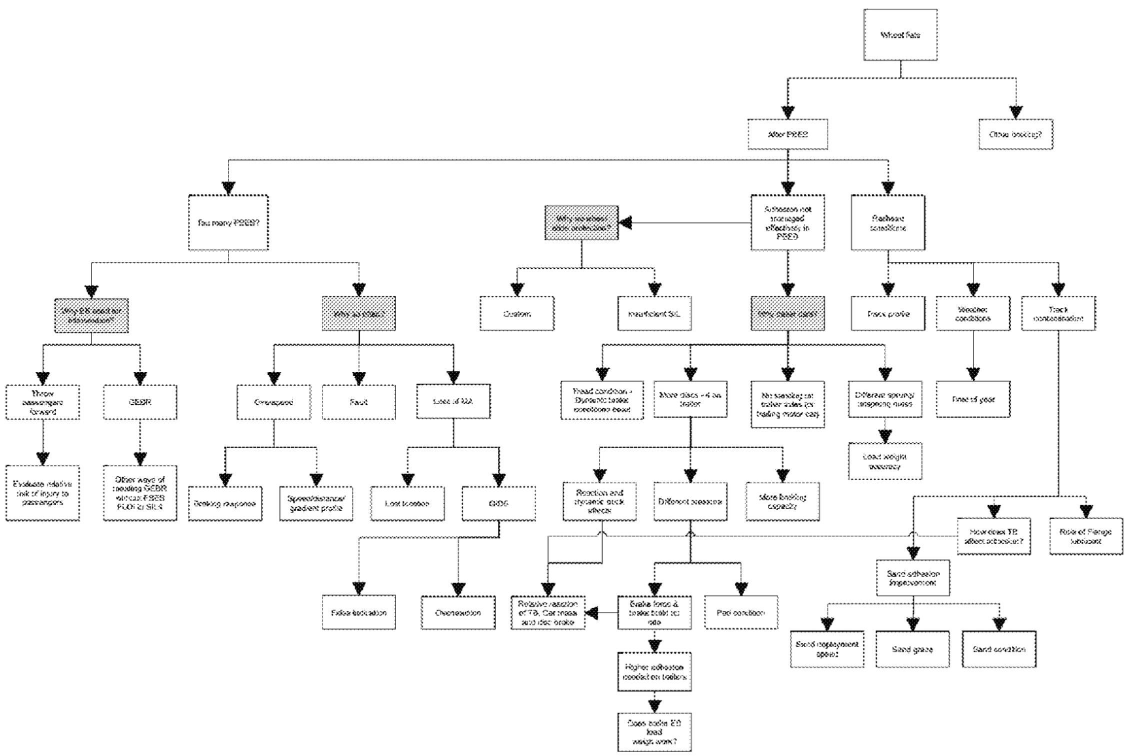
Figure 7 - Alstom Track brake data

5 Investigation process

5.1 Logical process

The investigation into the wheel flats was to proceed without prejudice to any party, so an investigation structure was created by JBA. The intention of this structure was to highlight possible causes in each subsystem on an equal level based on known and agreed assumptions. It also used other questions based on general knowledge of brake systems.

Note this investigation was within the scope of the train and guideway design and maintenance only, train operations were not part of the scope, nor was the train operator involved with the task team. This created problems when exploring practicable countermeasures for operating in low adhesion conditions and for braking in ATPM mode.



As the investigation progressed some of the questions could be eliminated based on evidence from failures, known functionality and logic. The highlighted questions in yellow were critical areas of enquiry for discussion with the signaling and rolling stock suppliers.

5.2 Flats caused by Service or Emergency brake

The dynamic brake uses the propulsion inverter control and speed sensors to induce current in the stator at a frequency below the actual rotary speed of the motor. The system is inherently lock-up proof as it has no way of forcing the rotor to go slower than the electrical frequency. In the event of a motor slowing faster than expected because of lost adhesion, the inverter reduces the torque to maintain the axle speed.

Because the trains are only full for very short times of the day, and the friction brake is only used when the train is loaded with passengers, the train almost always uses dynamic brake to stop except at very low speed (below 5km/h) when approaching a station stop.

During motoring and coasting it is necessary for the service brake to release fully by pressurizing the brake cylinders enough to release the spring-applied friction brakes. So effectively in motoring the service brake valve is active in releasing the brakes. Given the lack of reports of dragging brakes or stalled trains due to stuck brakes, it is unlikely the service brake is producing an un-demanded friction brake application to cause wheel flats, given that half the time the train is motoring and will result in stalled trains. On this basis, the possibility of service brakes causing flats was discounted early in the investigation.

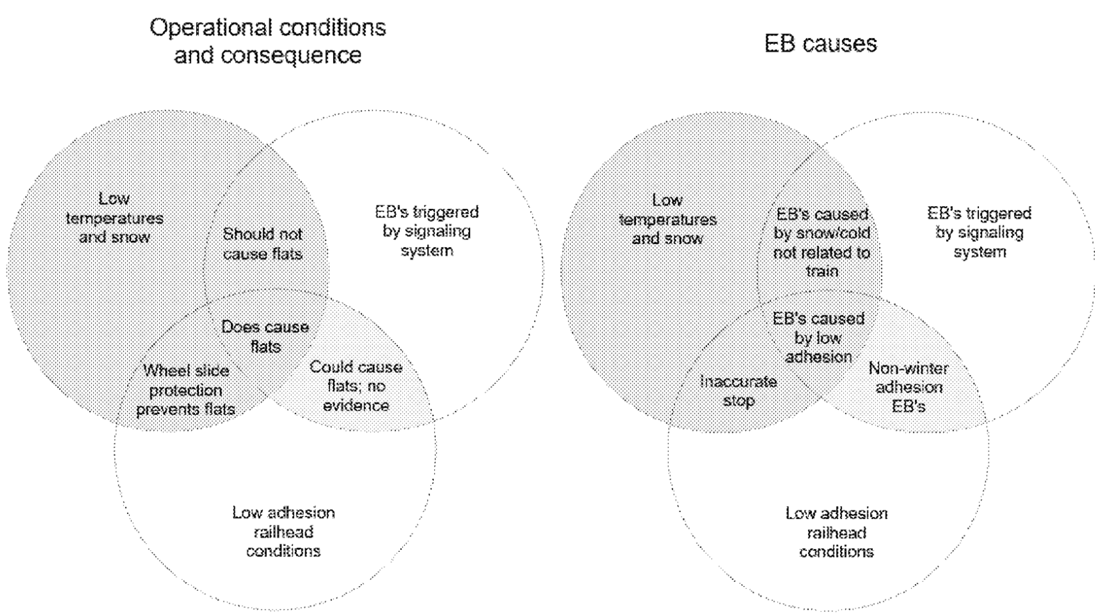
It is likely the flats are caused by emergency braking only and this has been the principle focus of the investigation.

5.3 Flats and winter conditions

Once it was established that flats were caused by emergency brake events, the main points of discussions were:

1. Did the cold conditions cause more flats, or more EB's, or maybe both?
2. Why did the EB result in wheel flats in the trailer cars?

The generic relationship between flats and winter is well-known and relates to railhead conditions only. In cases when temperatures/snow does not cause low adhesion, flats may also occur if low temperatures/snow cause more EB's on the train owing to factors unrelated to the train such as operations and signaling.



Even when the low adhesion conditions relate to snow and low temperatures, any evidence to identify the root cause and potential mitigation of the following was the target of the work team:

- Reducing the number of EB's that occur by reducing the causes of EB's
- Reducing the impact of EB's when they occur by preventing wheel slide and resulting damage.

5.4 Practical considerations

It was essential that the issues causing wheel flats in winter 2019-2020 cannot be repeated in winter 2020-2021 and some assurance must be given during 2020 that the problems are resolved.

The braking system on the LRV was designed and integrated with the signaling system to enable suitable traffic and safety levels to be obtained for the required service. Given that this was acceptable during non-winter conditions it is essential that any factors that affect performance and safety cannot be changed.

The cost implications of major changes to the braking system also must be considered. A major redesign of the braking system would have enormous cost and program implications to design, implement and test.

6 Failure data

6.1 IMIRS data

In November 2019 there started to be reported incidences of flatted wheels on the IMIRS system which is used by RTM to log service defects. The number of reports daily are shown below; these cover all reports including those where action was taken.

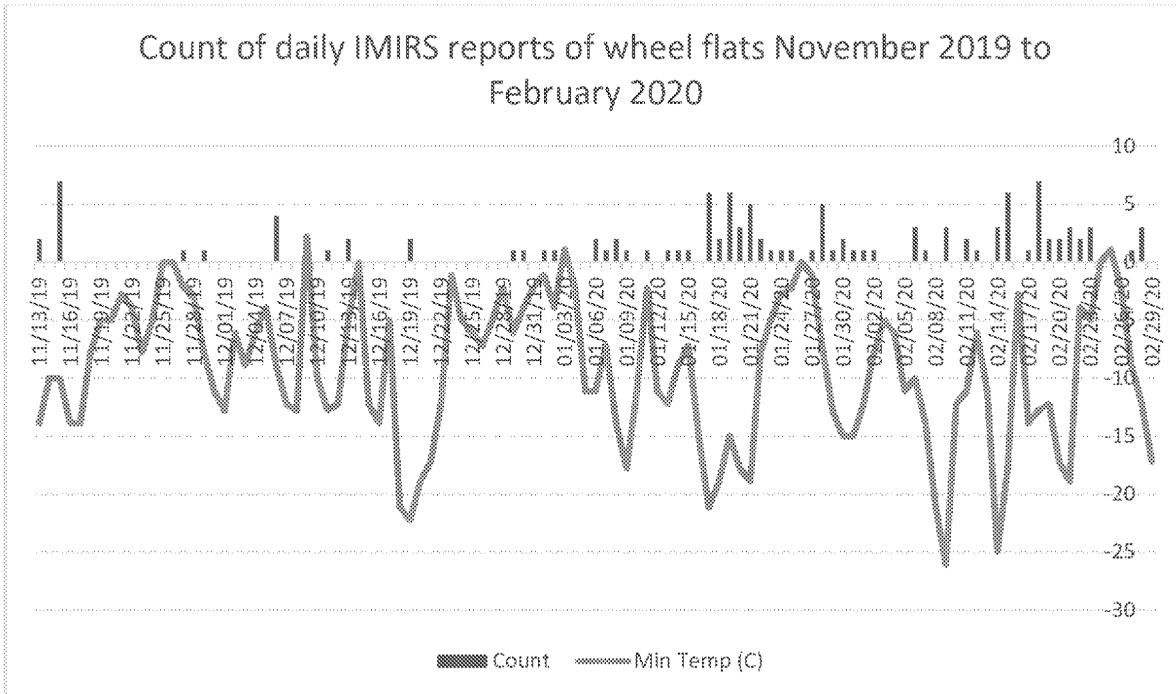
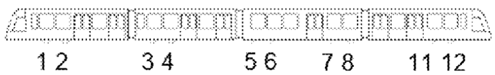


Figure 8 - Plot of number of wheel flats reports on IMIRS with minimum daily temperatures

The problem started with the onset of cold weather in November 2019. Some periods of cold weather had relatively few flats (such as around December 20th); there was more of a correlation between a combination of cold weather and snowfall occurring in late January and February 2020. Note that there can be a lag between the flats occurring and being reported by customers and staff.

The IMIRS outcome data was examined for axle identifications. Only 14 of the work orders reported exactly which axles were machined, as shown in Figure 9 .



Completion Date	Location	1	2	3	4	5	6	7	8	11	12
11/14/2019 05:28	LRV-1131							1	1		
11/16/2019 02:56	LRV-1131			1	1						
11/17/2019 14:13	LRV-1104							1	1		
11/17/2019 17:13	LRV-1132							1	1		
11/28/2019 03:22	LRV-1103			1							
12/07/2019 12:15	LRV-1128			1	1			1			
12/12/2019 21:34	LRV-1119			1	1			1	1		
12/14/2019 06:40	LRV-1126			1							
01/03/2020 14:23	LRV-1108			1	1			1	1		
01/07/2020 20:27	LRV-1132			1	1			1	1		
01/09/2020 16:25	LRV-1133			1	1			1	1		
01/12/2020 10:34	LRV-1113							1	1		
01/14/2020 03:18	LRV-1127			1	1						
01/14/2020 18:36	LRV-1127								1		

Figure 9 - Axles identified with wheel flats from IMIRS reports

In some cases, it appears what different axles on the same LRV were machined after separate reports soon afterwards, it is possible the same event caused the damage in both cases. In one case on LRV32 the axles were machined twice for flats. It is notable that the identified axles are entirely trailer axles, though this list is not exhaustive and other information seemed to indicate that some motor axles were affected by flats.

6.2 EVR data

Alstom provided EVR downloads for cars over the affected period. The range of the EVR data is typically 3 days but can be less than 1 day back from the time it is downloaded. There were few downloads from both cars in the train consist for the same time.

It was not Alstom maintenance policy to take EVR's from all cars routinely therefore the EVR's were not all available.

Car	Date	Comment
LRV5	2-6-2020	EB in sample
LRV5	2-14-2020	EB in sample
LRV6	2-14-2020	EB in sample
LRV6	2-21-2020	No EB in sample
LRV7	2-28-2020	No EB in sample

LRV8	2-15-2020	EB in sample, speed probe fault causing spurious slide detection in coast
LRV9	2-16-2020	EB in sample
LRV16	1-28-2020	No EB in sample
LRV14	2-16-2020	No EB in sample
LRV20	1-28-2020	No EB in sample
LRV23	2-15-2020	EB in sample
LRV25	1-28-2020	No EB in sample
LRV26	2-4-2020	No EB in sample
LRV26	2-11-2020	EB in sample
LRV26	2-28-2020	No EB in sample
LRV32	2-21-2020	No EB in sample
LRV33	2-21-2020	No EB in sample
LRV34	2-16-2020	No EB in sample

Figure 10 - EVR's provided by Alstom for brake investigation

Each EVR is a Bach-Simpson type fitted to each car. It provides a range of data relating to car controls, speed, brake effort. Limitations in the EVR data hindered the investigation:

i. The mechanical brake demand on the EVR does not always reflect the actual mechanical demand from the brake system
ii. The hydraulic brake pressure is only available on truck 1 and 4 of the train.
iii. There is a 'wheel slide active' signal which only shows that some wheel slide is occurring on the car, and it does not show which car.
iv. The signaling data including the location of the train, ATC speed and traction/brake demand from the ATC system does not show the actual brake demand.

JBA were provided with the 'TrackSyte' tool from Bach-Simpson which allows the EVR downloads to be analyzed and exported to Microsoft Excel for graphing and other analysis. The tool allows the data to be searched for wheel slide occurrences. Figure 11 shows a typical example, showing the speed at the time of the wheel slide around 70km/h. A dynamic brake effort of around 30KN is present at each of the motor cars, and no friction brake is demanded. The weight of the train is 97 tons (~100 tons). The adhesion required on each truck, assuming roughly 1/5 of the weight of the train is on the motor truck is 30 divided by (20 x gravity (9.81m/s/s)) which is roughly 0.15 ratio of horizontal force at the truck to vertical force caused by gravity. It is reasonable to assume, as the wheel is sliding at this point, that there is less than 0.15 adhesion available at this place.

Once the sliding is taking place the data for brake force is not valid as the force at the truck is bound to reduce if sliding is taking place. There is no way of knowing what the actual brake force at this point is:

a) The cars are running in multiple so both EVR's are required to assess the data.
b) There is no way of knowing which truck or how many trucks are sliding.

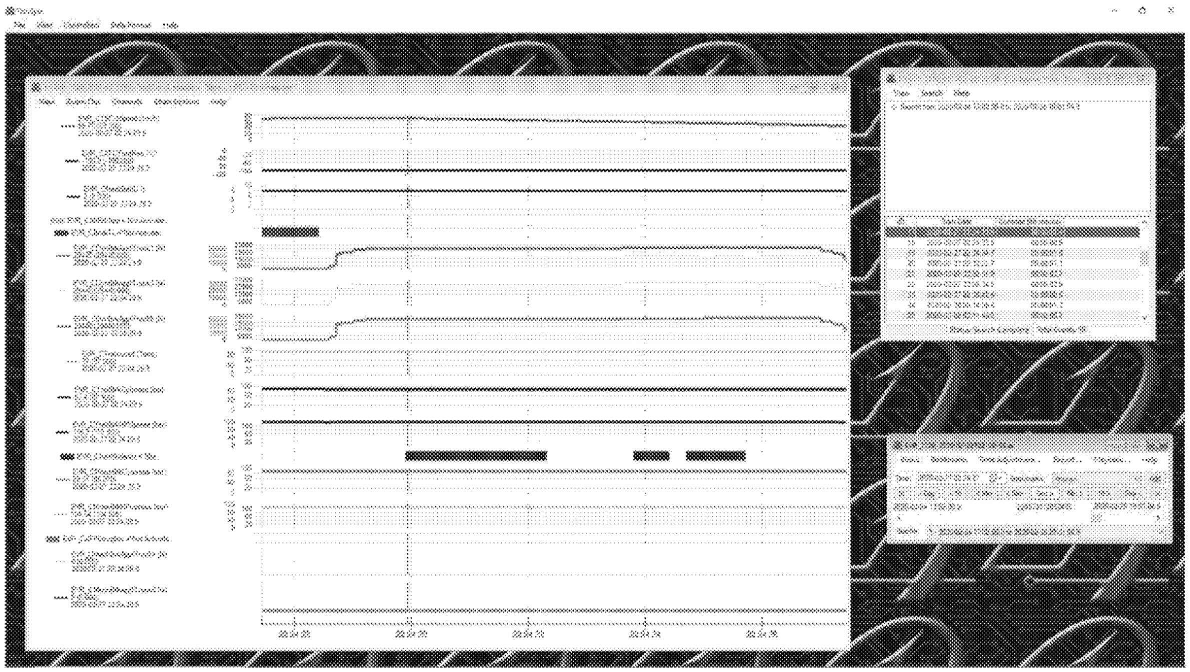


Figure 11 - Method for searching for and displaying wheel slide incidences

The other technique is to display the data in table form (Figure 12) and then export to Microsoft Excel. Excel enables the deceleration of the train to be calculated from the speed figures. The location is required to calculate the gradient, which is a significant part of the acceleration. The resulting total deceleration and braking force can then be calculated.

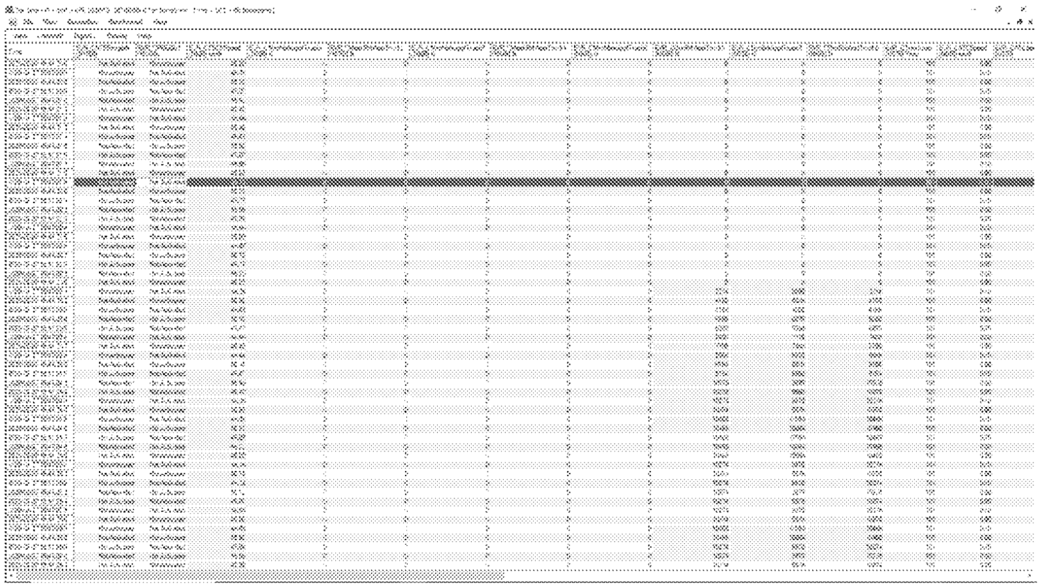


Figure 12 - Tabular extract from EVR for Excel analysis

The Excel data shows the figures every 1/10th of a second. It is possible to extract every incidence of a transition from 'not sliding' to 'sliding' and to capture the brake effort at that point. The location of the slide activity can be calculated the following way:

a) From ATC section number and chainage reported on EVR's where the OBCU is master on that car.
b) From odometry and last station ID when the OBCU is not master on that car.

If the OBCU is the master on that car the ATC traction demand is also shown on the EVR. If the train is being driven in ATP manual mode or the local car OBCU is not the master, then the demand will be shown as -100% which is also the same as a full-service brake.(Figure 13)

Figure 13

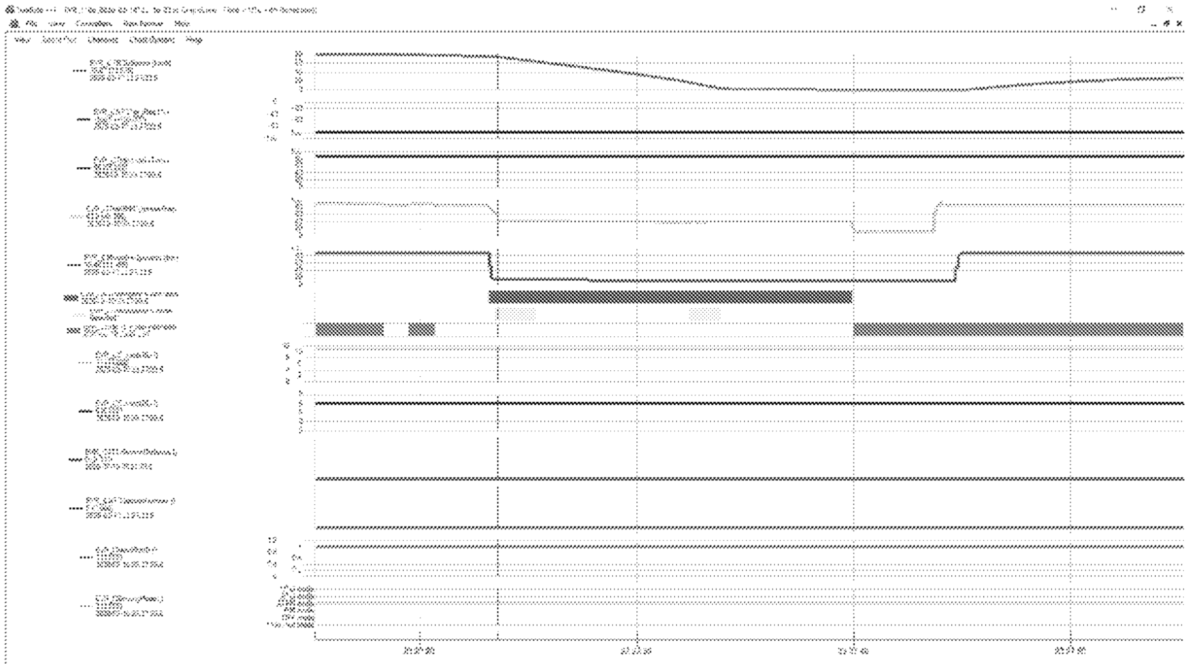


Figure 13 - EB application in ATP manual mode (driving mode 3)

If the ATC torque demand is available, it is possible to see possible reasons for an emergency brake. For instance, in the following case the ATC has a zero brake demand before the EB, pointing to an unexpected loss of movement authority (Figure 14)

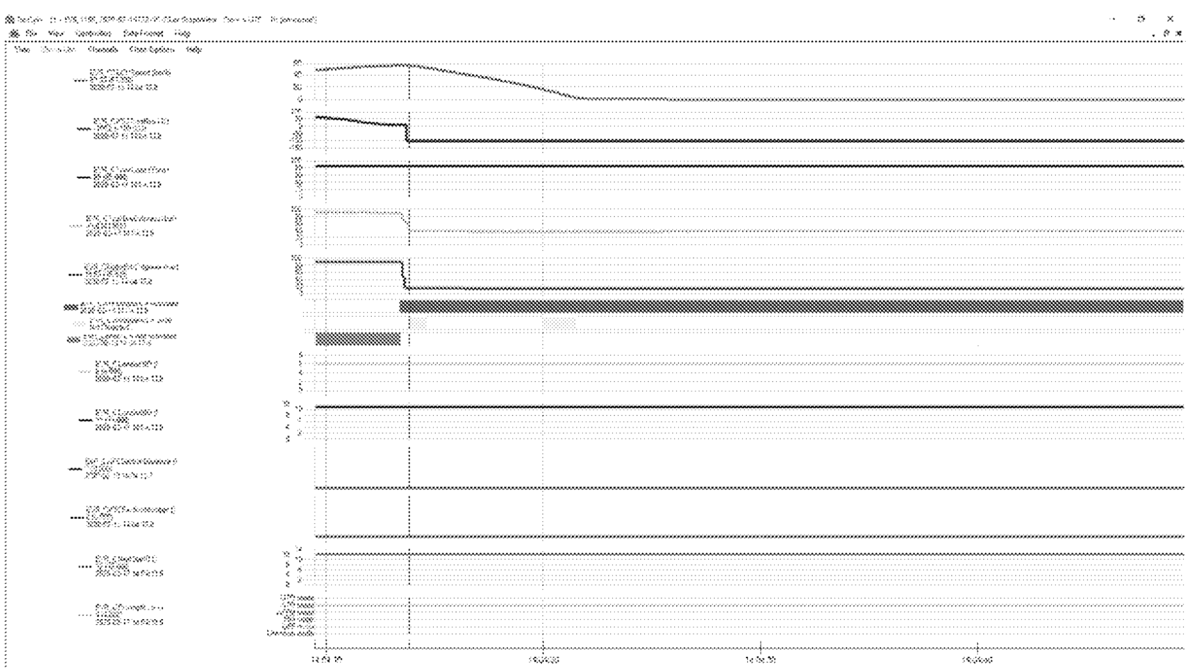


Figure 14 - EB application when driving in Auto

In the following case the car is sliding prior to the emergency brake and the ATC increases the service brake demand to 100% to try and stop the train. This requires some mechanical brake effort at 75km/h. The service brake does not respond, and the car is too far forward to stop safely in service brake, so an emergency brake is applied.(Figure 15)

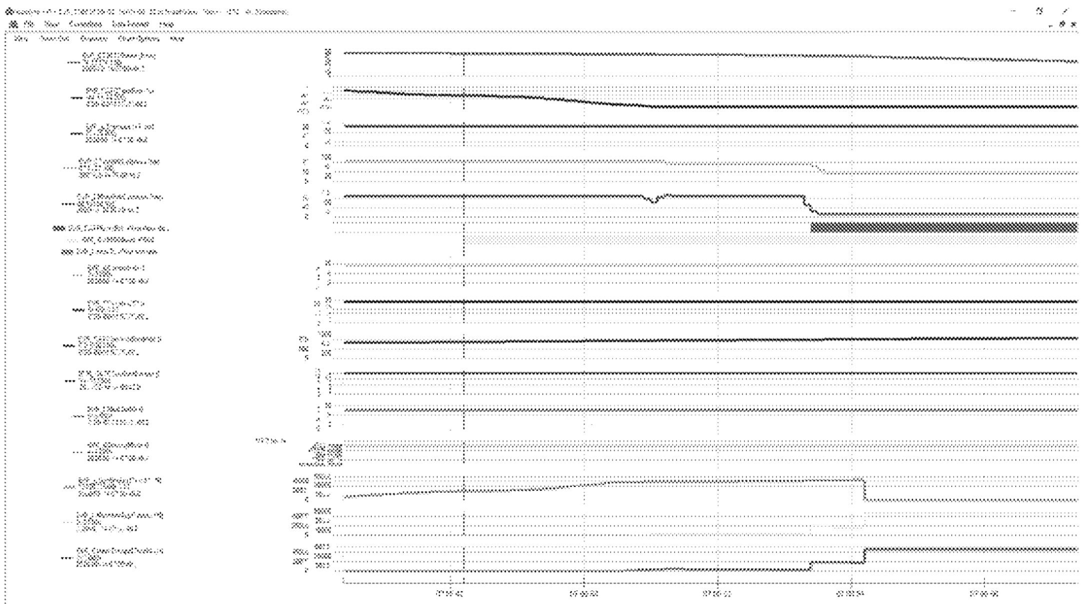


Figure 15 - EB application because of low adhesion

The EVR shows actual cylinder pressure for the brakes on truck 1 and truck 4 of each car. This allowed the diagnosis of loss of hydraulic pressure during emergency brake demands in some cases, where the loss of pressure coincided with the monitored trucks (Figure 16)

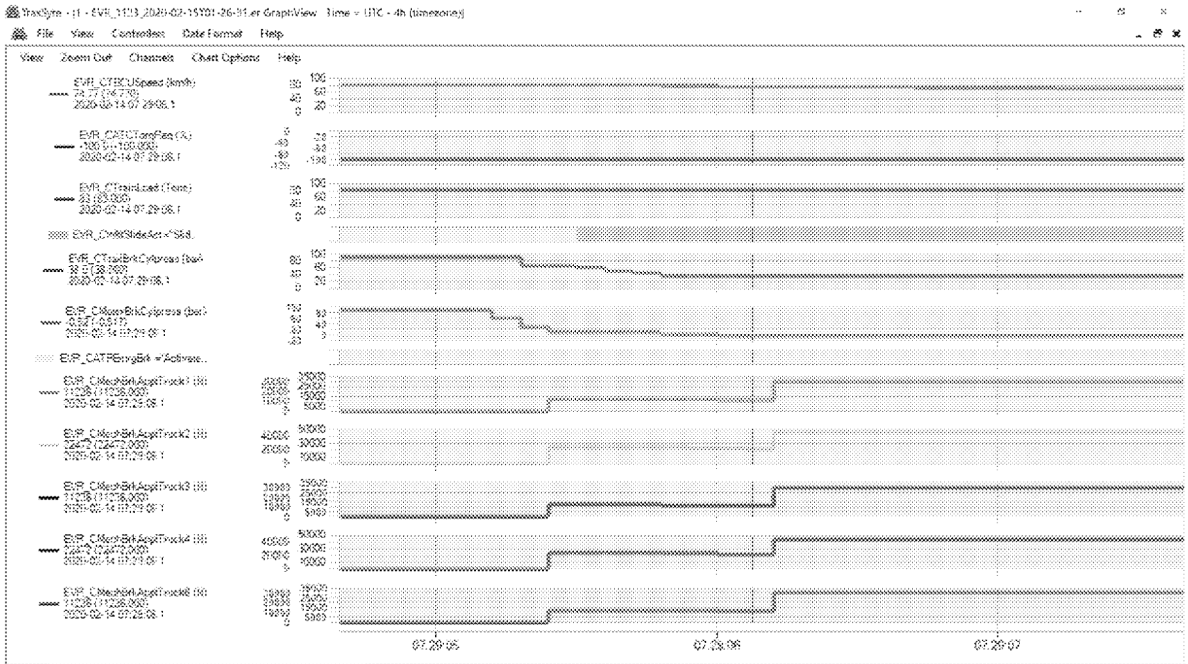


Figure 16 - EB with zero-cylinder pressure

6.3 Other data

6.3.1 Alstom

Information about emergency brake applications was presented to the meetings by Alstom from their own EVR recordings and other data. The relevant EVR reviewed is shown in yellow for the train. Irregularities with brake cylinder pressure are shown in red.

Date and Time (yyyy-mm-dd hh:mm)	Cars in train	Active VOBC	Speed at onset (kph)	Effort demand at onset (M/B +100/-100)	Train weight (tons)	Cylinder pressure MB (Bar)	Cylinder pressure TB (Bar)	Summary
2019-09-14 02:40	16		12.7	0	85	13.97	46.9	RM Mode slide from onset to 6 kph
2019-09-14 03:11	31		9.5	0	84	11.39	42.4	Rm mode no slide
2019-09-15 15:57	16-31	16	35.5	-49.4	90	11.21	46.5	Slide from 12-5 kph
	16-31	16	36.2	-49.4	86	11.56	43.3	Slide from 15-6 kph
2019-09-14 16:00	08-20	08	37.8	-67.8	77	11.21	41.4	Slide from 9.7 to stop
	08-20	08	37.8	-67.8	89	11.56	42.5	Slide from 12 to stop
2019-09-14 16:06	18-27	27	38.9	-60.7	88	11.39	42.9	Slide from 8k-3k

Date and Time (yyyy-mm-dd hh:mm)	Cars in train	Active VOBC	Speed at onset (kph)	Effort demand at onset (M/B +100/-100)	Train weight (tons)	Cylinder pressure MB (Bar)	Cylinder pressure TB (Bar)	Summary
	18-27	27	38.2	-60.7	78	12.25	41.1	Slide from 13k-4k
2019-09-26 00:14	13-20	20	11	86.6	79	11.39	45.2	Slide from onset
2019-10-06 01:06	18-27	18	75.3	-25 (estimate)	82	11.9	42.3	Driver was in ATPM and transitioned to ATO at moment of EB slide from 20 K down
	18-27	18	74.8	0	74	13.11	45.5	Slide from 20 kph to 5 kph
2019-10-06 01:15	20-21	21	20.4	39	83	9.83	42.5	Looks like ATPM followed by FSB command over the network, but insufficient time before EB
2019-10-07 05:40	01-28	28	47.5	-70 (estimate)	85	13.8	46.3	Slide from 17k-6k
	01-28	28	48.1	-64.3	77	12.42	42.1	Slide from 16k to zero
2019-10-07 07:12	01-28	28	58.5	-65 (estimate)	101	12.42	46.4	No slide
	01-28	28	58.6	-63.5	100	12.59	26.9	No slide
2019-10-09 09:01	07-10		6.6	0	80	11.39	44.3	RM mode assumed in yard
	07-10		6.7	0	77	11.04	43.7	RM mode assumed in yard
2019-10-17 17:50	03-09		4.3	0	83	11.56	41.6	RM mode location unknown
	03-09		4.1	0	83	12.42	44.7	RM mode location unknown
2019-10-18	24-11	24	41	-32.7% ATPM	78	11.56	45.6	Operator took the train ATPM and EB'd
2019-11-06 08:19	01-33	01	58.4	-72.1	107	13.11	29.2	No slide
2019-11-10 9:02	22-34	22	48.3	-74.9	76	12.25	40.3	Slide form 19-0
2019-11-10 23:31	16-23	23	5.5	0	81	11.39	46.8	
2019-11-12 01:31	03-19	19	55	20% (estimate)	86	14.32	44.7	Slide from 55 to 42 then from 16 to 6 kph
	03-19	19	55	26%	90	14.66	43.9	Driven in atp-m
2019-11-12 10:20	09-10	09	38.1	18%	87	12.59	38.6	Slide over the full stop
	09-10	09	39		86	11.9	44.2	Slide over the full stop
2019-11-12 10:51	09-10	09	27.7	0	86	12.77	34.1	in ATP-M

Date and Time (yyyy-mm-dd hh:mm)	Cars in train	Active VOBC	Speed at onset (kph)	Effort demand at onset (M/B +100/-100)	Train weight (tons)	Cylinder pressure MB (Bar)	Cylinder pressure TB (Bar)	Summary
	09-10	09	30	0	85	11.9	44.3	
2019-11-12 15:37	03-19	19	26.8	0	91	13.63	39.3	Slide over most of the stop
	03-19	19	26.5	0	100	15.35	36.7	Driven in atp-m
2019-11-13 01:38	21-29	21	28	10 atpm	82	0	45.6	Slide for all the stop
2019-11-14 10:38	16-23	16	66.8	-23	88	13.28	46.8	3 separate slip and slides between onset and stop
2019-11-14 12:27	11-14	14	68.5		97	10.35	46.3	Slide from 30-0
	11-14	14	67.9	-7%	97	13.46	46	Slide from 27 kph to 0
2019-11-14 14:01	03-19	19	26.8	50% (estimate)	88	12.42	40.1	Slide over most of the stop
	03-19	19	28.4	50% (estimate)	92	14.49	38	Slide from start of EB to 6 kph
2019-11-14 14:32	21-26	26	67.2	-27.4	86	10.87	42.7	Slide from 50k to stop
2019-11-14 14:37	21-22	22	67	-29.8	81	12.77	41.9	Slide down to 52 and then from 40 to stop
2019-11-14 15:12	16-23	16	67	-24.7	91	13.46	46.6	Slide from 44 kph down
2019-11-14 16:09	11-14	14	68.1		104	10.7	45.9	Slide from 28 - 0
	11-14	14	67.4	-16.7	100	14.15	44.5	Slide from 29-0
2019-11-14 19:53	16-23	16	64.7	-29.4	88	11.04	45.4	Slide from 23.5 to stop
2019-11-16 03:01	06-28		8.5	0	77	10.52	9.2	RM Mode no slide in yard
2019-11-30 08:29	03-19	03	41.2	50% (estimate)	90	16.2	37.9	Slide over whole stop
2019-12-02 08:05	11-13	11	58.9	-67.1	109	10.5	30.2	No slide
	11-13	11	58.9	-67.1	89	12.25	27.4	Slide from 18-0
2019-12-02 08:59	11-13	11	59.1	-54.9	106	10.18	30.1	No slide
	11-13	11	59.1	-54.9	89	12.08	30.7	Slide from 17 – 0
2019-12-04 06:43	10-19	19	49.3	-64.3	88	14.3	39	Slide from 21kph to stop

Date and Time (yyyy-mm-dd hh:mm)	Cars in train	Active VOBC	Speed at onset (kph)	Effort demand at onset (M/B +100/-100)	Train weight (tons)	Cylinder pressure MB (Bar)	Cylinder pressure TB (Bar)	Summary
	10-19	19	49.3	-60% (estimate)	80	11.21	44.3	Slide from 22kph to 5 kph
2019-12-11 17:24	22-21	22	12.5	(don't Know)	81	12.25	41.9	I don't have the EVR for leader train so no braking effort, Train was Lees
2019-12-13 20:36	04-21	21	.8	100	82	10.7	42.3	At tunneys looks like motion obstruction EB
2019-12-13 20:37	04-21	21	.8	100	82	9.83	42.3	At tunneys looks like motion obstruction EB
2019-12-13 22:03	04-21		6.4	0	82	9.66	42.3	RM Mode location unknown
2019-12-24 05:13	14-26		12.9	24	85	11.73	44.3	RM mode seems in yard
2020-1-11 10:56	25-13	13	53	-19%	75	13.80	46.8	Operator was driving in ATPM (21% traction effort) and put the train ATO and ATC requested braking Note transition to ATO requires handle in coast, and brakes apply at jerk limit
2020-01-16 06:00	12-30	30	27.9	-57	98	12.25	17.8	TS12 data Slide from application of EB to zero values for TS12 Note it seems on this train the variables for Motor Bogie HPU and cylinder pressure are mixed on the EVR cylinder pressures are OK
					80	11.73	47.3	TS30 data slide from 22 kph to zero
2020-01-16 10:48	02-10	10	38.8	0	83	11.73	44	Slide from 10k to zero
2020-01-17 07:22	*07-08*	*07*	*65.9*	*-100*	*79*	*11.39*	*41.7*	*Slide in service brake from 87 kph down to EB, slide continued to stop*
2020-01-17 08:23	12-30	12	66.6	-100	102	10.35	45.1	Slide from 88 kph and -50% effort. effort may be variable on the exact load carried by LCC Note it seems on this train the variables for Motor Bogie HPU and cylinder pressure are mixed on the EVR cylinder pressures are OK
2020-01-17 08:42	12-30	12	2.4	12	103	0	32.7	Note it seems on this train the variables for Motor Bogie HPU and cylinder pressure are mixed on the EVR **. Transient wheel slip for 1 second at start of brake but no slip after that**
2020-01-18 04:01	07-08	07	3.9	10 (estimate)	86	12.94	43.2	Rm mode in yard
2020-01-18 22:24	**01-09**	**09**	**61.7**	-100	88	13.97	46	Slide in brake before EB
2020-01-19 08:09	**02-10**	**02**	**49.2**	-54.5	82	12.77	40.5	TS 2 values Slide over the whole stop
					82	14.66	44	TS10 values slide over entire stop
2020-01-20 21:14	12-30	30	8.8	22	92	10.7	44.7	Note it seems on this train the variables for Motor Bogie HPU and cylinder pressure are mixed on the EVR cylinder pressures are OK
2020-02-10 22:27	06-11	11	73	-25 (estimate)	85	13.46	41	In ATP-M slide from onset to 63k and below 15k demand for about 25% brake at time of EB

Date and Time (yyyy-mm-dd hh:mm)	Cars in train	Active VOBC	Speed at onset (kph)	Effort demand at onset (M/B +100/-100)	Train weight (tons)	Cylinder pressure MB (Bar)	Cylinder pressure TB (Bar)	Summary
2020-1-11 10:56	25-13	13	53	-19%	75	13.80	46.8	Operator was driving in ATPM (21% traction effort) and put the train ATO and ATC requested braking Note transition to ATO requires handle in coast, and brakes apply at jerk limit
2020-2-11 00:23	26-05	25	51	0%	83	12.42	0.2	ATC was coasting for almost 3 seconds without any brake command active and train EB'd, SD 783 and SN5
2020-02-12 17:57	05-26	26	50	0	83	13.8	45.3	slide from 50kph-9kph on 05
2020-02-13 13:04	06-11	11	57	12	85	15.5	38.8	Slip from start to 55kph and below 20 kph
2020-02-14 06:01	09-32	09	67.8	-100	85	12.42	33.3	TS09 data Slide from 74 kph in brake starting at 44% brake effort down to stop
					97	13.46	41	TS32 data Sliding in brake from 75kph slid all the way to zero, blended friction before the EB
2020-02-14 06:30 2020-02-14 06:36 *	05-06	05	79	+71%	86	13.11	39.9	TS05 data Slide for entire stop on 05 and 06 (VOBC stopped reporting speed at instant of EB) note there seems to be a conflict with the consist ID, as we have 5&6 coupled at the same time as 6&11 below?
	06-05	11	79	+50	83	1	-1	TS06 data parking brake is ok but not EB Base time between the 2 evr is skewed by 6 minutes
2020-02-14 06:29	13-23	13	90	0	83	0	38	Slide for full stop
2020-02-14 06:40 *	24-26	24	80.7	0	92	13.63	22.6	Slide from 80 kph to 5 kph operating in ATO. Local VOBC went active only during the onset of the EB for about 2 seconds
2020-02-14 6:06	09-32	09	63	-100 (estimate)	97	13.46	42	Full dynamic plus blended friction at time of EB sliding form 75 KPh down to stop
	09-32	09	66	-100	85	12.42	33.5	
2020-02-14 08:20	09-32	09	30	-100 (estimate)	92	1.8	41	Sliding in brake from 75kph slid all the way to zero, blended friction before the EB No faults in train tracer on brakes
	09-32	09	35	-100	85	12.42	25	
2020-02-15 07:20	09-18	09	13.8	22	82	12.25	35.5	RM Mode in yard
2020-02-15 09:00	09-18	09	12.3	-22	87.2	12.08	31.2	RM Mode in yard
2020-02-19 07:05	18 - 09	18	30	9.4%	89	11.90	42.80	Train slide at 28kph to 5kph for 2 seconds at Blair station, SD 445 and SN 157
2020-02-19 14:39	28		4	22	76	0	40.9	RM Mode in yard

Date and Time (yyyy-mm-dd hh:mm)	Cars in train	Active VOBC	Speed at onset (kph)	Effort demand at onset (M/B +100/-100)	Train weight (tons)	Cylinder pressure MB (Bar)	Cylinder pressure TB (Bar)	Summary
2020-02-22 05:44	19 - 12	12	57	-100%	86	13.63	43.1	ATC was requesting -100% from 4 seconds until train EB at 57Kph to 9kph and slide for 6 seconds at Parliament
2020-02-28 13:49	28-33	28	40.9	25 (estimate)	87	13.11	46.5	Slide from 21.9 down
2020-02-28 20:27	20-24	20	15.7	0	88	11.73	48.1	No slide ATP-M mode appears to have transient FSB demand just prior to EB
2020-02-29 08:51	06		6.9	-23.5	76	13.28	40.5	Location unknown probably yard, in RM mode
2020-02-29 20:27	06-12	06	18.9	0	80	13.63	39.2	ATPM mode looks like driver transiting to coast at time of EB in yard
2020-03-03 5:32	33		3.2	0	83	12.42	47.4	RM Mode in yard
2020-03-01 05:55	06-12		5.8	0	78	15.35	0	Rm mode in yard
2020-03-01 19:24	28-33	28	45	-43.9	76	14.49	42	Slide from 19.3 to stop
2020-03-03 06:11	02-14	02	38.3	0	83	12.08	39.9	Slide for whole stop
	02-14	02	38.3	0	92	12.94	46.6	Slide for whole stop
2020-03-03 19:28	02-14	02	38.8	0	82	12.25	41.4	Slide for whole stop
	02-14	02	38.8	0	97	12.59	36	Slide for whole stop

Figure 17 - Alstom EVR emergency brake evaluation

6.3.2 Thales

Thales evaluated overspeed EB's in early February. It was noted that the majority appeared to relate to operation in ATPM. The following list of overspeed EB's were provided:

1) *03 Feb at 20:46:39 Train 28/31*
    a. *Train was entering LYO-E station in PM mode*
    b. *Train was at 43 KPH as train EB'ed*
    c. *ERO responsible*
2) *03 Feb at 21:52:05 Train 15/30*
    a. *Train was entering STL-W in PM mode*
    b. *Train was at 73 KPH as train EB'ed*
    c. *Train was just switched back to Auto from PM mode when EB immediately occurred*
    d. *ERO responsible*
3) *06 Feb at 11:10:11 Train 14/34*
    a. *Train was midway between LEE-E and HUD-E*
    b. *Train was at 51 KPH and in Auto*
    c. *Active LRV was 14 which was lead unit*
    d. *This was investigated by Thales as a new occurrence location*

   e. *There is a speed restriction in the area of the Zone 2/3 border which this train was not able to handle*
   f. *Updated ASC control included in SW version 6.0 should be correcting this issue*

4) *07 Feb at 11:43:06 Train 14/34*
   a. *Train was entering CRY-W station in PM mode*
   b. *Train was at 66 KPH as train EB'ed*
   c. *ERO responsible*
5) *08 Feb at 23:38:53 Train 3/16*
   a. *Train was approaching TSR area west side of LEE-E*
   b. *Train was at 69 KPH just prior to EB*
   c. *TSR is set at 45 KPH*
   d. *Train was under normal braking mode*
   e. *LRU 3 was lead unit with active VOBC*
   f. *After EB alarm, train also reported lost position and slip alarms and NCO was created around train*
   g. *Recommendation by Thales was sent 12 Feb to change TSR to 55 KPH and use Type 2 brake rate during wet weather*
6) *09 Feb at 08:30:06 Train 2/19*
   a. *Train was approaching TSR area west side of LEE-E*
   b. *Train was at 68 KPH just prior to EB*
   c. *TSR is set at 45 KPH*
   d. *Train was under normal braking mode*
   e. *LRU 19 was lead unit with active VOBC*
   f. *After EB alarm, train also reported lost position and slip alarms and NCO was created around train. Same reaction as item 5 above*
   g. *Recommendation by Thales was sent 12 Feb to change TSR to 55 KPH and use Type 2 brake rate during wet weather*
7) *10 Feb at 15:41:20 Train 1/18*
   a. *Train was approaching TSR area west of Blair Stn*
   b. *TSR is set at 30 KPH*
   c. *Train was at 49 KPH as train EB'ed*
   d. *Train was in PM mode*
   e. *ERO responsible*

6.3.3 OLRT

As part of the investigation into EB's caused by GIDS OLRT investigated the GIDS trips over the month from 2020/02/21 to 2020/03/21.

DATE	TIME	LOCATION	TRAIN	SPEED	TR MODE	Trip Type	Reason for GIDS tripping
02/23	09:38:52	GIDS TUN E	08/28	02	Auto, PM	Possible intrusion	Three trips were detected at 9:38:54, 9:39:58 & 9:52:58. 9:39:58 was triggered by slow train; other two trips are unknown
02/28	13:52:04	GIDS LYO E	28/33	42	Auto, PM	Operator Error	Gids trip caused by maintenance personnel. No train in station and no EB.
02/29	20:24:58	GIDS TRE E	12/06	17	Auto, PM	Possible intrusion	GIDS trip after train stop in station (15 seconds later); GIDS reset by operator; train left station and stop for no apparent reason. GIDS did not cause train to EB after it left station.
03/01	19:23:45	GIDS TRE E	33/28	44	PM	Animal	GIDS trip racoon intrusion on EAST side and train arriving from WEST had plenty of time to stop no EB should have been required. Maybe debris, no camera view possible. Same as above.
03/02	22:50:52	GIDS PIM E	10/03	39	Auto, PM	Possible intrusion	Rain: Two unknown trips were detected at 22:50:57, 22:51:56 possible debris. Train arriving from WEST had plenty of time to stop no EB should have been required. Maybe debris, no camera view possible.
03/02	23:16:49	GIDS PIM E	21/15	09	Auto, PM	Possible intrusion	Rain: Two unknown trips were detected at 23:16:51, 23:17:36 possible debris. Train arriving in station may have blown debris in GIDS area, tripped again while train still stationary in station. GIDS bypassed to let train depart and issue was resolved.
03/02	23:26:26	GIDS BAY W	15/21	08	Auto, PM	Possible intrusion	Rain: Unknow trip after train had entered the station; GIDS trip had to be caused by the other track side as this track was already disabled by the active train.
03/06	09:09:07	GIDS BLA W	06/10	06	Auto, PM	Snow drift	Snow drift is detectable from CAM-01, train almost stop before EB
03/06	09:31:30	GIDS BLA W	12/34	11	Auto, PM	Snow drift	Snow drift is detectable from CAM-01, train almost stop before EB
03/11	17:47:55	GIDS CYR E	18/13	61	Auto, PM	Animal	No train EB in the area while GIDS was tripped by crow landing on top of rail. CAM-009 17:47:55
03/12	19:43:57	GIDS PIM W	02/14	47	None(from PM to None)	Configuration Issue	Wiper from train arriving on track 1; Angle must be raised by 2-3 degrees. Newly installed GIDS.
03/13	10:02:32	GIDS BLA W	10/06	70	None(from Auto,PM to None)	Possible intrusion	Rain: No train EB in the area and unknown reason for GIDS trip.
03/17	08:23:12	GIDS BLA W	03/32	28	Auto, PM	Possible intrusion	Snow: Unknown trip; No train in the area
03/21	02:14:08	GIDS BAY W	14/15	05	None(from Auto,PM to None)	Driver Error	Train 14/15 stop short at station and caused GIDS trip
03/21	02:14:08	GIDS BAY W	30/34	33	None(from Auto,PM to None)	Driver Error	Train 30/34 arriving in other direction had to stop but no EB was required.

Figure 18 - List of GIDS trip causes

7 Evaluation of data

7.1 Causes of EB's

7.1.1 GIDS EB's

The Guideway Intrusion Detection System (GIDS) uses a LIDAR (Light Detection and Ranging) sensor to detect persons on the platform ramp. A LIDAR sensor uses a laser light source and a scanning mechanism to detect and measure the distance between a light reflective object and the sensor.

The sensor used in the GIDS system is a Sick LMS511 from Sick sensors GmbH. of Germany. This is a LIDAR scanning sensor with a built-in computer to scan defined areas ('fields') and detect objects of a minimum size ('Blanking'). There are complex set up parameters to try and eliminate spurious detection of objects owing to contamination, snow, and fog. The scope of the investigation into the sensor is outside the scope of the wheel flats report.

The GIDS sensor detection has the following consequences for EB's on the fleet:

1. If a sensor is tripped when a train is on approach, the movement authority into that zone will be removed and any approaching trains will EB.
2. If the GIDS' are cut out at a station the train will have to drive in ATP manual mode, and the driver may overspeed the train.

As part of the investigation OLRT produced an analysis of typical GIDS trips and reasons shown in Figure 18. This does not include a known software problem occurring at low temperature with the heating control.

It is hoped that changes to the sensor configuration and software, as well as maintenance and adjustment can resolve the issues. The task team have not been directly involved in assessing the GIDS built-in software.

7.1.2 Overspeed EBs

The signaling supplier, Thales, used the ATS download facility to investigate overspeed EB's. An overspeed EB is when the signaling system detects that the train is going too fast if it needs to stop before it goes outside its movement authority. It assumes the train will stop at the GEBR, which is 0.92m/s/s.

Thales identified 3 causes of overspeed EB's

1. Existing known issue relating to under-reaction of the ATC system and delay to train controls.
2. EB's because of use of ATP manual
3. EB's because of low adhesion

7.1.2.1 Known ATC software issue

There was an issue of over-speeding owing to a delay in transitioning to braking specifically when a train is held (delayed) and is accelerating towards a civil speed limit, just prior to either an upcoming station stop or other speed limit. This is should be resolved in the next release (version 6 or 6.1) of ATC software due to be tested and rolled out in May 2020.

7.1.2.2 EB's because of ATP manual

The operators use ATP manual driving mode for operational reasons. The wheel flats task team did not have the full operational reason the ATPM mode was used.

The EVR does not record the warnings or indications on the operator display to indicate when to apply the brake in ATP manual mode. Therefore, it is impossible to verify whether the operator did not brake correctly on the approach to the end of a movement authority. This is essential in driving in ATP manual mode in case of an incident it may be necessary to prove the operator took the correct action.

Alstom said that the data regarding driving warnings sent by the ATC system is not available to the EVR to record. This data is supposed to be downloadable from the ATS system.

JBA requested data from the ATS system to verify the correct operation of the train under these circumstances which was not supplied as part of the task team. It did not appear that this data was available.

There were EB's identified as being caused by the operator switching between ATP manual and fully automatic operation when the train was at or approaching a point where braking is required. This caused EB applications, because to place the train in ATO requires the master controller handle to be placed in coast which then requires the ATC to ramp the brake demand from coast to what is necessary to stop, usually too late.

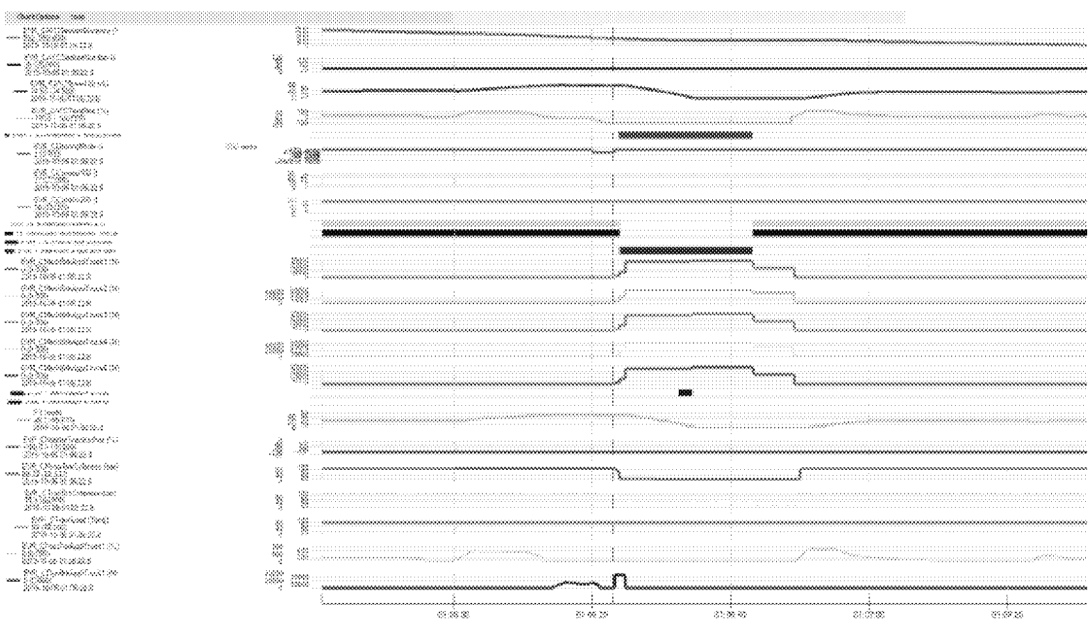


Figure 19 - EB caused by mode change from ATO to ATPM and back at speed

The task team sent a message to OC Transpo requesting the operators did not change modes when moving.

7.1.2.3 EB's because of low adhesion

Some EB's were identified as occurring because of low adhesion. The dynamic service brake, when wheel slide is occurring, controls the motor torque to keep the wheels turning at the slip speed, which is slightly slower than the actual speed of the train. This torque is lower than the demanded torque by some margin. Friction brakes normally work slightly differently in maintaining the brake force at the level at which it starts to slip.

The EVR results from the EB from Figure 15 were examined to calculate the additional acceleration that would be available based on the adhesion available at the time of the slide (Figure 20). This was then used to calculate the actual speed profile that would have occurred if the additional axles had been used to stop the train up to the adhesion level available.(Figure 21). There are inaccuracies because the model cannot really assume that all the brake system in both cars is behaving the same.

In this case the car starts to slide when the adhesion reaches 0.11. At that point, the brake effort available from the trailer axles at an adhesion rate of 0.11 is added to the total effort. The resulting effort makes up the loss of effort from the slide to give the demanded acceleration once the orange and light blue lines cross.

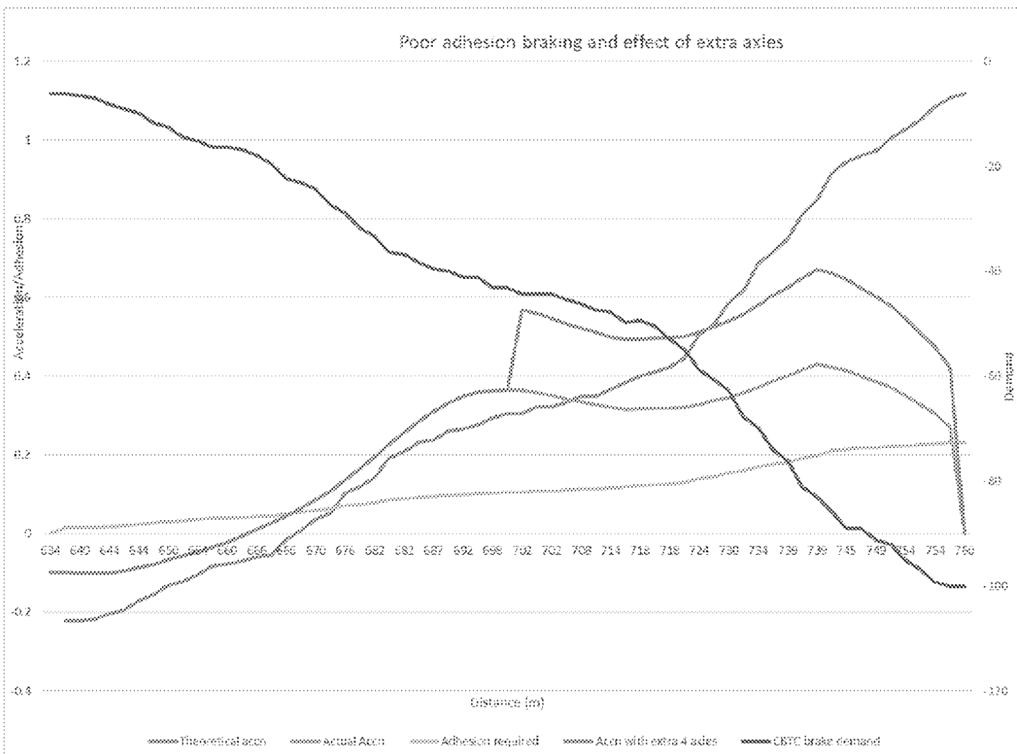


Figure 20 - Effect of additional 4 trailer axles on actual acceleration in low adhesion conditions

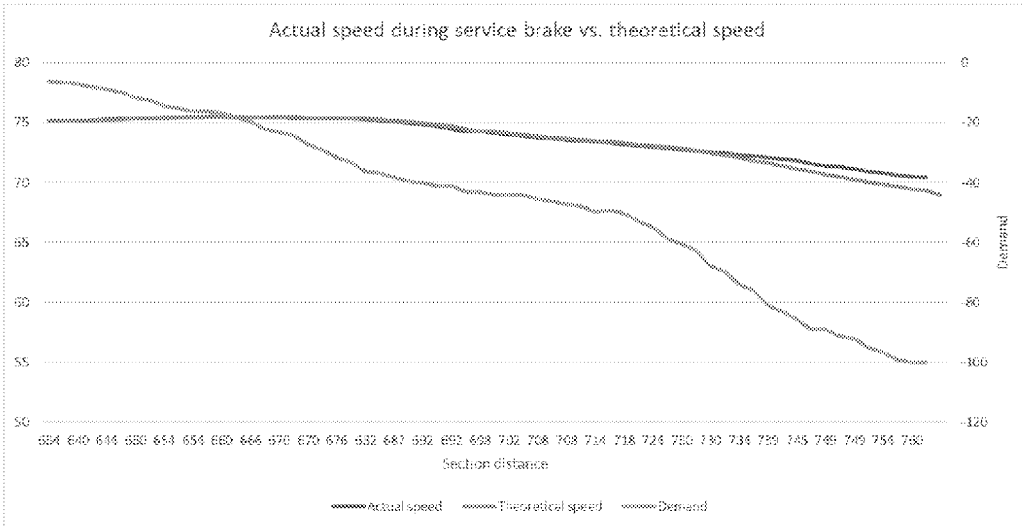


Figure 21 - Simulation of speed with additional axles braking against demand

Alstom are proposing a more sophisticated adhesion management system based on the following:

1. If the service brake demand goes above 2/3 full-service brake (0.89m/s/s) any additional brake is blended in from the trailer cars as friction brake. The effect of this on the graph in Figure 20 can be seen in Figure 22, the grey line will ramp up to the blue line at the rate of the theoretical brake effort increase.
2. This it is proposed that this feature can be turned on and off as required from the ATS as 'Enhanced adhesion mode', in addition to manually by the ERO on any train. This will require modification to the interface with the signaling system and ATS, and operational instructions to turn the system on and off when adhesion is poor.

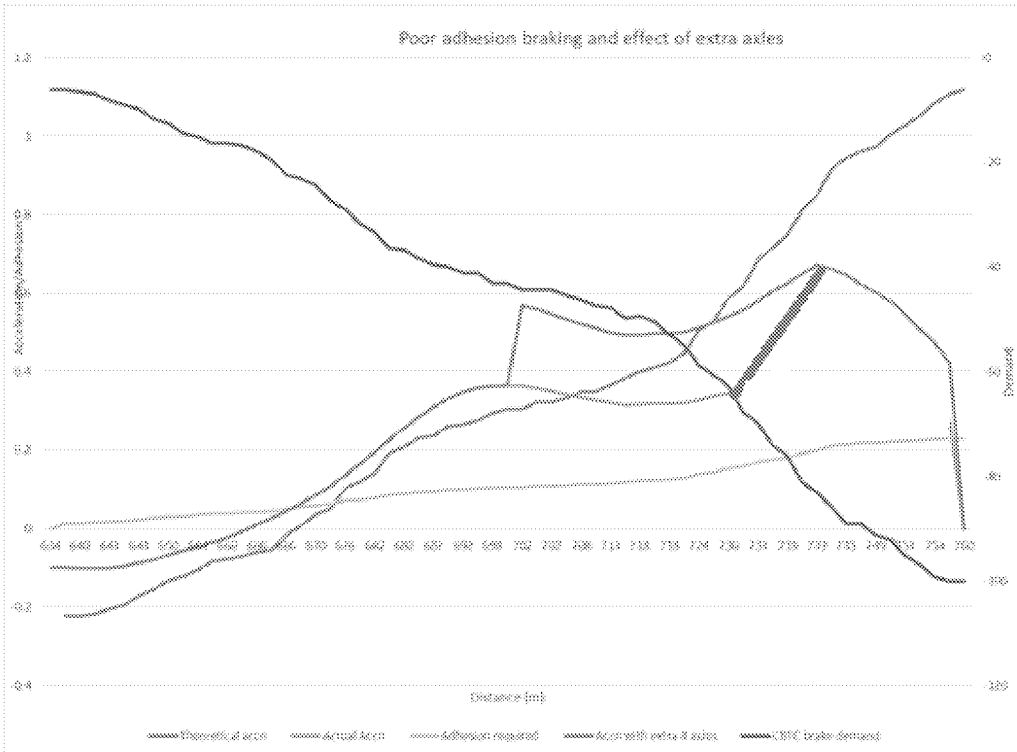


Figure 22 - Annotated diagram showing the increase in acceleration in enhanced adhesion mode when demand is 0.66 of maximum

7.2 Function of brake system

The sample of EVR logs evaluated by Alstom (Figure 17) showed intermittent loss of brake pressure in emergency brake detected on 9 trucks out of all 76 available EB brake logs in all weathers, including where 2 trucks have the wrong pressure on a single car.

For the 45 EB's in the available EVR logs occurring on a day when the minimum temperature has been -11 degrees C or less, 9 trucks have shown a low brake pressure at any of the 2 monitored positions on each car.

The EVR monitors 2 out of 5 of the truck brake pressures. 3 out of 5 low brake pressure EB incidents cannot be measured on the EVR. As there is no connection between the brake behavior and whether it is monitored or not, another 9 ÷ 2 x 3 = 18 random EB brake pressure losses on unmonitored trucks can be extrapolated within the sample of 45 EB's on cold days in the sample.

Alstom maintenance staff attempted to re-create the emergency brake fault at low ambient temperatures in the maintenance shed and managed to recreate 1 incorrect emergency brake pressure after testing the emergency brakes on all 5 trucks of 6 LRV's (30 trucks). It was not possible after the first attempt to recreate this issue even on the one truck that exhibited the problem.

It was not possible to use downloaded faults logged by the brake system diagnostics, because the diagnostics did not log an event when the loss of brake pressure occurred. Therefore, there is some uncertainty about the extent of this problem on the fleet.

Since the initial investigation the supplier, WABTEC, have identified a specific problem with the HPU in cold temperatures which relates to this issue, therefore no further field investigations in this area are necessary.

In addition to the problem with loss of EB pressure, some EVR's show an intermittent 'overshoot' of pressure during service braking, normally at station stops, but sometimes during brake blending. Figure 23 shows the pressure dropping below the EB level during a station stop, causing a brief wheel slide. Figure 24 shows the cylinder pressure dropping to emergency levels during a small blended brake application. In both cases these pressure drops are rapidly corrected by the system.

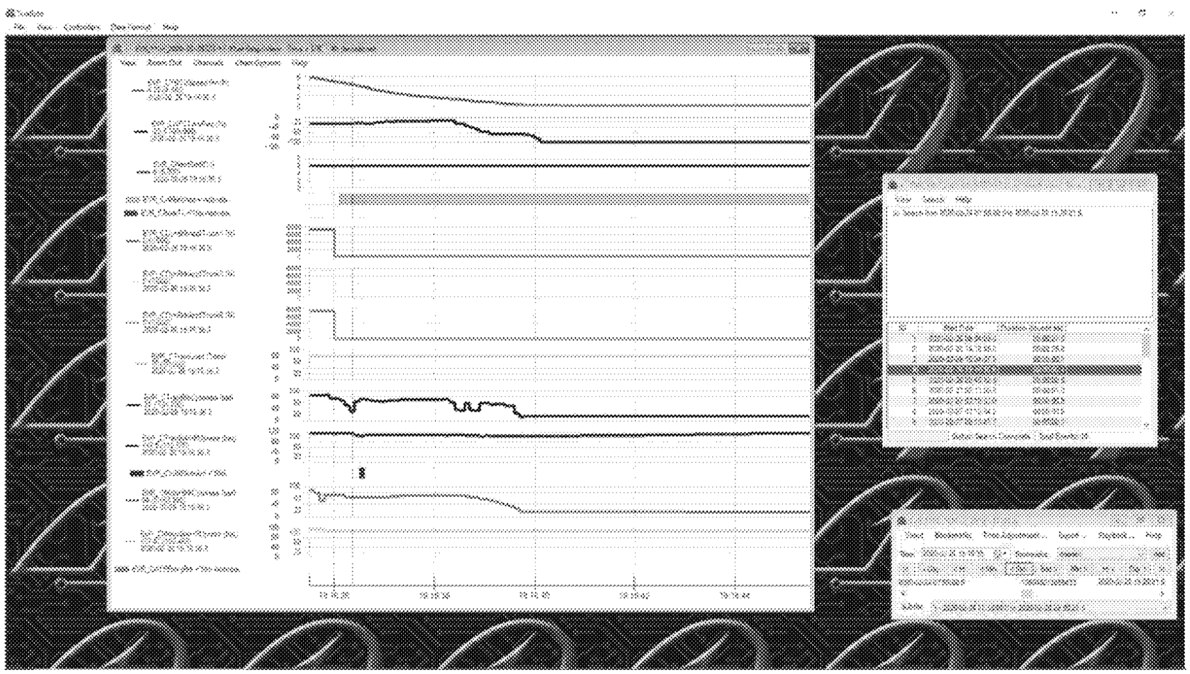


Figure 23 - Overshoot of cylinder pressure during station stop

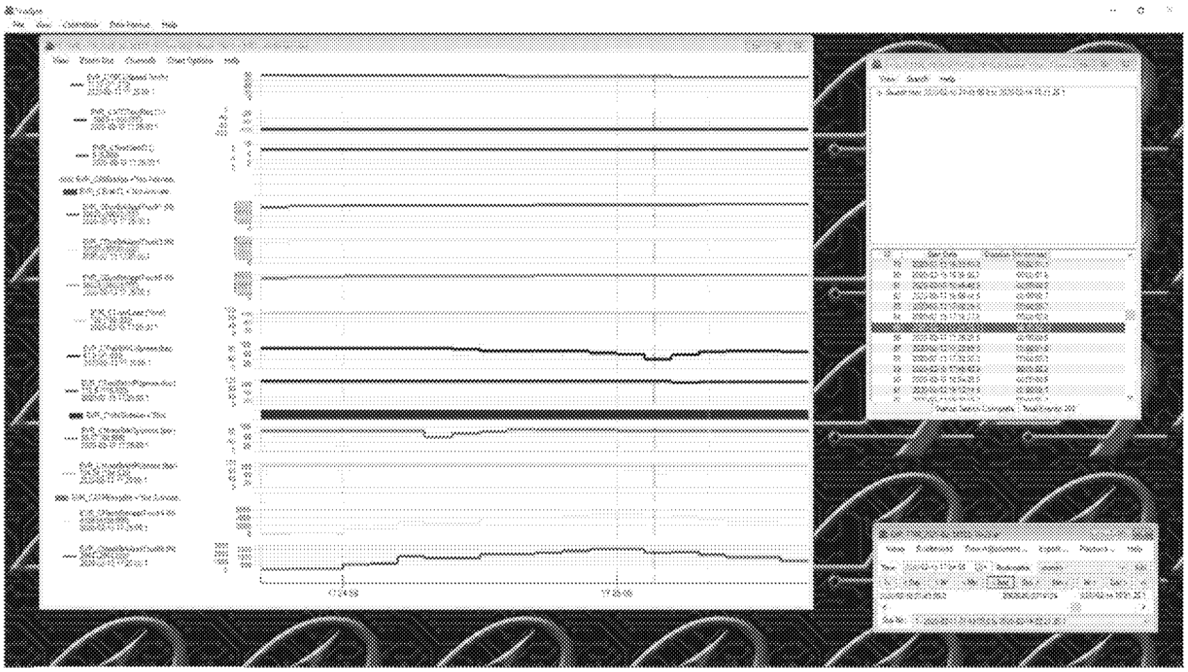


Figure 24 - Overshoot of brake pressure during blending

Because the motor car has only a single caliper, a zero hydraulic brake pressure during emergency will require an adhesion coefficient of 0.25 to prevent slide of the axle. For the trailer, the axle will require adhesion of 0.5 or higher, therefore a slide is guaranteed in any adhesion conditions (Figure 25) as long as the ambient temperature is low enough combined with other yet to be determined factors, to cause the brake malfunction.

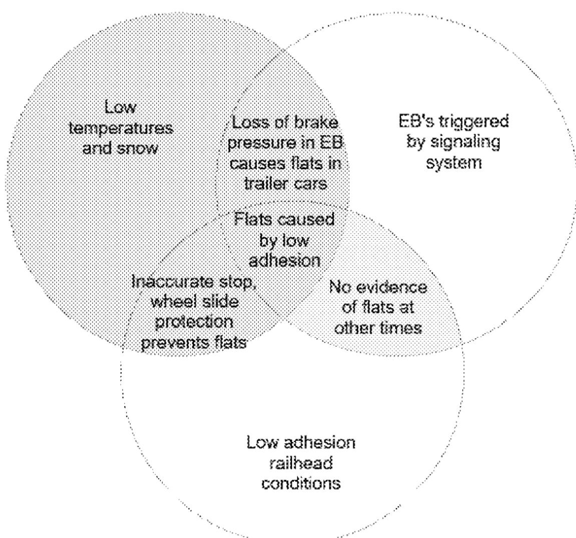


Figure 25 - Causes of flats on LRV

The following actions are necessary to eliminate this issue and ensure that it does not reoccur:

1. The cause is eliminated in the design of the HPU and that a thorough evaluation of any solution proposed by WABTEC takes place to ensure that it is consistent with the failure modes seen.
2. The brake software monitoring is improved to log a fault when the pressure is not maintained correctly during an emergency brake application.

7.3 Low adhesion by location

The low adhesion both causes EB's by preventing the train slowing to keep to the speed profile, it also causes flats during EB's for this reason or other reasons. Therefore, there is a considerable benefit in ensuring adhesion is consistent on the rails.

All braking data for LRV's available from the 10th to the 14th February was extracted from the EVR's into excel.

The point at which the dynamic brake started to slide was identified at each slide location. The load was then used to calculate the approximate adhesion at that point.

The location was calculated relative to the last station using odometry; this was cross-referenced for accuracy with the ATC section data when available. Each wheel slide and the calculated adhesion was plotted on a graph with the locations of the slide on the X axis (Figure 26)

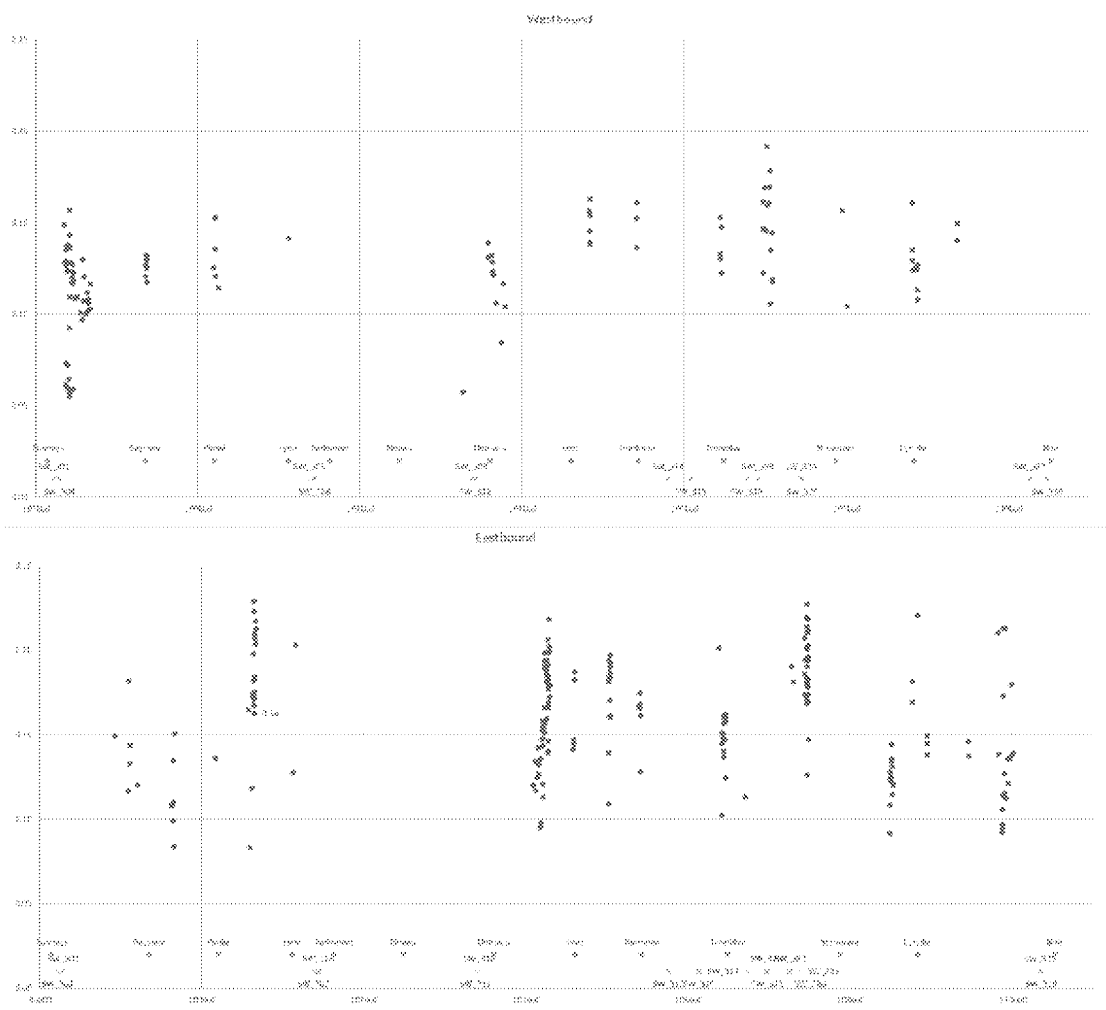
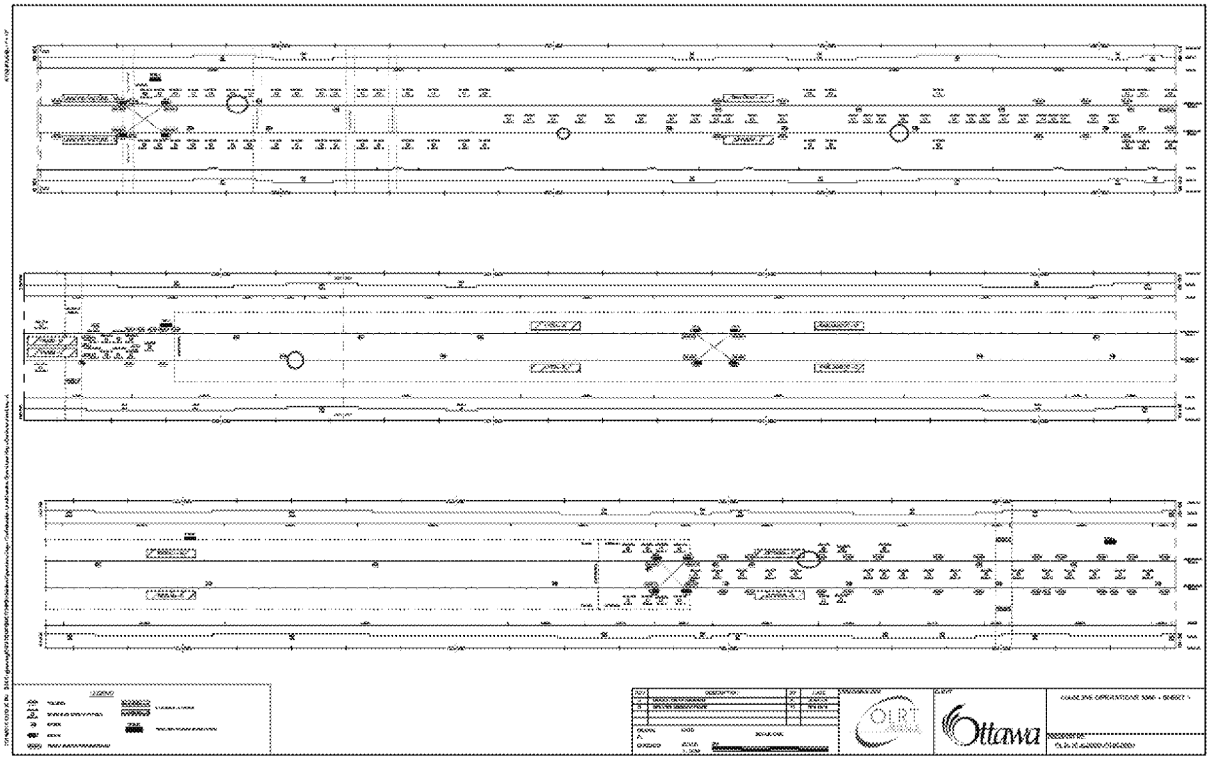


Figure 26 - Plots of wheel slide location against the chainage on the Confederation line in each direction

The locations were also highlighted on the line diagrams (Figure 27)



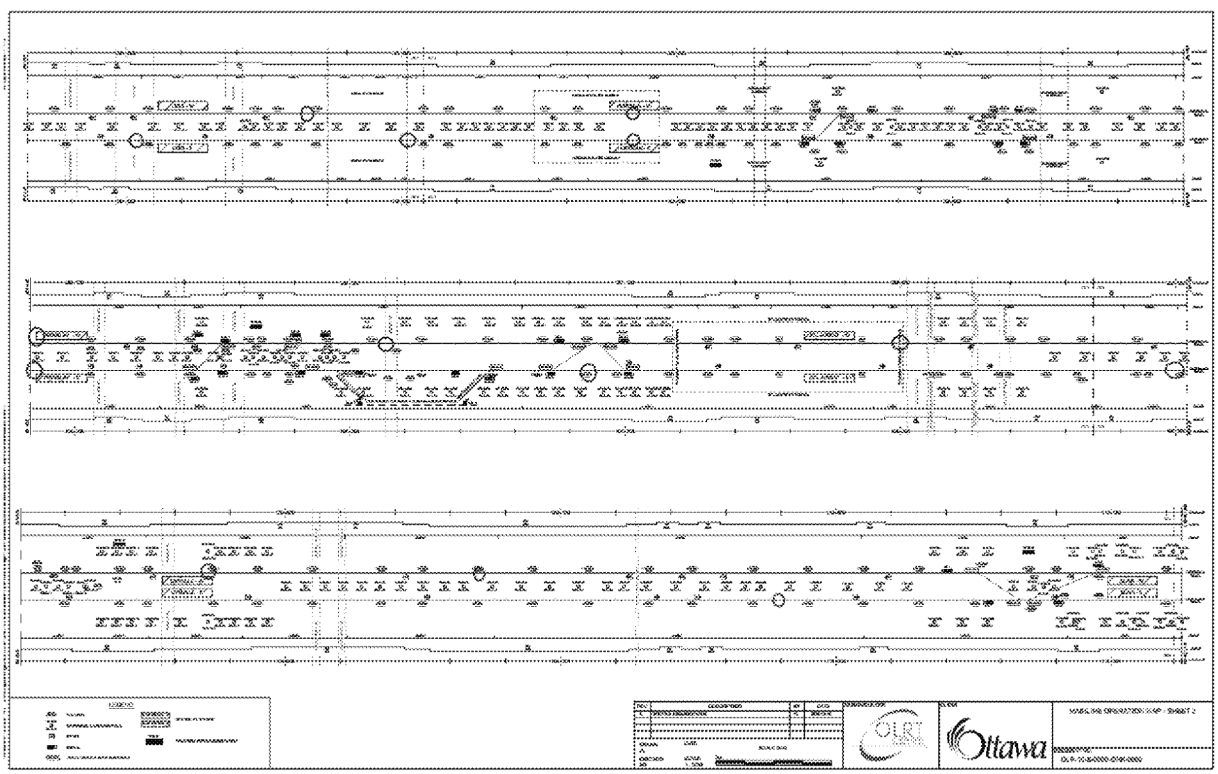


Figure 27 - Wheel slide locations marked on line diagrams for Confederation line

The data was given to RTM for evaluation of the worst slide locations for the following:

1. Railhead condition including porosity of the rail head, gauge, and wear.
2. General conditions of the line including sources of contamination and physical factors which may increase the risk of low adhesion.

It is intended to use a specialist consultant to attend these locations and assess the friction of the railhead and other conditions in May 2020.

7.4 Adhesion and weather

The EVR's supplied by Alstom seemed to cover times and cars which had experienced problems with flats. This gave limited ability to assess times when adhesion was good.

One of the worst periods for slide and flats occurred on the February 14th. This was partially caused by a signaling fault caused by tag damage which caused many EB's. The EVR's showed a high level of slide on the morning of the 14th. Note the weather report shows no snow that morning, though temperatures were very low overnight.

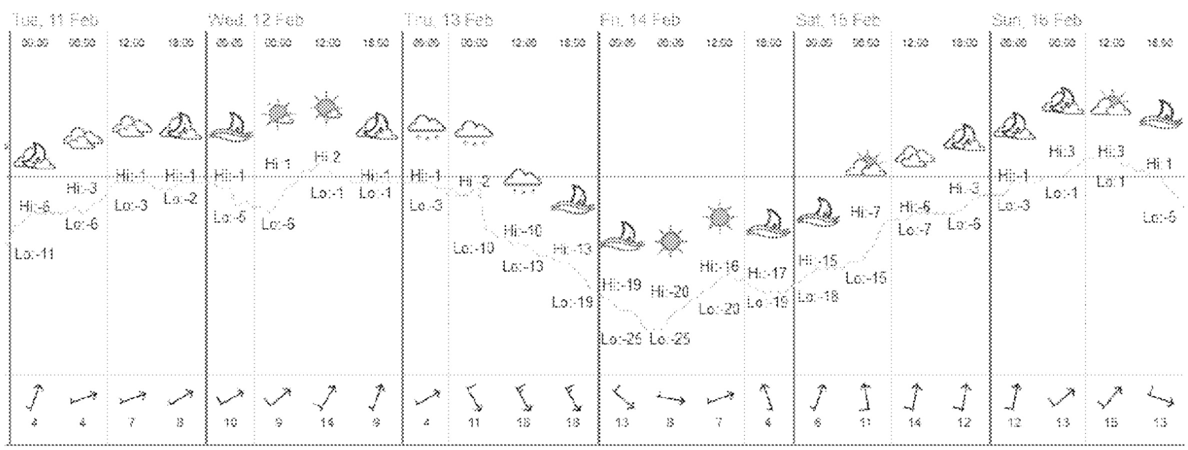


Figure 28 - Weather conditions from Feb 11 to 16, 2020

The data extracted from the EVR is selective and incomplete given the number and data range of the EVR downloads available. There is a strong correlation with the lowest temperatures occurring in the morning of the 14th, even before the fault with the signaling system occurring around 7am.

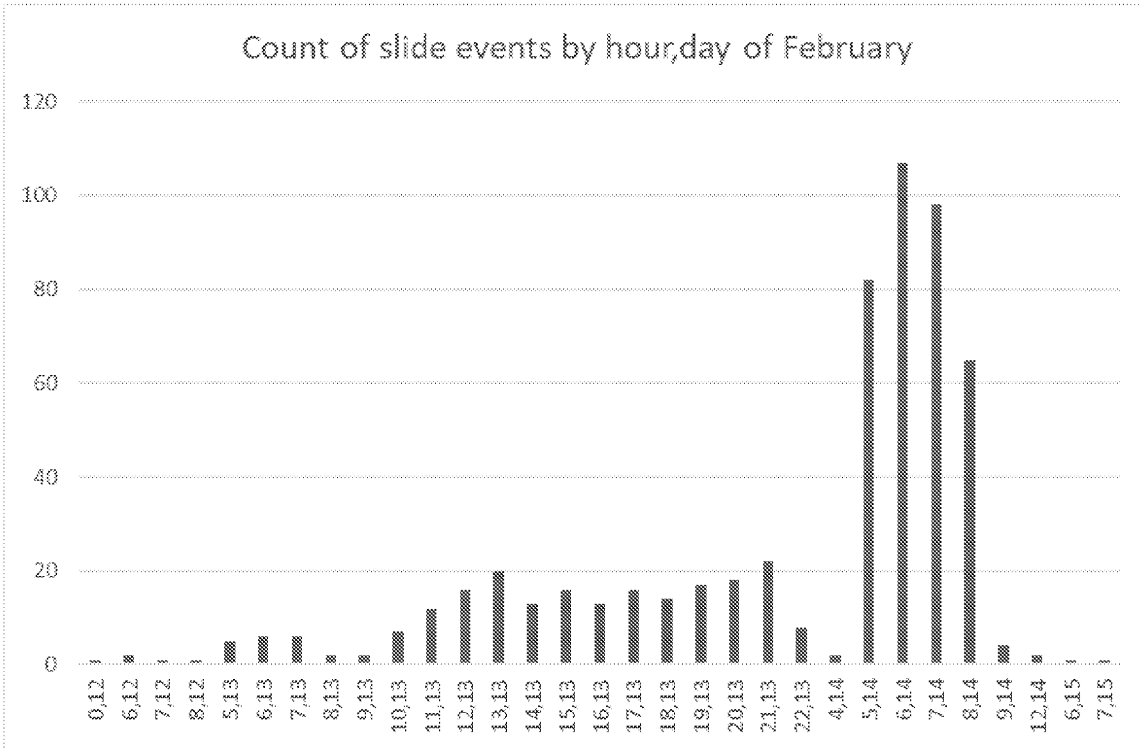


Figure 29 - Number of wheel slides reported from EVR sample by day/ hour, 12-15 Feb 2020

The snow conditions on the 13th did not cause large amounts of sliding during mild conditions and a relatively warm day and night on the 12/13th. The sliding seemed to increase with the snow and dropping temperatures on the 13th PM. There was no snow on the morning of the 14th though there was significant cumulative snowfall at the time.

A workable theory for how poor adhesion can occur in winter conditions is as follows:

1. Rail temperatures are substantially below zero; a reasonable threshold of -5 degrees appears to be significant which causes very rapid re-freezing of moisture on the rail.
2. Fresh or accumulated snowfall which lands on the railhead and refreezes when crushed by passing trains.
3. Infrastructure which exacerbates the effects of falling and cumulative snow:
    i. Cuttings or buildings which provide shade, preventing crusting of snow and allowing it to remain in powder state
    ii. Infrastructure which allows drifting of snow into pockets on the track or prevents snow blowing off the track.
    iii. Aerodynamic affects around the track which provide significant air disturbance to settled powder snow, blowing it up and onto the rail head with passing trains. This may happen on subsequent trains or trains on the adjacent track.

There were downloads from LRV7 and LRV26 which covered a relatively mild period between February 24th and February 27th, after which snow fell and temperatures fell. The weather in Ottawa tended to cycle in February 2020 between milder periods around freezing followed by precipitation and fast drops in temperature.

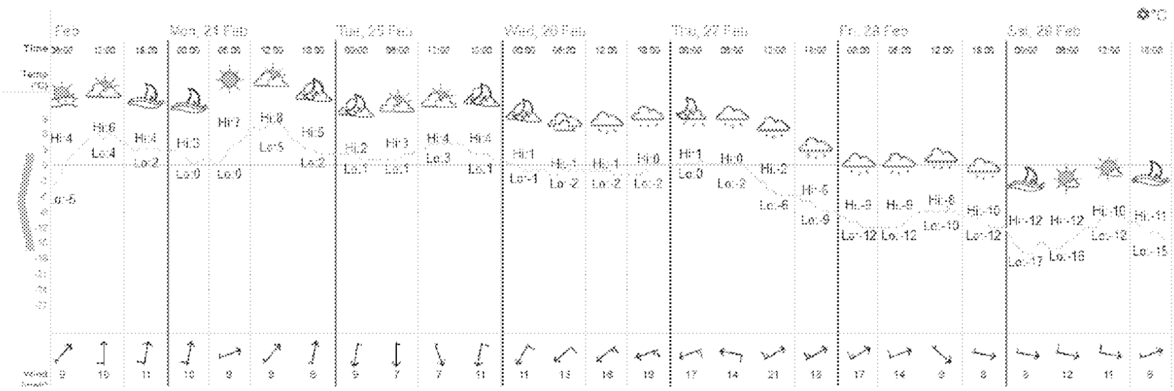


Figure 30 - Weather conditions 24-29 Feb 2020

The following EVR extract from LRV26 on the 25th February over a period of 8 hours shows no wheel slide activity for the first 7 hours of service that day; the red line is the sample time. (note EVR time is around 1 hour ahead of actual time). The X axis shows 1-hour intervals and the greed line is the speed of the train, indicating it was in service for that time.

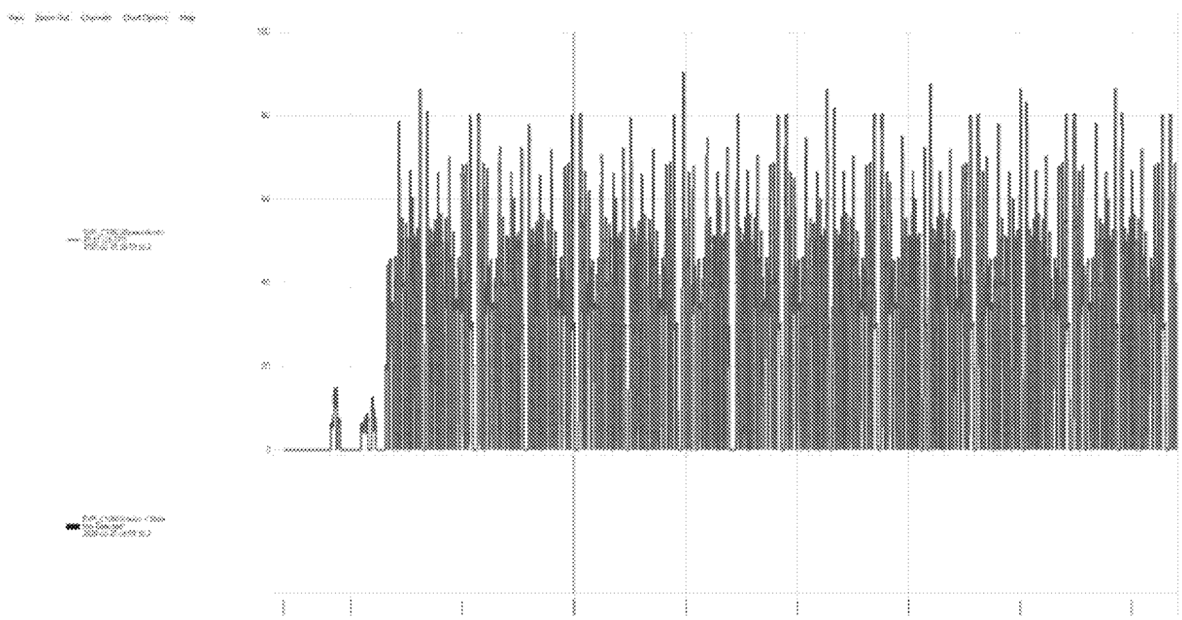


Figure 31 - No wheel slide activity LRV26 on Feb 25, 2020

The 26th saw a small amount of wheel slide activity although there was snow falling. The blue markers show incidences of wheel slide activity.

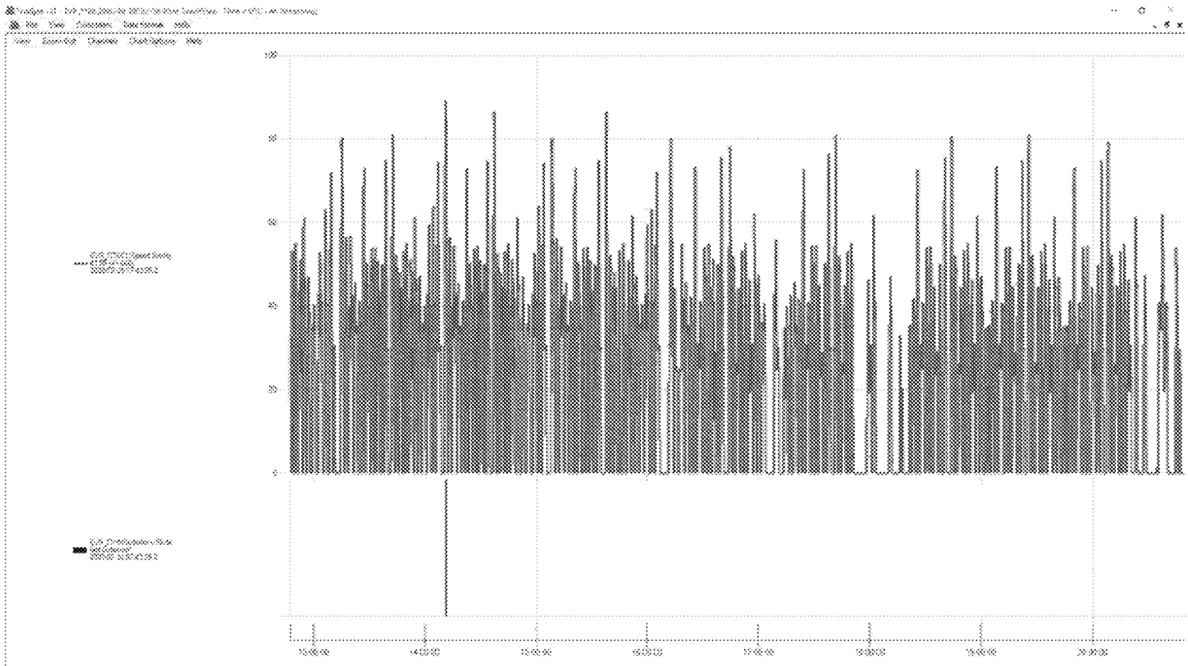


Figure 32 - Limited slide activity LRV26, Feb 26, 2020

The following evening on February 27th, significant wheel slide activity only commenced in the evening, as the temperature started to fall below -5 degrees C.

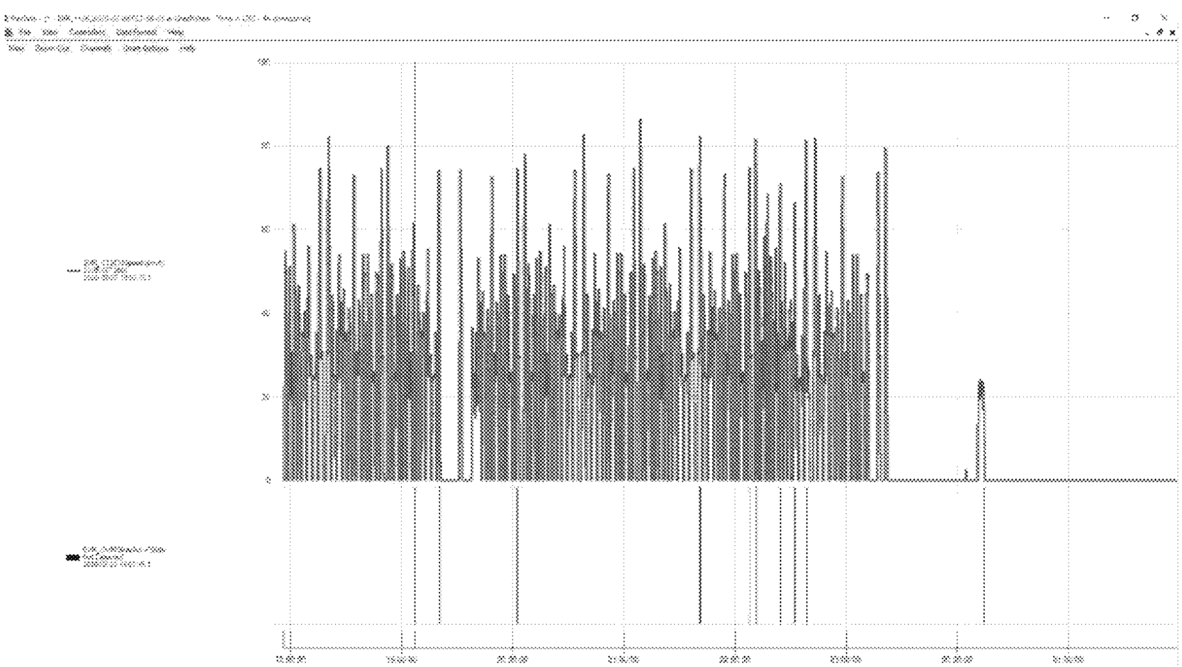


Figure 33 - Significant slide activity LRV26, Feb 27, 2020 PM

From Alstom's train tracer data collection system, the number of slide events (all cases) could be reviewed over the entire period of revenue service, and compared with the weather conditions (Figure 34)

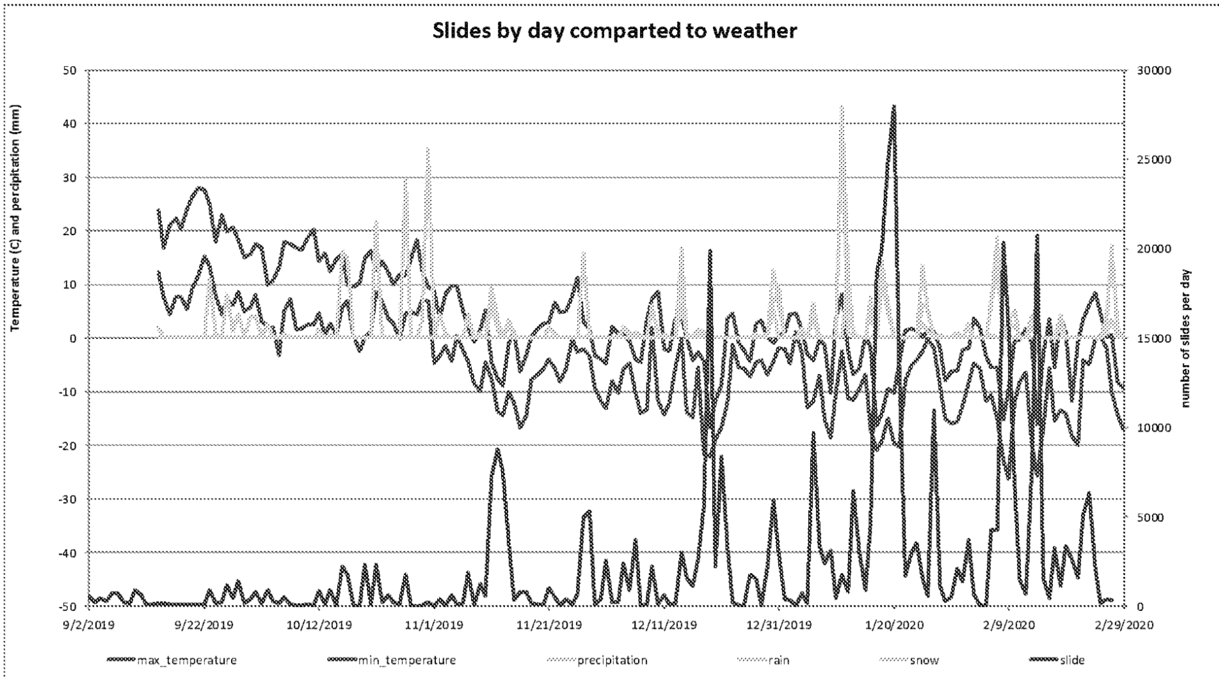


Figure 34 - Total slides and temperature

There is a clear correlation between very cold days and a high number of slides, especially when the weather station temperature is below -15 C. (note exact track conditions are impossible to determine)

7.5 EB rate

Alstom suggested reducing the emergency brake rate on the train from 2.29ms-2 to 1.79 ms-2 at speeds over 80km/h. As the Track brake gives deceleration of 0.5ms-2 in AW3 this will involve reducing the emergency brake to the same as the full-service brake. The brake force can be reduced by around 25% as a result.

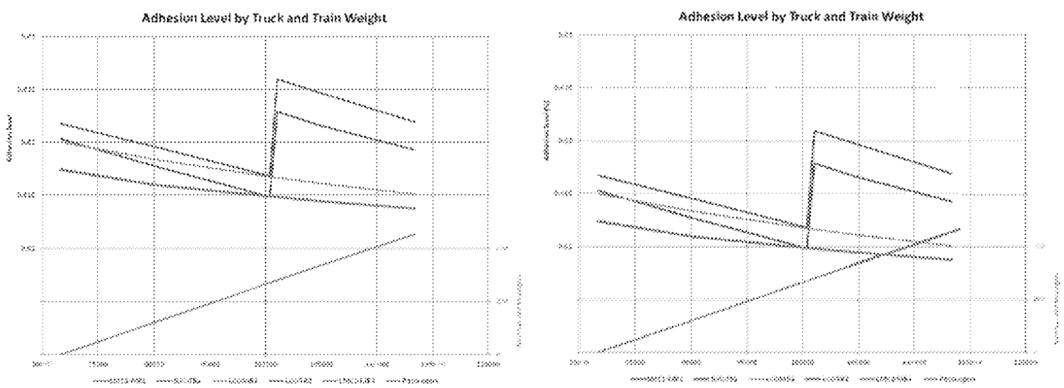


Figure 35 - Adhesion requirement before and after pro-rata brake effort reduction by 25%

The effect of doing this is to reduce all the truck adhesion requirement in weights up to AW2 to below the current lowest adhesion requirement at that weight level. If flats are being caused on the trailer car up to AW2 and not on the motor cars the brake change will be effective in preventing flats on trailer cars up to AW2 and reduce the risk at higher weights.

In weights greater than AW2 the adhesion will still be higher. Out of the 76 EB's examined by Alstom only 7 were at 100 tons or greater (Figure 36), and some of these appear to be braking at the lower rate, as shown by the trailer brake pressure being 40 bar or above (the load weighing for the trailer brake depends on the local truck loading does not exactly align with the overall train brake)

Date and Time	Cars in train	Active VOBC	Speed at onset (kp…	Effort demand at onset	Train weight	Cylinder pressure …	Cylinder pressure …	Summary
07/10/2019 07:12	Jan-28	28	58.6	-63.5	100	12.59	26.9	No slide
06/11/2019 08:19	Jan-33	1	58.4	-72.1	107	13.11	29.2	No slide
12/11/2019 15:37	Mar-19	19	26.5	0	100	15.35	36.7	Driven in atp-m
14/11/2019 16:09	Nov-14	14	68.1		104	10.7	45.9	Slide from 28 - 0
	Nov-14	14	67.4	-16.7	100	14.15	44.5	Slide from 29-0
02/12/2019 08:05	Nov-13	11	58.9	-67.1	109	10.5	30.2	No slide
02/12/2019 08:58	Nov-13	11	59.1	-54.9	106	10.18	30.1	No slide
17/01/2020 08:23	Dec-30	12	66.6	-100	102	[illegible]	45.1	Slide from 88 kph and -50% effort. effort may be variable on the exact load carried by LCC [illegible]
17/01/2020 08:42	Dec-30	12	2.4	12	103	[illegible]	32.7	[illegible] **Transient wheel slip for 1 second at start of brake but no slip after that**

Figure 36 - EB's at 100 tons car weight or greater

Alstom are confident that the GEBR is not affected by reducing the brake rate by this amount.

8 Conclusion

The cold weather in Ottawa has caused problems with adhesion and braking:

1. The GIDS system and ATC have caused too many emergency brake applications.
2. The brake system on certain cars does not always respond properly in very cold conditions causing severe flats. The extent of this problem is difficult to establish with the evidence available.
3. The adhesion on the track appears to be very low in persistent cold conditions (<-11 degrees C) when snow is present, either falling or settled.

Because the LRV has no wheel slide protection in emergency braking and a high brake rate there is always some inherent risk of wheel flats during emergency braking. As real emergencies are rare, and the maintenance facility has good wheel turning capacity, this should be sustainable.

The major causes of spurious EB's should be eliminated including:

- Necessary upgrades to the GIDS system:
  - Although the wheel flats task team were not involved with GIDS system directly, examination of the documentation indicates that the detection algorithm built into the sensor may be too simplistic to make a distinction between snowflakes, snow accumulation and persons.
- ATC software control leading to over speeds:
  - Roll out of the new ATC system software
- Improvement of the vehicle utilization of available adhesion in bad weather:
  - Once the major issues of the GIDS and ATC are resolved, vehicle braking performance in poor adhesion conditions will be the largest remaining cause of emergency brake applications, and therefore should be addressed to reduce the emergency brake frequency as low as practically possible

The problem with the hydraulic system has been recreated on bench testing and seems specific to cold conditions. A solution must be rolled out over summer 2020 to prevent serious flats winter 2020-2021

Effort will be expended into understanding the root cause of poor adhesion and working on relatively simple countermeasures for the coming winter. Further data studies of good and bad adhesion days and areas can give an understanding of the locations affected. Railhead treatment or other countermeasures can be developed with relatively few resources. For instance, "sandite" or rail deicer fluids can be trialed over the summer for other side effects.

It is by no means assured that all these problems will be resolved over the summer with the current Coronavirus pandemic. This could affect complex modifications, specification changes and testing.