A P T A   P A P E R

Baltimore LRV Case Study

Braking Functionality and Operator Vigilance System Improvements

MARYLAND DEPARTMENT OF TRANSPORTATION

MTA Maryland

Prepared jointly with the

Maryland Transit Administration

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OMNI STRATEGY, LLC.
Strategy | Planning | Execution

20 S. Charles Street, Suite 1103
Baltimore, MD 21201

ch2m

201 N. Charles Street
Suite 1201
Baltimore, MD 21201

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Authors:

Michael Wiedecker — Maryland Transit Administration
Director, Training and Development

Patrick S. Albright — Omni-Strategy, LLC
Senior Vehicle Engineer
(formerly: Maryland Transit Administration)
Chief of Equip. Engrg. and Rolling Stock

Glenn D. Gardner — CH2M Hill, Inc.
Senior Systems Engineer

1 Abstract

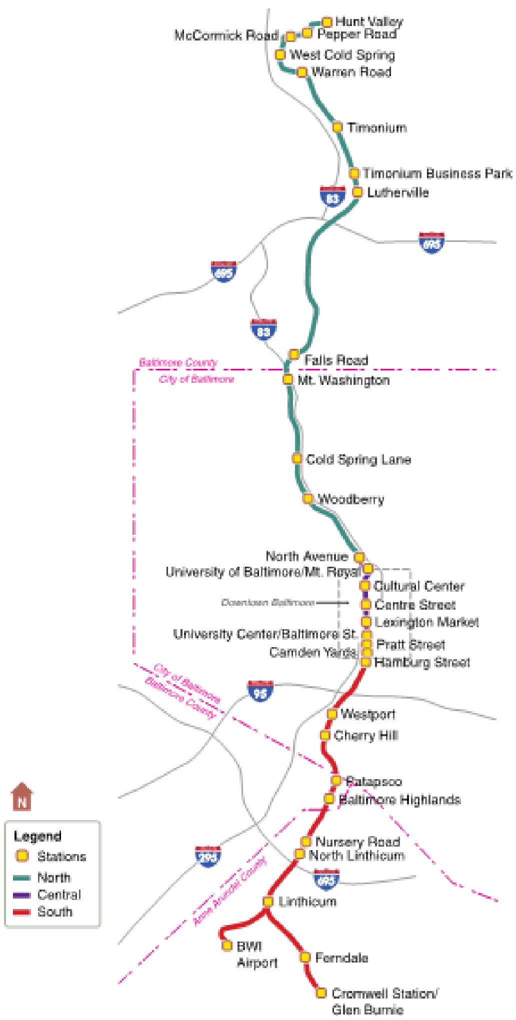
The Maryland Department of Transportation's (MDOT) Maryland Transit Administration (MTA) Light Rail, as with other rail transit properties, has faced operational demands throughout its 25-year history. This paper identifies some of the operational challenges encountered and a timeline of their responses. Various actions have been taken through the years to improve upon operational safety and reliability– mainly through the addition of equipment and changes to braking hardware and/or electrical control circuits. For all efforts described in this paper, the MTA Office of Safety, Quality Assurance, and Risk Management conducted System Safety Assessments before implementation. The paper also provides insights to the lessons learned as a result of this activity. Perceived advantages and/or disadvantages to each of the changes are conveyed as well.

The paper also provides a discussion of the latest equipment upgrades being installed as part of the LRV Overhaul Program and what they are anticipated to accomplish. The primary goals are to:

- Provide monitoring of the Operator's actions (or inactions).
- Ensure that the Guaranteed Emergency Brake Rate (GEBR) and associated stop distance are met when low wheel-to-rail adhesion levels are encountered.
- Maintain protection against wheel flats.

2 Background

2.1 Description of the Light Rail System



Baltimore City has a long history of operating rail transit vehicles along city streets, beginning with Baltimore City Transit PCC street cars in the 1950s. Light Rail opened for service for the Baltimore Orioles opening day on April 3, 1992 between Timonium and Camden Yard stations. The MDOT-MTA Light Rail system continues the tradition of serving Baltimore, Maryland, and its surrounding suburbs with transportation services that extend from Hunt Valley in Baltimore County, through Baltimore City's Central Business District (CBD), and on to Cromwell Station in Anne Arundel County. The system also includes service to Penn Station and Baltimore/Washington International Thurgood Marshall Airport (BWI Marshall Airport). The Central Light Rail Line, also called the mainline, consists of 29.5 miles of right-of-way and includes 33 passenger stations.

Most of the light rail's mainline is on a dedicated right-of-way, with 43 grade crossings equipped with crossing gates. However, on the CBD portion of the mainline that runs along Howard Street (between the University of Baltimore/Mt. Royal and Camden Yards stations), trains mix with automobile traffic and Light Rail Vehicle (LRV) movements are controlled by bar signals that are interfaced with the traffic signals. A transit signal priority system was implemented on this portion of the mainline, resulting in time savings of 25%.

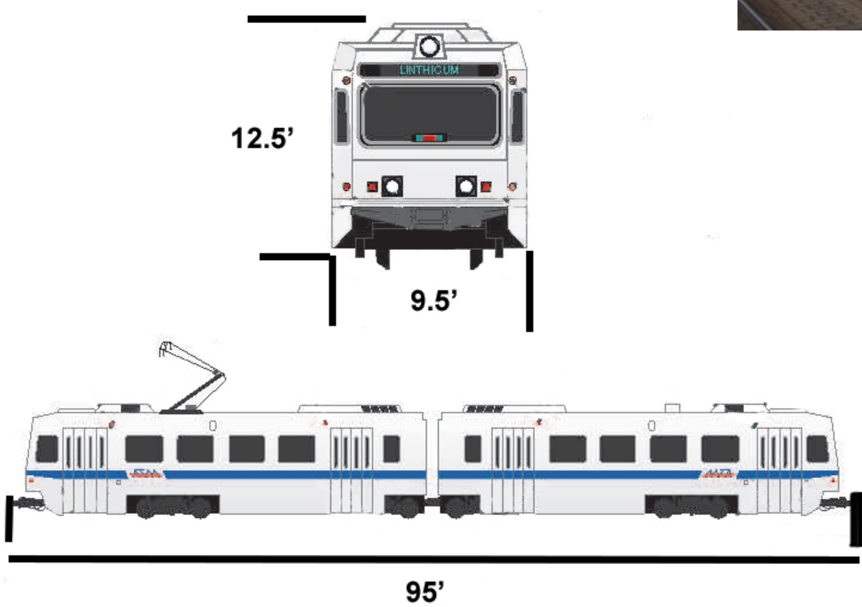
The space mean speed between Hunt Valley and BWI (based on a scheduled running time of 1 hr. 20 min. and a distance of 29.5 miles) is about 22 mph.

2.2 Description of the Rolling Stock

MDOT-MTA's Light Rail vehicles (LRVs) were built by ABB Traction, the U.S. division of Asea Brown Boveri. The original fleet of 35 LRVs was delivered between 1991–1993 as the system was being built.

Eighteen essentially identical LRVs where delivered from July 1997 to November 1998 while three extensions (Hunt Valley, Penn Station and BWI Marshall Airport) were constructed.

MDOT-MTA's LRVs are quite large—much larger than traditional streetcars and bigger even than those used on San Francisco's Muni Metro or Boston's Green Line. The LRVs are comprised of two articulated cars; measure 95 feet (29 m) long (over coupler faces), 9.5 feet (2.9 m) wide, and 12.5 feet (3.8 m) high with lowered pantographs. Each LRV can accommodate 84 seated passengers, 177 standing passengers and 260 passengers with a crush load (one person per square foot). These vehicles operate on standard 4 ft. 8 $^{1}/_{2}$ in. (1,435 mm) gauge track. One, two and three vehicle trains are routinely seen in service. LRVs are powered by an overhead catenary system and have a maximum speed of 60 miles per hour (97 km/h). When delivered, they were the first transit rail vehicles in the United States to employ A/C propulsion. Each LRV is powered by four 275 HP motors for a total of 1100 HP-- the center truck is unpowered.



The MDOT-MTA currently has 53 individual Light Rail vehicles. During typical weekday peak-time service, approximately 30 to 35 vehicles are required; a somewhat higher number of vehicles are put into service immediately after Orioles and Ravens games. For weekday service, as well as on days of events at the 1st Mariner Arena or the Baltimore Convention Center, trains going from Hunt Valley to Cromwell and BWI Airport are generally run with two-vehicle trains, while three-vehicle trains are put into service for Orioles games, Ravens games and major downtown events. Usually the Penn Station-Camden Yards shuttle is operated with one LRV.

There is a mid-life upgrade/overhaul of the light rail vehicles currently in progress involving testing, removal of all interior and exterior components-- and replacement with new propulsion control and door systems among other upgrades.

2.3 Head-End and Local Controls (1992 until 2017 Mid-Life Overhaul)

Normal LRV movement is controlled by a Master Controller handle that is connected to a computerized control unit known as TRACS which communicates the Operator's requests to the TRACS units throughout the consist. The TRACS unit coordinates local Propulsion and Friction Brake control commands based on the Operator's request(s), movement interlocks, and status indications for its specific LRV. TRACS provides automatic conventional wheel slip-slide correction control during full service braking.

There is an independent trainlined control circuit for emergency braking (friction brake + track brake + sanding). Conventional wheel slip-slide correction control is disabled during an emergency brake application.

Other than the use of wayside emergency trip stop equipment placed in strategic locations throughout the Light Rail system, a Deadman feature built into the Master Controller handle, and an Overspeed feature, there are no other train performance or Operator monitoring safety enhancing features. Safe movement of the LRV relied solely upon the Operator and his/her line of site. Additional safety enhancing features were added through the years.

3 Operational Issues

3.1 Deadman Feature (disabled in 1993)

The Deadman feature consists of an electric switch and a spring-loaded telescoping extension of the Master Controller handle. The telescoping extension causes the electric switch to "make" and "break" its electrical contacts based on the extension's position when depressed or released. The handle must be in its "depressed" state in order for the vehicle to follow control requests signaled by the Master Controller. If the handle is in its "released" position for a period exceeding five (5) seconds, a Full Service brake application (Service Brake with Wheel Slip-Slide Correction) is automatically requested until the train comes to a stop.

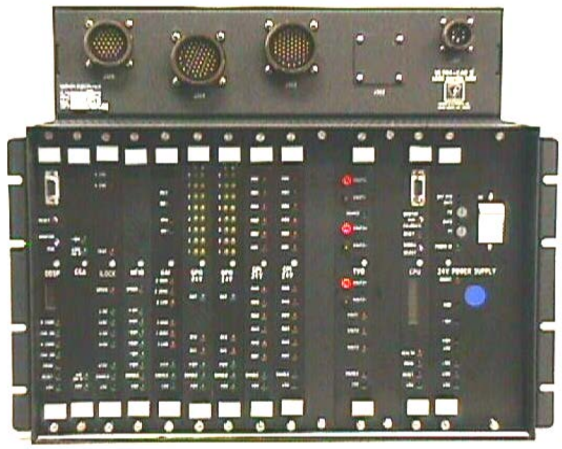
The problem is that the spring load requires significant force to keep the handle depressed-- tiring the Operator's hand and arm. As a result, nuisance stops and complaints were encountered due to the fatigue of the Operators.

The cost-effective means of solving the issue was to disable the Deadman feature by installing revised TRACS control software. In this way, the feature could be re-enabled easily, if necessary.

3.2 Removed Truck Mounted Lubricators (1996)

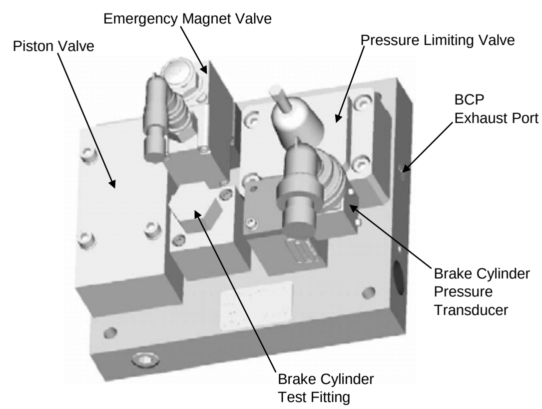
The original truck mounted wheel lubricators were difficult to maintain and were not that effective. It was decided that the Light Rail Maintenance of Way (MOW) department would begin lubricating the rail. Therefore, the truck mounted wheel lubricators where removed from all LRVs.

3.3 Automatic Train Protection (ATP) added in 2001- 2002



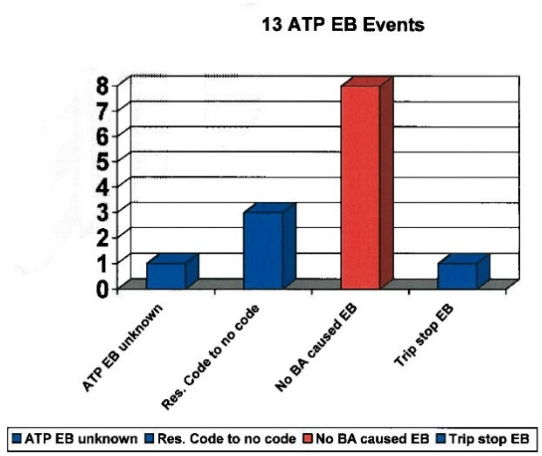
With the implementation of the Double Track project and a few accidents on the mainline, the MDOT-MTA decided to add Automatic Train Protection (ATP). ATP provides a more comprehensive monitoring of vehicle speed to ensure train separation. ATP applies full service braking when an overspeed condition occurs. If the LRV does not achieve the brake assurance rate (minimum 1.5 mphps) within 3 seconds after the full service brake application, the ATP then applies emergency braking until the LRV is stopped for at least 3 seconds and the Master Controller is in the full service brake position. The advantage to applying the emergency brakes, is that track brake is introduced automatically due to the emergency brake request. A disadvantage to this approach is that wheel slip-slide correction control is disabled during an emergency brake application.

An independent means (ATP Emergency Magnet Valve - EMV) for the ATP to request an emergency brake application was also added which involved the use of a trainline wire and the addition of independent brake valves for each Motor Truck (ATP-EMV). This approach was Option No. 1 of two options that were presented. Although Option No. 2 may have been the preferred option, it was a little more than twice the cost to implement. Option No. 1 applies emergency brake without allowing adjustment for passenger load. A crush-loaded (AW3) vehicle was assumed. Option No. 2 would have kept automatic load-weigh active based on the passenger loads for each powered truck.



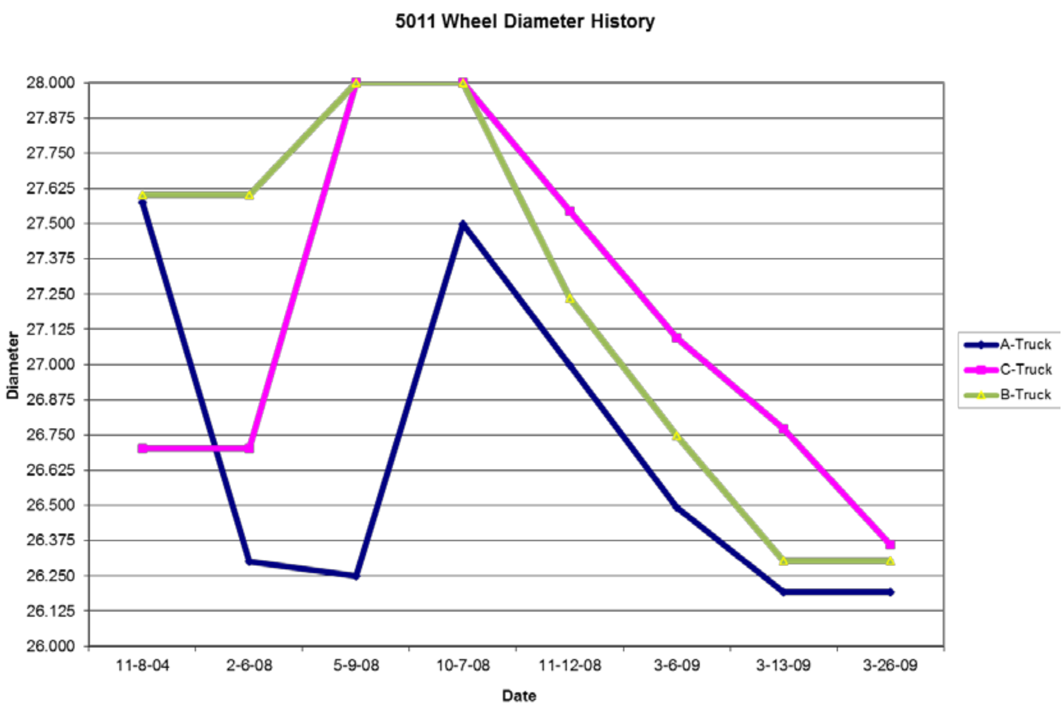
Although Option No. 1 had an increased possibility of generating wheel flats, the assurance that the necessary LRV safe braking distance would be met was considered to be a fair tradeoff. But as time marched forward, the frequent instances of ATP emergency brake application caused wheel flats that ultimately led to a wheel tire fracture. The tire fracture initiated an earnest investigation in 2008 into the cause of the wheel flats. The MDOT-MTA changed the allowable condemning limit dimension of the wheel diameter from 26.0 to 26.125 inches in order to mitigate the tire fractures

3.4 Automatic Train Protection (ATP) Control Mods in 2008 thru 2010



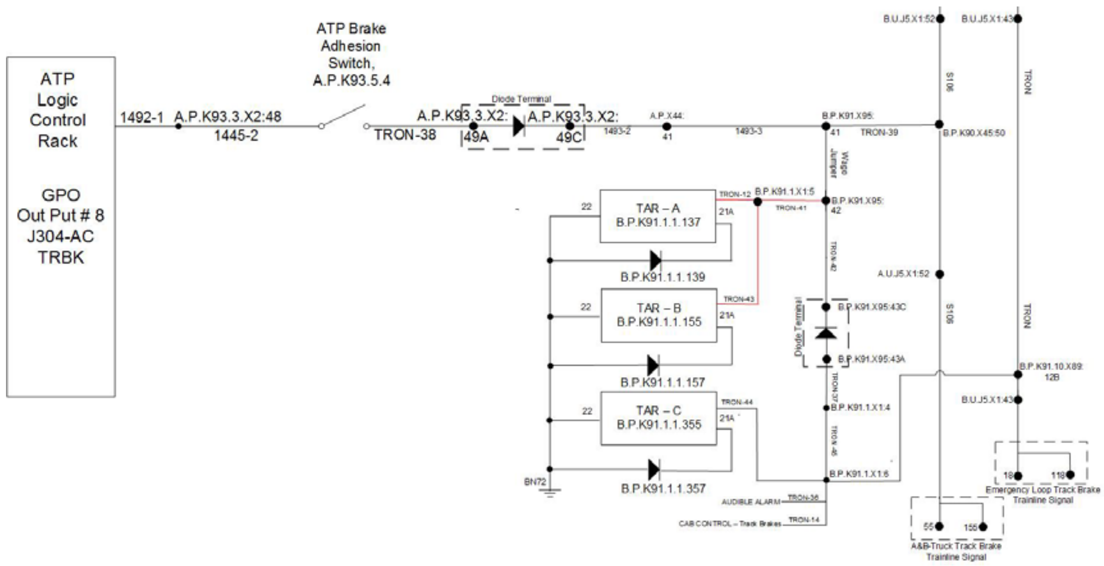
The wheel truing machine at the Light Rail, Rail Car Maintenance shop experienced a significant increase in utilization. LRVs were experiencing wheel flats on a frequent and regular basis. In fact, there were so many trucks that required wheel truing that Light Rail transported some of their trucks 7.5 miles to the Metro Rail Car Maintenance shop to be trued. In 2008, serious scrutiny of the LRV's operation identified the key issue to be the inability of the LRV to maintain the minimum 1.50 mphps brake rate expected when full service brake (w/wheel slip-slide correction control active) is applied following an ATP overspeed condition. As a result, the ATP system applied emergency braking which included the activation of the independent ATP-EMV. The application of emergency braking resulted in wheel flats during low wheel-to-rail adhesion (i.e. below 7%) conditions encountered during light misty rain, early morning dew, and leaf season.

The graph below illustrates how often LRV tires had to be trued due to flats. From October 2008 thru March 2009, LRV 5011 powered trucks (A and B trucks) where trued three times and the non-powered (center C-truck) had been trued four times. This means the twelve LRV tires only lasted five months. With the requirement of extensive wheel truing, and to maintain fleet availability, Light Rail transported truck assembles to the Metro Rail Car shop to be trued. This issue was fleet wide and had to be addressed.

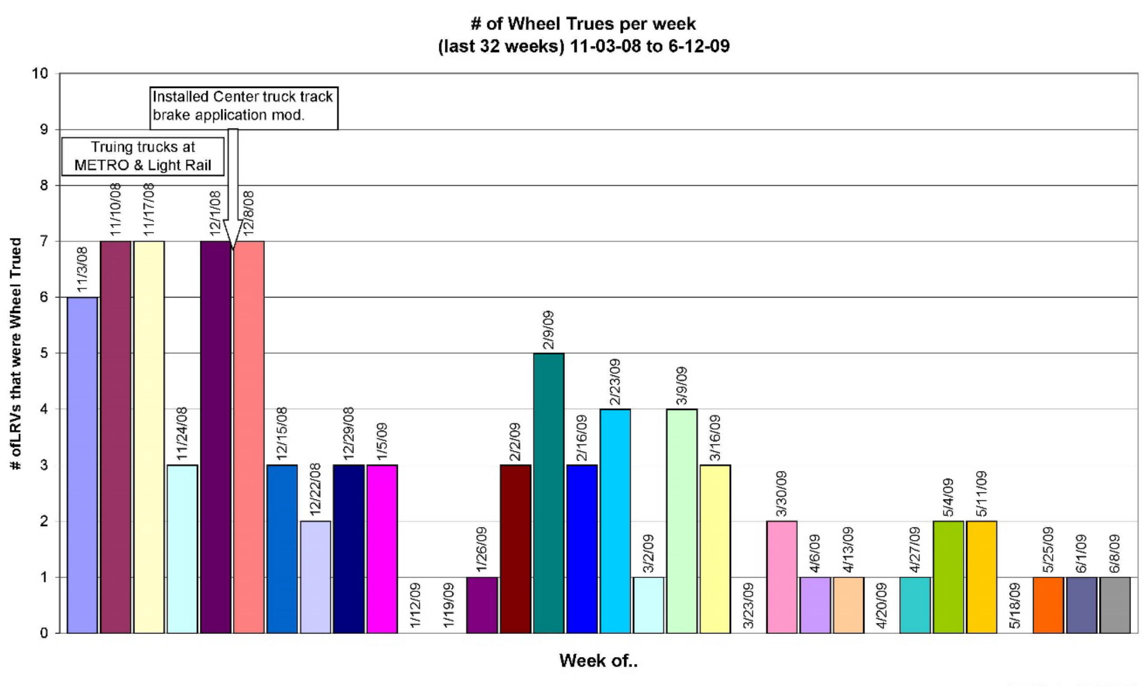


In an effort to assist the LRV in maintaining the minimum 1.50 mphps brake rate, it was established that the application of at least one set of track brakes during the initial ATP overspeed full service brake application would likely mitigate the ATP emergency brake applications. With the application of track brakes, the minimum brake rate of 1.50 mphps would likely be achieved during the low availability of wheel-to-rail adhesion.

A track brake control circuit was developed in November 2008. This circuit simultaneously energized the set of track brakes on the center truck (C-truck) whenever ATP detected an overspeed condition. By January 2009, it was decided to energize the B-truck (powered truck) track brakes rather than the C-truck and to delay track brake energization for one second while determining achieved deceleration. By March 2010, it was decided to energize each set of track brakes on the two powered trucks (A-Truck and B-Truck). The circuit applies A and B truck track brakes on all LRVs in the consist whenever the Lead LRV's ATP system initiates a full service brake application or an over speed enforcement is active for longer than one (1) second (time delay is controlled by the ATP Software) and the Light Rail Vehicle's deceleration rate is less than 2.5 mphps (as monitored by the ATP Software). A switch was also added to the circuit to "enable" and "disable" the activation of track brakes by the ATP system-- depending on the seasons.



The effect of the control circuit change was significant as depicted in the histogram below. The number of vehicles developing wheel flats decreased by more than 50% from 7 vehicles per week to 3 vehicles per week and ultimately to one (1) vehicle per week approaching summertime.



3.5 Training Light Rail Operators to Anticipate Speed Reductions (2009)

In January 2009, MTA Light Rail initiated a training program to remind LRV Operators to reduce the speed of the LRV to match the approaching cab code change. Based on their experience, LRV Operators knew where ATP cab codes would decrease in speed along the mainline. By anticipating these speed reductions and slowing the LRV speed, the LRV Operators significantly assisted in reducing the number of times an ATP overspeed condition occurred which, in turn, reduced the number of times the ATP system could possibly apply emergency braking due to the train neither achieving nor maintaining the required minimum 1.5 mphps brake rate.

3.6 LRV Sanding Mitigation Efforts (addressed in 2009)

Also addressed were other identified causes for wheel flats which were attributed to the location of the sand tubes on the trucks and to wayside/track issues involving the greasing of curves/etc. and speed code equipment. In the case of the location of the sanding tubes on the trucks, efforts were made to reduce the original distance of the tube from the wheel-to-rail interface of 12 inches.

3.7 Track/Wayside Issues Pertaining to Wheel Flats (addressed in 2009)

Based on a study of wheel flat occurrences, three mainline locations were identified as significant offenders. They were:

- Chain Marker 397 North, Falls Road
- Chain Marker 711 North, Texas Road
- Chain Marker 373 South, Camp Meade Junction

Inspections of these track areas and tests of their track signals highlighted the following issues that were then checked throughout the system,

- Rail lubrication grease and crushed leaves on rail head for an extended distance.
- LRV receives cab code for Restricted 8 mph to NO CODE when in a normal 30 mph code area-- causing an immediate Emergency Brake application.
- Missing or Incorrect cab code signals.
    - Repairs of the various cab code signals identified the causes to be frequency shift and failures of the R11 resistor on the 700 Amplifier Modules.

Wayside maintenance employees and MTA track maintenance practices/procedures were evaluated and revised where necessary in an effort to ensure that the application of grease, along with the correct type of grease, is made in the appropriate places and amounts and at appropriate time intervals.

Top-of-Rail (TOR) friction modifiers have been used from time-to-time with varied results-- primarily positive. The cost of material and its application seems to outweigh the benefits recognized.

3.8 MOW VAC Truck Modified to Clean Top-of-Rail in 2009

In addition to LRV ATP control circuits, training, sanding and wayside lubrication, Light Rail also modified their MOW VAC Truck to clean the top-of-rail with high pressure water.

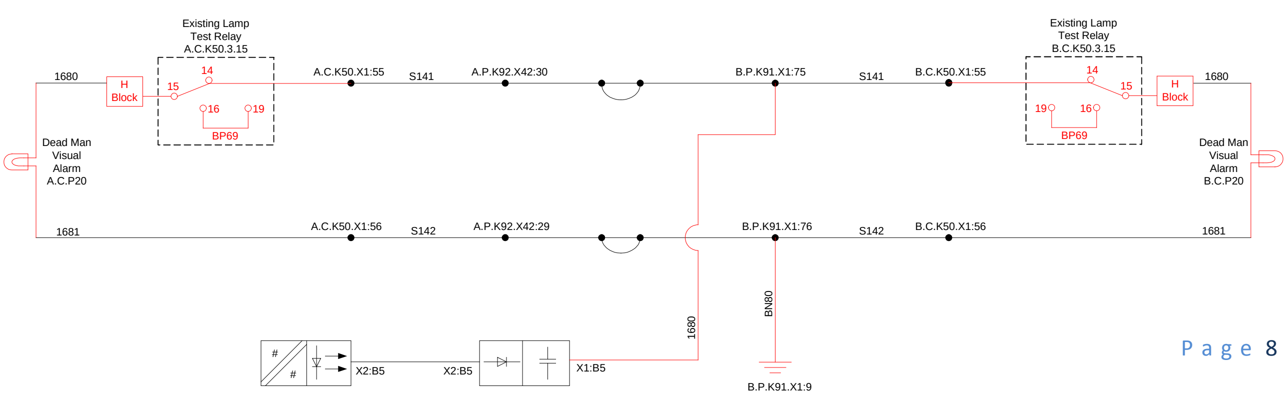
Some areas with dense foliage identified as having high wheel slip-slide potential are,

- Chain Marker 754 North, Recycle Way Gate Crossing
- Chain Marker 658 North, Timonium Fair Grounds
- Chain Marker 357 North, Falls Road Gate Crossing
- Chain Markers 184 thru 235 North, Woodberry Station to Cold Spring Station
- Chain Marker 189 South, Patapsco Road TPS

During the "leaf season" MOW personnel would clean the top-of-rail to remove leaf residue. This effort enhanced wheel-to-rail adhesion.

3.9 Deadman Feature (re-enabled and modified in 2009)

Precipitated by an accident, the original Deadman feature was re-enabled but included modifications to the TRACS software and to Operator Indicator circuits so that the operator is required to momentarily release and re-depress the Deadman every 20 seconds. If the operator fails to release the Deadman every 20 seconds or if the operator does not re-depress the Deadman within 5 seconds after the blinking of the added blue light to the console starts, the LRV executes an irrecoverable Full Service brake application. In this way, the LRV Operator must remain vigilant and also has the opportunity to rest his hand and arm at periodic intervals.

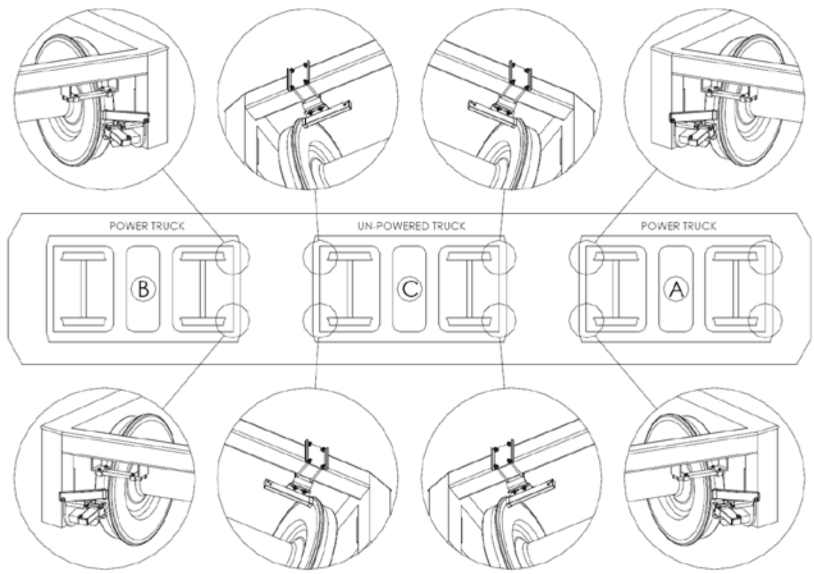


3.10 Reinstall Truck Mounted Lubricators & Install Traction Enhancers (2010)

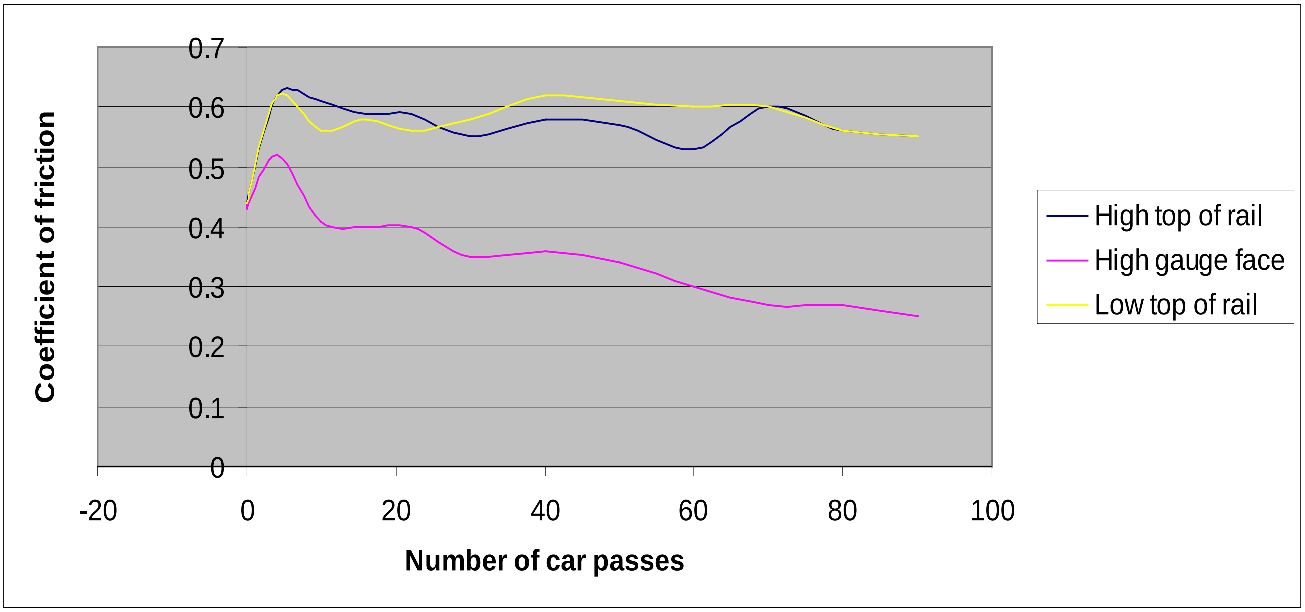
In October 2010, Zeta Tech performed a lubrication test of an on-board truck mounted lubricator. The evaluation procedure was as follows:

1. One LRV (number 5011) was equipped with both the Low Coefficient of Friction (LCF) and High Positive Friction (HPF) solid stick materials. LCF was used to reduce the friction coefficient between the wheel flange and rail gauge. LCF lubricant was also applied to the back-of-flange (BOF). HPF optimizes friction levels between the wheel tread surface and top of rail. The LCF and HPF solid stick materials were used to perform the test. A curved section of track in the Cromwell Yard area was chosen to run the following test.

    a. The curve was measured for coefficient of friction at several locations using a tribometer prior to any traffic being on it.
    b. The LRV was then run through the curve 4 times and the coefficient of friction was again measured using a tribometer.
    c. This procedure was repeated until sufficient lubrication (both top of rail as well as gauge face) had accumulated on the rail to stabilize the coefficient of friction.



The photo below shows the top-of-rail and gauge face of the high rail after 30 runs of the test LRV. The top of rail has several bands of friction modifier transferred from the wheel tread, and the gauge face shows a dark coloration of LCF material transferred from the wheel flange.



From the graph of test runs versus coefficient of Friction the following was determined:

1. The initial dry rail coefficient of friction for both the top-of-rail as well as the gauge face was measured and found to be 0.44 percent. (There may have been a residual amount of degreaser still on the rail which would have brought the coefficient of friction to this lower level).
2. The final top-of-rail coefficient of friction for both the high and low rails tended to be higher at 0.55 percent.
3. The graph indicates that the top-of-rail coefficient of friction was reached and tended to level off after 20 runs of the test LRV.
4. The high rail gauge face coefficient of friction shows a leveling off at between 0.25 – 0.27 percent.
5. The final gauge face coefficient of friction took much longer and many more runs before it stabilized. As indicated by the graph, the gauge face coefficient of friction didn't become less than 0.3 percent until after the 60th test run.

Implementation

It can be seen in the table that only 41% of the fleet would need to be equipped with LCF and HPF materials to stabilize the coefficient of friction in the Central Business District.

However, without a dedicated fleet on all the other lines, it may be possible to send all unequipped LRVs over a particular line for a day which could effectively remove all LCF and HPF material that is on the rail.

Location	Number of Round Trips Per Day	% of fleet to be Equipped
CBD	145	41%
BWI	50	100%
Cromwell	50	100%
Timonium	25	100%
Hunt Valley	75	80%
Average		**84%**

After testing, it was determined that more than half of the LRV fleet would need to be equipped to mitigate this possibility. The analysis shows that a minimum of 84% of the LRV fleet would need to be equipped in order to ensure complete coverage and to bring the coefficient of friction in all areas to equilibrium.

It was decided to install truck mounted lubricators on all 53 LRVs. As of the writing of this paper, all LRVs remain equipped with functioning truck mounted lubricators.

4 Mid-Life Overhaul (2017 - Performance Testing)

4.1 Equipment / Functional Upgrades and Associated Goals

As the various subsections in Section 3 indicate, methods for achieving a better braking performance through an enhancement to the available wheel-to-rail adhesion, improving monitoring of the Operator's actions, and reducing wheel flats serve to improve daily operation, maintenance, and safety. The following equipment / functional changes were established with specific goals in mind,

1) Replace the "Deadman" feature discussed in Section 3.9 with a more Operator friendly computerized vigilance system that monitors multiple actions associated with the Operator's control of the vehicle and that also requires a specific acknowledgement action by the Operator on a time-dependent periodic basis. Add an independent relay inserted into the original Emergency Brake loop trainline circuit to automatically request an Emergency Brake application in the event the cognizance of the Operator is in question.

   The goals of such a system are to provide a more ergonomic method for the Operator to directly indicate cognizance; to improve safety by monitoring multiple control elements as verification of Operator cognizance; and to record Operator activity for use during investigations into undesired operational events to better understand the state that the train was exhibiting at the time.

2) Replace the independent trainlined method discussed in Section 3.3 for the ATP to automatically request an emergency brake application using the ATP Emergency Magnet Valves – EMV on each of the Power Trucks with an independent relay inserted into the original Emergency Brake loop trainline circuit. Remove the ATP Emergency Magnet Valves – EMVs.

   The goal is to utilize a load-compensated brake application, rather than a brake application which assumes a fully-loaded vehicle, in order to reduce the likelihood of damaging wheel flats while maintaining the inherent safety element of such an arrangement.

3) Add an additional Brake Control Unit (BCU) and associated Electronic Control Unit (ECU) so that each Power Truck may be controlled independently to keep from demanding more wheel-to-rail adhesion than necessary. In essence, Option 2 discussed in Section 3.3 is to be implemented.

   The goals are to reduce the likelihood of experiencing wheel slip-slide activity which tends to increase stopping distance due to the reduced braking tractive effort ultimately achieved, and to improve safety by reducing the likelihood of losing friction braking on more than one truck in the event of a malfunction / failure.

4) Replace the "on/off" wheel slip-slide control valves with "on/hold/off" valves. Also replace the associated wheel slip-slide correction control software to properly control the new valves. In this way, the original "conventional" wheel slip-slide system is replaced by an "aggressive" wheel slip-slide system controlled by the Friction Brake system rather than by the main vehicle control unit (VCU).

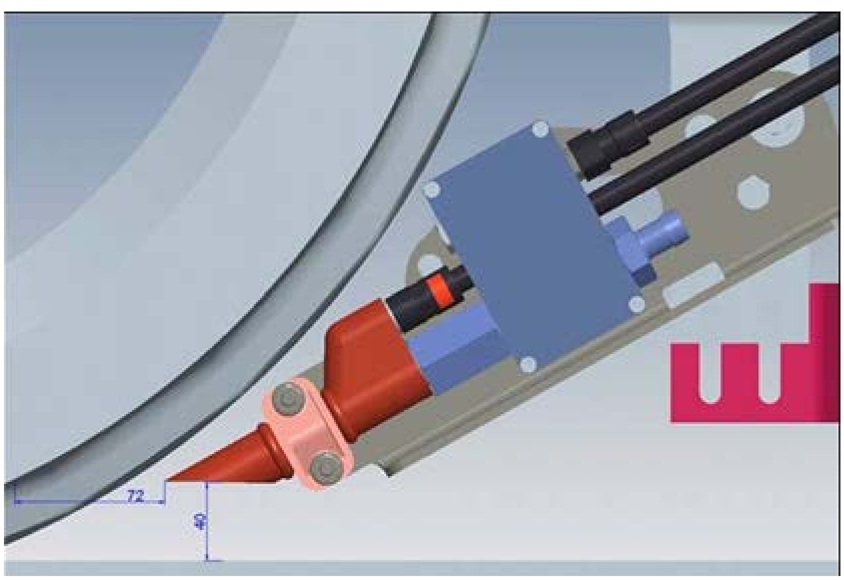
The goal is to significantly improve the available wheel-to-rail adhesion by the wheel slip-slide activity without relying on either the TOR friction modifiers discussed in Sections 3.6 and 3.7 or the traction enhancing materials discussed in Section 3.10. In this way, stop distance can be reduced by achieving a higher brake rate which also serves to improve the ATP Overspeed correction issues discussed in Section 3.3 without ultimately resulting in an Emergency Brake application.

5) Replace the "conventional" wheel slip-slide correction control software logic of the Dynamic Brake system with "aggressive" software logic to match that of the upgraded Friction Brake system. In this way, the original "conventional" wheel slip-slide system is replaced by an "aggressive" wheel slip-slide system controlled by the Dynamic Brake system rather than by the main vehicle control unit (TRACS). The new main vehicle control unit (TCMS) serves to monitor and coordinate the wheel slip-slide handoff between Dynamic Brake and Friction Brake rather than to perform the wheel slip-slide correction itself.

   The goal is the same as that provided in No. 4 above.

6) Replace the original sanding "on/off" sanding control valves with "regulated" sanding control valves. Also add software logic to appropriately control the new valves in a manner that makes the sanding system behave in an "intelligent" manner-- using vehicle speed and the amount of reduced tractive effort to regulate the flow / quantity of sand to the rail. The limited use of Main Reservoir air pressure is added to help mitigate the clumping of sand in the sandbox by driving moisture away from the granules.

   The goal is to improve the reliability of sand availability and flow while also improving the performance of the sand deposit by dropping it closer to the wheel-to-rail interface as discussed in Section 3.6.



7) Change the existing single mode of Emergency Brake application where wheel slip-slide correction is disabled so that there are two (2) modes of Emergency Brake

application-- one where wheel slip-slide correction remains active and one where it is disabled. The latter, known as EM-1, is in effect when the Emergency Mushroom button on the console is depressed. The former, known as EM-2, is in effect when ATP and Operator Vigilance request an Emergency Brake application.

The goal is to keep the new "aggressive" wheel slip-slide correction feature discussed in #5 above active as much as possible to take advantage of the improved stop distance that is anticipated. Locked wheels provide a braking performance that is more consistent with that experienced during "conventional" wheel slip-slide correction activity. The one advantage to locked wheels is the creation of wheel flats that serve to verify that the brakes actually applied.

4.2 "Conventional" vs. "Aggressive" Wheel Slip-Slide Correction Control

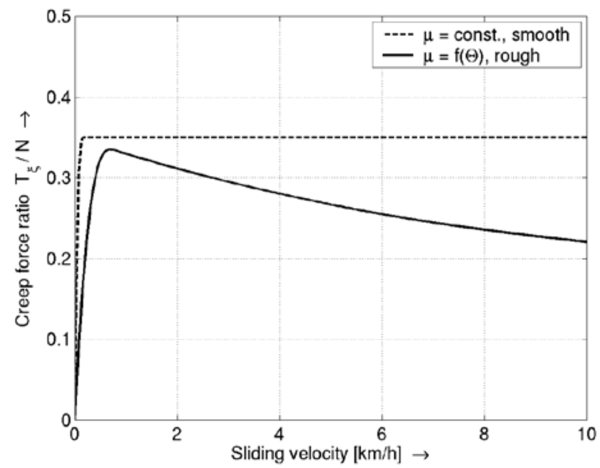
In order to possibly have a better appreciation for the preliminary wheel slip-slide correction performance results and comparative stop distance improvements, some elaboration is warranted.

The "conventional" wheel slip-slide control and associated performance originally provided by the vehicles utilized a percentage of the "available" wheel-to-rail adhesion that was termed "efficiency". In other words, the vehicle could not perform better than what the available wheel-to-rail adhesion could support as identified in the following table.

Speed (mph)	Wet Leaves		Damp Rail (Lower Limit)		Dry Rail (Lower Limit)		Dry Rail (Upper Limit)	
	% Adhesion	AW0 Decel. (mphps)	% Adhesion	AW0 Decel. (mphps)	% Adhesion	AW0 Decel. (mphps)	% Adhesion	AW0 Decel. (mphps)
10	**3.5**	**0.77**	**8.0**	**1.76**	**11.0**	**2.41**	**21.5**	**4.72**
30	**3.0**	**0.66**	**7.0**	**1.54**	**9.5**	**2.09**	**18.0**	**3.95**
50	**2.5**	**0.55**	**6.0**	**1.32**	**9.0**	**1.98**	**15.5**	**3.40**

Note: The table is derived from information presented by Harry G. P. Burt and E. Saumweber at the IEEE/ASME Joint Railroad Conference, 1985. The AW0 Deceleration figures assume an evenly distributed load and that all wheels in the train (or vehicle) are doing equal amounts of work

Slip-slide performance was measured using Brake Cylinder Pressure modulation during wheel slip-slide correction versus the constant Brake Cylinder Pressure present when no wheel slip-slide correction is necessary. The percentage was calculated based on the area under the modulations (peaks and valleys) throughout the stop divided by the area under the constant pressure line for the same duration of stop. The problem with this measurement is that it does not represent performance in terms of stop "distance" which is dependent on the number of times wheel slip-slide correction is commanded and at what vehicle speeds. Wayside signaling and block design is based on distance.



The present approach to wheel slip-slide control is to maintain the wheel in a controlled slip condition (known as, "creep") once wheel slip-slide correction is required. The term "creep" is defined as the net result during braking that the wheel advances further than would be expected. The amount of "creep" is usually stated as a "percentage" reduction in wheel rotational speed when compared to normal wheel rotational speed. Typically, wheel slip-slide correction control uses a "creep" range of 10% - 35% off rail speed. In Brazil, as much as 65% creep is used. The higher the percentage of "creep" that is used, the interaction of the wheel with rail becomes more significant whereby the concentration of heat on the wheel tread and the mechanical interaction between the wheel and the rail increases. It is through the heating and the mechanical interactions that available wheel-to-rail adhesion is dynamically improved throughout the stop. The term "aggressive" may be used to distinguish this approach to wheel slip-slide correction control from that for "conventional" wheel slip-slide correction control.

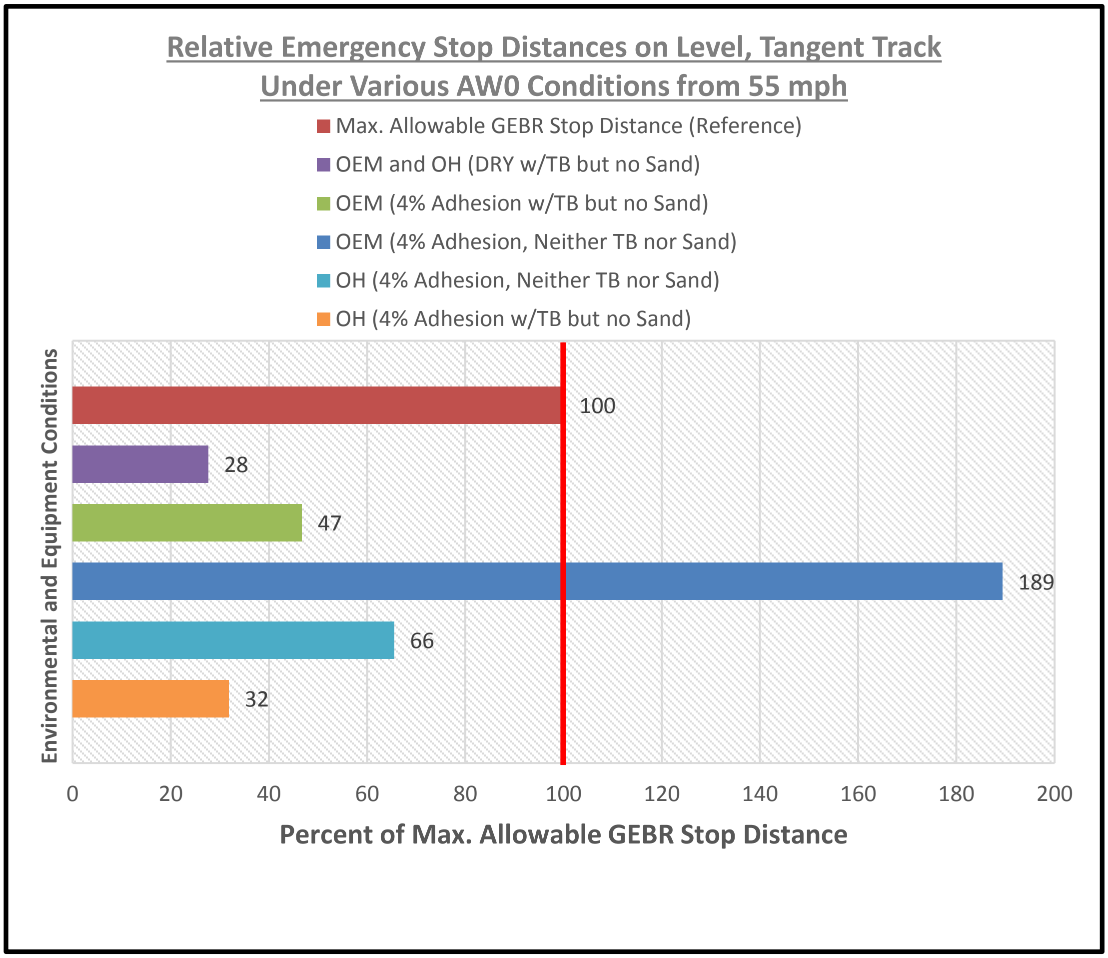
While the long term effects of "aggressive" wheel slip-slide correction control on wheel treads and rail heads is either not known or has apparently not been documented, experience has shown that 65% creep may peel metal from the rail head and may cause a blue ring to develop on the wheel tread (at least for high speed trains). Experience has also shown that 10% - 35% creep is effective in improving wheel-to-rail adhesion by as much as 4.5% which translates into the possibility of stopping at an average brake rate 0.95 mphps higher than in the "conventional" manner. In addition, there are no apparent detrimental effects on either the wheels or on the rail heads.

4.3 Preliminary Brake Performance Results (Various Modes of Operation)

The following graph is offered to provide a visual perspective of the preliminary test results and comparisons in the stop distances during various modes of braking operation. The significant comparison is between the BLUE colored bar (4th down on graph) and the TIEL (or LIGHT BLUE) colored bar (5th down on graph). These bars show the "key" difference in stop distance between "conventional" wheel slip-slide correction control and "aggressive" wheel slip-slide correction control.

1) Even though the OEM vehicle is able to stop within the maximum allowable GEBR stop distance as long as Track Brakes **<u>are</u>** **<u>functioning</u>**, the OEM vehicle is unable to stop in the distance needed should the Track Brakes malfunction / fail.

2) The Overhauled Vehicle is able to stop within the maximum allowable GEBR stop distance **<u>without</u>** the Track Brake and Sanding functioning and to have significant stop distance margin to spare. Hence, operational safety is enhanced.



Perhaps the more significant consideration of the 4th and 5th bars on the graph is the fact that they also represent the performance of normal FULL SERVICE braking when there is a light dew / misty rain on the rails in the early morning hours of the day or when there are wet leaves on the rail. Due to the readily apparent improvement in stop distance of the Overhaul Vehicle which translates into a higher brake rate (mphps), this fact should serve to mitigate the ATP Overspeed correction issues discussed in Section 3.3 without ultimately resulting in an Emergency Brake application. Only revenue service throughout the entire system will ultimately provide an indication as to how successful the upgrade efforts are to the ATP Overspeed correction function under all situations.