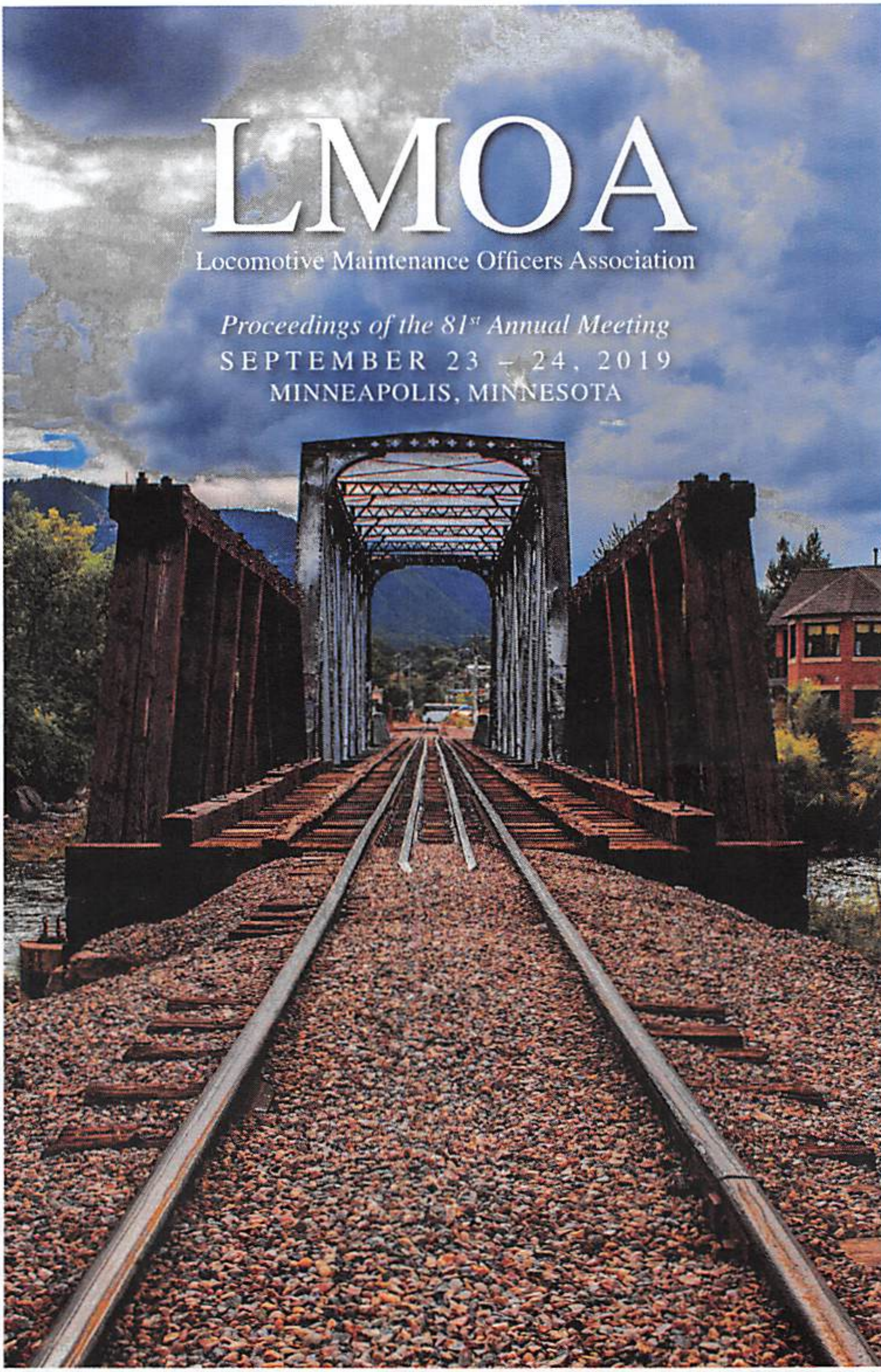
LMOA

Locomotive Maintenance Officers Association

Proceedings of the 81st Annual Meeting

SEPTEMBER 23 – 24, 2019

MINNEAPOLIS, MINNESOTA



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2019 TOC and Index

2018 LMOA MVP RECIPIENTS

The executive board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable Person of their respective committees for 2018:

NAME	COMMITTEE	COMPANY
Jeff Brunson	Mechanical Maintenance	Link Up International
Nick Chodorow	Facilities, Material and Support	The Belt Railway of Chicago
Eugen Grecu	Electrical Maintenance	Via Rail Canada
Tom Mack	Locomotive Software and Systems	VeRail Technologies
Kelle Ravn	Fuel, Lubricants and Environmental	Cummins, Inc

This honor is bestowed on an annual basis to those individuals who perform meritorious service and make significant contributions to their respective committees. The honorees receive a plaque that is presented to them by their supervisors.

LMOA EXECUTIVE COMMITTEE

THE LMOA EXECUTIVE BOARD WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO 1ST VICE PRESIDENT TOM KENNEDY FOR HIS TIRELESS EFFORTS IN MAKING ALL OF THE ARRANGEMENTS FOR A SUCCESSFUL JOINT TECHNICAL COMMITTTEE MEETING IN KANSAS CITY, MISSOURI ON APRIL 29 AND 30, 2019

THE BOARD WOULD ALSO LIKE TO THANK JEFF BINK, JMA RAILROAD SUPPLY FOR CONTACTING THE WESTIN HOTEL FOR MEETING ROOM AND HOTEL ACCOMMODATIONS FOR OUR COMMITTEE MEMBERS

LMOA COMMITTEE MEMBERS HAD THE OPPORTUNITY TO TOUR THE FOLLOWING FACILITIES:

BNSF-ARGENTINE YARD

MID AMERICA CAR

NORFOLK SOUTHERN CHARGING STATION

WABTEC GLOBAL SERVICES

THE LMOA EXECUTIVE BOARD WOULD LIKE TO THANK MICHAEL CLEVELAND, BNSF, FOR ARRANGING TOUR OF THE BNSF-ARGENTINE YARD, JEFF BINK, JMA RAILROAD SUPPLY, FOR HIS EFFORTS IN PUTTING THE MID AMERICA CAR TOUR AND MARK DUVE, NORFOLK SOUTHERN FOR HIS DIRECT INVOLVEMENT FOR THE TOUR OF THE NORFOLK SOUTHERN CHARGING STATION

THE LMOA EXECUTIVE BOARD WOULD LIKE TO EXPRESS THEIR GRATITUDE TO LMOA PAST PRESIDENT JACK KUHNS FOR HOSTING THE TOUR OF WGS IN KANSAS CITY.

THE LMOA EXECUTIVE BOARD WOULD ALSO LIKE TO EXTEND THEIR SINCERE APPRECIATION TO TEMPLE ENGINEERING AND AFTON CHEMICAL FOR HOSTING A LUNCH AT JACK STACK BARBEQUE IN KANSAS CITY ON MONDAY, APRIL 29TH

THE ANNUAL JOINT TECHNICAL COMMITTEE MEETING WAS HELD AT WESTIN HOTEL-KC ON MONDAY, APRIL 29TH AND TUESDAY MORNING, APRL 30TH

The Executive Board of the Locomotive Maintenance Officers Association would like to express their deep and sincere appreciation to LMOA Past President Dwight Beebe of Temple Engineering for sponsoring the Executive Board meeting and luncheon at the Music City Convention Center in Nashville, TN on Tuesday, September 11, 2018.

Thank you Dwight for your long and continued support of the LMOA.

PAST PRESIDENTS

1939 & 1949	F.B. DOWLEY (Deceased) Shop Supt., C. & O. Ry.
1941	J.C. MILLER (Deceased) MM, N.Y.C. & St. L.R.R.
1942-1946, Inc.	J.E. GOODWINN (Deceased) Exec. Vice President, C. & N.W. Ry.
1947	S.O. RENTSCHILLER (Deceased) Chief Mechanical Officer, Bessemer and Lake Erie R.R.
1948	C.D. ALLEN (Deceased) Asst. C.M.O. - Locomotive, C. & O. Ry. & B. & O. R.R.
1949	J. W. HAWTHORNE (Deceased) Vice-Pres.- Equipment, Seabord Coast Line R.R.
1950	G.E. BENNET (Deceased) Vice-Pres.- Gen, Purchasing Agent, C. & E. I. Ry.
1951	P.H. VERD (Deceased) Vice-Pres.- Personnel, E. J. & E. Ry.
1952	H.H. MAGILL (Deceased) Master Mechanic, C. & N. W. Ry.
1953	S.M. HOUSTON (Deceased) Gen. Supt. Mech. Dept. Southern Pacific Co.
1954 & 1955	F.D. SINEATH, Retired Chief of Motive Power, Seabord Coast Line R.R.
1956	T.T. BLICKLE (Deceased) General Manager-Mechanical, A.T. & S.F. Ry.
1957	J.T. DAILEY (Deceased) Asst. to Pres.-Mech., Alton & Southern R.R.
1958	F.E. MOLLOR (Deceased) Supt. Motive Power, Southen Pacific Co.
1958	F.R. DENNY (Deceased) Mechanical Supt., New Orleans Union Passenger Terminal
1959	E.V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry.
1960	W.E. LEHR (Deceased) Chief Mechanical Officer, Pennsylvania R.R.
1961	O.L. HOPE (Deceased) Asst. Chief Mechanical Officer, Missouri Pacific R.R.
1962	R.E. HARRISON (Deceased) Manager-Maintenance Planning & Control, Southern Pacific Co.
1963	C.A. LOVE (Deceased) Chief Mechanical Officer, Louisville & Nashville R.R.
1964	H.N. CHASTAIN (Deceased) General Manager-Mechanical, A.T. & S.F. Ry.
1965	J.J. EKIN, JR. (Deceased) Supt. Marine & Pier Maintenance, B. & O. R.R.
1966	F.A. UPTON II (Deceased) Asst. Vice-President-Mechanical, C.M. St. P. & P. R.R.
1967	G.M. Beischer, Retired Chief Mechanical Officer, National Railroad Passenger Corp. Washington, D.C. 20024
1968	G.F. BACHMAN (Deceased) Chief Mechanical Officer, Elgin Joliet & Eastern Ry.
1968	T.W. BELLHOUSE (Deceased) Supt. Mechanical Dept., S. P. Co., - St. L. S.W. Ry.
1970	G.R. WEAVER (Deceased) Director Equipment Engineering, Penn Central Co.
1971	G.W. NEIMEYER (Deceased) Mechanical Superintendent, Texas & Pacific Railway
1972	K.Y. PRUCHNICKI (Deceased) General Supervisor Locomotive Maintenance, Southern Pacific Transportation Company
1973	W.F. DADD (Deceased) Chief Mechanical Officer, Chessie System
1974	C.P. STENDAHL, Retired General Manager, M.P.-Electrical, Burlinton Northern Railroad
1975	L.H. BOOTH (Deceased) Retired Assistant C.M.O.-Locomotive, Chessie System
1976	J.D. SCHROEDER, Retired Assistant C.M.O.-Locomotive, Burlinton Northern Railroad, 244 Carrie Drive, Grass Valley, CA 95942
1977	T.A. TENNYSON (Deceased) Asst, Manager Engineering-Technical, Southern Pacific Transportation Co.
1978	E.E. DENT (Deceased) Superintendent Motive Power, Missouri Pacific Railroad
1979	E.T. HARLEY, (Deceased) Senior Vice President Equipment, Trailer Train Company, 289 Belmont Road, King of Prussia, PA 19406
1980	J.H.LONG (Deceased) Manager-Locomotive Department, Chessie Systems
1981	R.G.CLEVENGER, Retired, General Electrical Foreman, Atchison, Topeka & Santa Fe Rwy

1982	N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
1983	F.D. BRUNER (Deceased), Asst. Chief Mechanical Officer, R&D, Union Pacific RR
1984	R.R.HOLMES (Deceased), Director Chemical Labs & Environment, 600 Brookestone Meadows Place, Omaha, NE 68022
1985	D.M.WALKER, Retired, Asst. Shop Manager, Norfolk Southern Corp, 793 Windsor St, Atlanta, GA 30315
1986	D.H.PROPP, Retired, Burlington Northern RR, 10501 W. 153rd St, Overland Park, KS 66221
1987	D.L.WARD (Deceased), Coordinated-Quality Safety & Tech Trng, Burlington Northern RR
1988	D.G. GOEHRING, Retired, Supt. Locomotive Maintenance, National RR Passenger Corp, 1408 Monroe, Lewisburg, PA 17837
1989	W.A.BROWN, Retired, I&M Rail Link, 9047 NE 109th St. Kansas City, MO 64157
1990	P.F.HOERATH (Deceased) Sr. Mech. Engr. Shop, Conrail 1534 Frankstown Rd, Hollidaysburg, PA 16648
1991	D.D.HUDGENS, Retired, Sr Mgr R&D, Union Pacific, 16711 Pine St., Omaha, NE 68130
1992	K.A.KELLER, Retired, Supt. Locomotive Maint, Reading RR, 241 E. Chestnut, Cleona, PA 17042
1993	W.R.DOYLE, Commuter Rail Transportation Superintendent, Sound Transit, Seattle, WA 98104
1994	M.A.COLES, Retired, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
1995	C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
1996	G.J.BRUNO, Retired, Supt.-Mechanical, Amtrak 14142 S.E. 154th Pl, Renton, WA
1997	D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
1998	H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
1999	JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak, 25531 NE 138th St., Salt Springs, FL 32134
2000	RON LODOWSKI, Retired Production Mgr, CSX Transportation, Selkirk, NY 12158
2001	LOU CALA, Retired, Duncansville, PA 16635
2002	BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
2003	BRIAN HATHAWAY, Consultant, Port Orange, FL 32129
2004	BILL LECHNER, Retired, Sr Genl Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp, Altoona, PA 16601
2005	TAD VOLKMANN, Director-Mech. Engrg., Union Pacific RR, Omaha, NE 68179
2006	BRUCE KEHE, Retired, CMO, CSS&SB, Michigan City, IN 46360
2007	LES WHITE, Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
2008	MIKE SCARINGE (Deceased), Director-Locomotives, Amtrak, Beech Grove, IN 46109
2009	DENNIS NOTT, Sole Member, Northwestern Consulting, Boise, ID 83703
2010	BOB REYNOLDS, Sales Manager, Amglo Kemlite Laboratories, Calgary, Alberta T24 2V8
2011	JACK KUHNS, Director-Sales, Graham White, Salem, VA 24153
2012	RON BARTELS, Sr. Manager - Equipment Reliability and Electrical Engineering, Via Rail-Canada, Montreal, Quebec
2013	R. BRAD QUEEN, Manager of Locomotive Utilization - RCO, BNSF Railway, Fort Worth, TX
2014	DAVE RUTKOWSKI, President, JAB Rail Services, LLC, Green Cove Springs, FL
2015	BOB HARVILLA, VP-Sales, PowerRail, Inc., Duryea, PA
2016	STUART OLSON, Sales Director-Infrastructure, Wabtec Corporation, Alpharetta, GA
2017	JEFF CUTRIGHT, Contractor-L&J Services, Retired Norfolk Southern, Roanoke VA
2018	DWIGHT BEEBE, Temple Engineering, Liberty, MO

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2018 State of the Union Address

Dwight Beebe
Monday, September 10, 2018
Nashville Convention Center

Good afternoon ladies and gentlemen, members of the executive committee, Mr. Secretary and fellow LMOA members. I hope you are enjoying the convention.

Over the past several years the LMOA has made major strides to serve our members and the rail industry better.

Our website has been upgraded and members can search for past articles and access them online. We have received correspondence from railroaders all over the world with our "Ask the LMOA" query on the website.

Reorganization of the LMOA subcommittees has aligned them more closely with the industry and prepared us for future developments. Our committees are robust; the work is important and valued.

I would like to recognize members of three categories today; the first are individuals who have retired from a career in the rail industry and have chosen to continue working with the LMOA on our mission to develop, educate, and promote the rail industry. We are grateful for your wisdom and dedication.

The second group is from government agencies. This year, we will have a question and answer presentation from the US environmental protection agency. Thank you for your service to the country and for reaching out to educate and confer with the rail community via the LMOA.

I would also like to recognize members of the American Association of Railroads locomotive committee. The AAR is a trade group funded by the railroads. Their locomotive committee meets regularly to discuss common problems and issues. These issues are recorded on a docket for further research and hopefully resolution. Over the years this docket has grown to over a 100 items. This year, the LMOA and AAR reached an agreement wherein the AAR shares their docket with us. This gives the LMOA a comprehensive list of issues the industry is facing. In turn, the LMOA's annual papers are now placed on an AAR docket for coordination between the two groups.

There are a few topics I would like to report on. The first one that comes to mind is safety. The railroad injury rates seem to be steady, which I will take as good news given all of the changes that the railroads have gone through. Still, there is room for improvement. Having an industry safety culture means a lot. For the seasoned railroader it means that they are valued; it shows that we care. For someone just learning the trade it means that the industry is a place that they can have a career. To attendees, a safety briefing at the beginning of a meeting shows professionalism. For everyone in railroading it means that they will be able to go home to loved ones and families at the end of the day.

At the LMOA we are constantly searching for ways to make things better, easier, more efficient, and that last longer. But I hope we will always remember the overarching theme that we make things safer.

Adapting to change is another topic. Positive Train Control, Tier I to IV locomotives, New Fuels, New Maintenance Practices, Interoperability and reacting to market fluctuations are just a few of the changes we have seen over the past 15 years. It has been truly incredible to see this level of innovation. Sometimes we can slip into the mindset that “once these changes get done then we will be able to rest for a while”. But, I can guarantee you all, that when you go back to work your boss will still ask “what have you done for me lately?”

One significant change has been the EPA’s regulation to lower emissions by reducing locomotive idling which was enacted 10 years ago. The LMOA has a significant body of work on this issue. We have done at least 4 papers on the issue dating back to 2008. Our committees are continuing this work in part because after 10 years the industry is still experiencing issues with battery and starter life. If we look at these papers, the first dealt with implementation and the last one dealt with problems. Which points to how we as an organization deal with industry changes.

With change comes opportunity. If, as an organization, the LMOA will embrace changes, we can have a more significant and positive change on the industry. Coordinated work between committees can develop planning documents which could provide realistic timelines for implementation, anticipated problems and recommended product developments. The LMOA offers a rare body of experts with the capability to plan for changes.

There are definitely examples where the LMOA has embraced change. Retrofitting New Systems to old Locomotives, Biodiesel, DC conversion and renewable diesel to name a few. When we embrace change unexpected opportunities arise.

For example: PTC implementation was and continues to be a daunting task. But, as companies push ahead, they are able to influence the interpretation of the regulations the most.

Embracing the technology has allowed them to have more control over the implementation. Furthermore, companies have found that the network capability that PTC has opened up has incredible potential for locomotive communication. Predictive maintenance seems to be within our grasp. Control and optimization of locomotives while in the field running is completely feasible.

The topic of developing talent is becoming more and more important. We have never seen a greater need for new talent with new skill sets. New talent needs to be paired with experience. Team building is a crucial skill, to foster mutual respect and leverage each individual's strengths. Communication skills are becoming more and more important. Successful leaders must be able to present ideas and findings professionally. Has anyone known of good ideas that were not implemented simply because they were not properly communicated? It is a lose, lose scenario. The industry loses, the company loses, and the employee loses. Employees, particularly new talent, need the skills that the LMOA can help hone. To interact with other industry leaders, research thoroughly, to write effectively, and present convincingly.

It has been an honor to serve as the President of the LMOA. I would like to thank: the executive committee, the committee chairpersons and their members, and of course, our beloved Secretary, Mr. Ron Pondel. I genuinely appreciate all the support I have been given.

As I always say,
It is a great day,
To be in the LMOA.

Acceptance speech

Ian Bradbury

Tuesday, September 11, 2018
Nashville Convention Center

It is an honor to accept the nomination to serve as your President for the next year and very humbling to join such a long list of colleagues who have contributed so much to the industry.

Now, it would have been nice to have been elected by the popular vote, but understand that the electoral college is the system that we have!

First, I would like to say thank you to my wife Kathy, occasional Mini Pearl and full time supervisor of happiness as well as my sons, James and George, for their love and support.

I would like to recognize the stalwart efforts of our Secretary, Ron Pondel, who is tireless in keeping the organization glued together and a font of institutional memory.

I would also like to extend a particular note of appreciation to outgoing President Dwight Beebe for the significant work he has done:

- Dwight led the effort to capture the Voice of the Customer from the CMO's so we may more tightly align the work of the LMOA with the current needs of the railroads
- He introduced Executive Summaries early in to the paper development process, which has provided a timelier feedback mechanism as well as a successful revised format for the Joint meeting this year
- Reorganization of the committee structure based upon CMO feedback has both streamlined and revitalized our organization
- The LMOA website has been significantly updated and proceedings are available to members electronically going back to 1990
- And, we are delighted to welcome participation of the EPA in LMOA and outreach to the AAR will enable us to coordinate our technical committee work with relevant issues on the locomotive docket.

Finally, I would like to note our appreciation to Joaquin Flores and his team for hosting our Joint meeting at CN's Homewood facility this year as well as the Indiana Harbor Belt Railroad for providing a tour of their CNG dual fuel converted locomotive and fueling facilities.

I had the privilege of working with the late Dr. W. Edwards Deming when I was at GM and became an advocate of his philosophy. In The New Economics, he said:

… there [should] be cooperation on problems of common interest between people, divisions, companies, competitors, governments, countries. The result will in time be greater innovation, applied science, technology, expansion of market, greater service, greater material reward for everyone. There will be joy in work, joy in learning. Anyone who enjoys his work is a pleasure to work with.

The LMOA is an organization that exemplifies many of these ideals

- We provide a mechanism for cooperation across the industry on problems of common interest
- We provide opportunities for our members to learn from the knowledge and experience of each other
- We provide a collegial professional development environment for research and exposition of ideas as well as becoming a more effective presenter
- Our members are a pleasure to work (and socialize) with

It is my hope that this year we will develop and deepen our relationships with other industry organizations to improve the benefit LMOA provides to the rail industry. The AAR adoption of the Gen. VI lube oil standard developed by LMOA's Fuels, Lubes & Environmental Committee is a great example of a need being identified by our members; taking a knowledge leadership role in developing a standard to meet that need and then working with the AAR to obtain industry adoption. Similarly, there are items on the AAR's locomotive docket that LMOA committees could provide valuable assistance with.

I would also like to explore ways in which the LMOA can improve how it supports the professional development of its members. A couple of ideas in this area are formal mentorship and classes offered to pass on the wisdom of our most distinguished fellows.

Currently, foreign power locomotives requiring repair are often shipped back dead instead of being repaired on the foreign road. If a standardized repair system existed, far more of this work could occur locally with significant cost savings to the industry as a whole. Development of such a system will require standardized part numbering and standardized work. I believe the LMOA is particularly well suited to taking on this challenge with our mix of railroad and supplier expertise. Let's choose some common repairs that are high on the Pareto chart and see what we can do on a pilot basis this year.

I would like to end with a story of a lady who entered her dog every year in the Westminster dog show. Her dog was a mutt and never came close to winning a medal. She was viewed as an odd eccentric. One year, a judge approached her and asked whether she knew that her dog is a mutt. She said "yes, of course". Well, this is a prestigious dog show. Your dog stands no chance of ever winning a prize. "I know, but it gives him a chance to hang out with some good dogs". It's times like this that I believe I know how the dog felt. Thank you.

Past President Dave Rutkowski, JAB Rail, assisting newly elected 3rd Vice President Michael Hartung, Norfolk Southern, with his LMOA blazer.

Secretary Treasurer Ron Pondel with his lovely wife, Lijana.

Sid Bakker making a technical presentation to attendees at the Nashville Conference.

Outgoing President Dwight Beebe presenting gavel to newly elected President Ian Bradbury which was witnessed by Ron Pondel.

Past President Bob Runyon proudly holds a locomotive bell. Bob was given the prestigious LMOA Lifetime Achievement Award.

Past President Jeff Cutright points to Past President's Pin which was given to outgoing President Dwight Beebe.

Past President Bob Runyon presents LMOA Past President's Watch to outgoing President Dwight Beebe.

Report on the Committee on Mechanical Maintenance

Monday, September 23, 2019 at 9:00 AM

Chair

Mark Duve

Manager-Locomotive Engineering

Norfolk Southern Corp., Atlanta, GA

Vice Chair

John Hedrick

Principal Scientist

Southwest Research Institute, San Antonio, TX

Commitee Members

M. Abbott	Product Design Engineer	Hotstart	Spokane, WA
D. Bellemare	Manager-Business Development	DLL Inc	St. Jean Richelieu, Quebec
J. Bink	National Sales Manager	JMA Rwy Supply	Seymour, IN
J. Brunson	Sales Manager	Link Up International	Roanoke, TX
T. Casper	Vice President-Operations	PowerRail, Inc.	Duryea, PA
M. Cleveland	Senior Mgr-Emerging Technology	BNSf Railway	Fort Worth, TX
J. Cutright	Contractor	L&J Services	Roanoke, VA (Past President)
E. Dillen	Advanced Engineering Leader	GE/Wabtec	Erie, PA
D. Freestone	Chief Mech. Officer	Alaska RR	Anchorage, AK
F. Jalili	President	FJ, LLC	Dallas, TX
T. Kennedy	President	Kennedy Rail Consulting	Omaha, NE (Executive)
B. Marty	Marketing Director	Metro East Industries	E. St. Louis, IL
A, Meek	Manager-Rail Business Dev	Cummins, Inc	Westminster, CO
D. Nott	Sole Member	Northwestern Consulting	Boise, ID (Past President)
D. Osborne	Principal Engineer	Southwest Research Inst.	San Antonio, TX
D. Parsons	Senior Manager-Engrg.-Diesel	Amtrak	Chicago, IL
A. Pope	Manager-Technical Liaison	Bharat Forge	Troy, MI
D. Rutkowski	President	JAB Rail Svcs	Green Cove Springs, FL (Past President)
C. Shepherd	Chief Mechanical Officer	Arkansas & Missouri RR	Springdale, AR
B. Singleton	Owner	Transpar Corp	Niskayuna, NY
K. Ulbick	Sales Manager	Peaker Services	Brighton, MI
G. Wilson	Superintendent of Cars	Iowa Interstate RR	Cedar Rapids, Ia
R. Wullschleger	Chief Mechanical Officer	New York & Atlantic Rwy	Flushing, NY

PERSONAL HISTORY

Mark Duve

Manager-Locomotive Engineering
Norfolk Southern Corp.
Atlanta, GA

Mark Duve is the Locomotive Engineering Manager at Norfolk Southern. Mark began his career in locomotives at the Electro-Motive Division of EMD in 1994 where he worked various departments over 16 years including the Purchasing Department, Engine Group, and Locomotive Systems Engineering. While working in those departments, Mark worked on connecting rods, piston pin carriers, fuel economy testing, adhesion testing and locomotive configuration management. In 2010, Mark took a position as Mechanical Engineer Locomotive Design at Norfolk Southern and has since worked at System Manager Locomotive Reliability Manager and now Manger Locomotive Engineering. At NS, Mark has worked on various projects such as the ECO locomotives, DC to AC conversions, the natural gas mother slug and locomotive reliability. Mark is the chairman of the Association of American Railroads Locomotive Committee and the Natural Gas Tender Committee.

Mark grew up in a small town in the hills of northern New Jersey. Mark's post high school education includes a Bachelors in Marketing from Colorado State University, a Bachelors in Engineering from Stevens Institute on Technology and a Masters Degree in Mechanical Engineering from Illinois Institute of Technology. Mark works out of Norfolk Southern's downtown Atlanta office and lives in the Atlanta suburb of Milton with his wife and 3 kids. Besides work and assisting with his kids activities, Mark's past times include photography and home renovation.

Over the last year, the Mechanical Maintenance Committee has hosted many phone/web ex conferences along with two committee meetings.

The Mechanical Maintenance Committee would like to express their sincere gratitude to HOTSTART for hosting our winter meeting in Spokane, WA on March 13 & 14, 2019 along with the hospitality from Terry Judge, Michael Abbott, Casey Hall and Leslie Czernik. During the winter meeting the team also visited Pend Oreille Valley Railroad for a shop tour. The Committee was also able to tour the BNSF Hauser fueling facility. All the tours were extremely interesting.

The Mechanical Committee would also like to thank Metro East Industries for hosting our summer meeting in East Saint Louis, IL on August 11 & 12, 2019 with the hospitality from Brian Marty and Wade Clevenger.


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Locomotive Storage and Return to Service - Update Best Practices

Prepared by:
Tom Kennedy
Kennedy Rail Consulting

The Locomotive Storage and Return to Service Paper was first published in the LMOA 2011 proceedings when the weak economy created a surplus power condition that required locomotives to be stored. With the implementation of Precision Scheduled Railroad (PSR) practices many locomotives are again being stored. In light of this LMOA has determined that it would be prudent to revisit the proper principles and practices for locomotive storage. The original paper was a joint effort between the Mechanical Committee (Tom Kennedy and Dave Cannon) and the Fuels and Lube Committees (Glen Bowen). This paper is essentially identical to the 2011 paper since the identified practices still apply. One Caveat is the introduction of the High Pressure Common Rail fuel systems and Tier 4 locomotives which may require additional preservation steps. This paper will not address any specific actions required if these later units are stored and it is recommended that the OEM be contacted for specifics if these units were to be stored.

The requirements for storage vary between the OEM's and were typically considered by the railroads to be overly complex and time consuming with little supporting rationale. The OEM's typically developed their requirements to protect new locomotives during storage prior to and during international shipping which is a different environment that the railroads experience in their storage process. Just like the storage process the return to service processes vary between railroads too. To minimize product degradation during storage and optimize reliability once the locomotive is returned to service the railroads requested the LMOA to develop a standardized set of Best Practices. This is the intent of this paper.

All locomotive systems and components are potentially degraded to varying degrees by the environmental factors, such as humidity, experienced during storage, see photos below. This paper focuses primarily on the mechanical, fuels and oil, and pneumatic systems of a locomotive. The storage affects to the electrical systems and electrical components are addressed in a separate paper from the LMOA Electrical Committee.

It should be noted that not all reliability issues are due to storage effects. Inherent reliability is affected by multiple factors such as historical performance, the products inherent reliability, maintenance history, etc. A fundamental goal of any storage process is to store and return the product to service at an equal reliability that the product went into storage with. Expecting an improvement in reliability when the units come out of storage is unrealistic without some intervention such as reliability modifications and upgrades.

This paper is the product of cross functional participation between the LMOA Mechanical Committee, the LMOA Fuels, Lubricants, and Environmental (FL&E) Committee and includes participation from the railroads, the OEMs, the oil and fuel companies, and a variety of additional locomotive component and material suppliers. A balanced perspective of the storage issues and development of consistent and standardized best practices is the objective of this paper.

Storage Principles

To develop best practices the LMOA team established the following guidelines:

- Used the best recommendations from OEM's and RR's
- Only practices that promote safety will be considered
- Recommendations have to be practical (good bang for buck)
- Practices have to show a proven benefit
- Practices have to based on sound science

Some practices are still under study or review so the railroads and OEM's are continuing their assessment of these for possible further enhancement of the best practice recommendations for continuous improvement. As units are returned to service from storage new opportunities may be identified and the plan is to have future updates added to future “Best Practices” document.

Storage Definitions

A stored locomotive is a locomotive that is not started or moved for an extended period of time, typically greater than 30 days. Each stored locomotive should be classified with one or more of the standardized definitions shown below.

- Stored serviceable: Unit was functioning when stored
- Stored unserviceable: Unit was not functioning when stored
- Short-Term Storage: Stored less than 180 days
- Long-Term Storage: Stored greater than 180 days
- Good order - Can be returned to service with minimal effort
- Needs light repair (Wheel truing, TM change, COT&S)
- Needs heavy repair (PA, Gear train, Turbocharger)
- Bad order - Will take more than 30 days to repair
- Pending sale or evaluation

The best practices discussed in the following sections are annotated with LT or ST to show applicability to either Long Term or Short Term or both

Placement into Storage – Location

Dry and mild temperatures are preferred environments for storage since moisture is the primary cause of degradation. A common storage location enables consistent and efficient storage and by staging locomotives with a last in first out strategy this helps expedite return of the most desirable locomotives to service quickly, or the return of locomotives under lease, etc. The preferred location should also be logistically separated from main lines where vibration from passing trains may cause brinelling of wheel bearings. Note: False brinelling may be mistaken for actual brinelling but it is still a good practice to store locomotives, if possible, away from heavy vibration sources.

Best Practices: Into Storage – Fuel System

- Drain condensate from fuel tank (ST, LT)
- Remove all but 500 gallons of fuel from tank (ST, LT)
- Add an appropriate biocide/stabilizer to fuel tank (ST, LT)
  - Obtain approval of your Environmental, Safety, and Health Department prior to the use of any biocide additives
- Include MSDS data precautions into work planning
- Conduct appropriate training
- Ensure proper PPE is available and used
- Operate locomotive 15 min to circulate treatment (ST, LT)

Best Practices: Into Storage – Cooling System

- Add an appropriate amount of a "filming" corrosion inhibitor (ST, LT)
  - Obtain approval of your Environmental, Safety, and Health Department prior to the use of any corrosion prevention additives
- Include MSDS data precautions into work planning
- Conduct appropriate training
- Ensure proper PPE is available and used
- Start and run the engine to ensure the coolant is fully circulated through entire cooling system, including radiators (ST, LT)
- Allow system to cool, vent, and completely drain. (ST, LT)
- Failure to drain the system will degrade EPDM seals if the "filming" corrosion inhibitor is petroleum based
- Purge trapped water to prevent freeze damage, e.g., fuel preheaters, dead headed lines, etc.
- Remove water pump drain plugs (only required on GE locomotives), bag and wire plugs to pump.
- Lubricate cooling fan shutter and louver linkage (LT)
- Close all cooling fan shutters (ST, LT)
- "Fail open" shutters must be disconnected/secured in the closed position

Best Practices: Into Storage – Engine and Engine Oil

- Test lube oil for fuel dilution with lab test or a fuel sniffer (ST, LT)
  - If fuel dilution is detected find the source and correct
- Test lube oil for free water using a Crackle Test (ST, LT)
  - If free water is detected find the source and correct
- Governors (non-sealed), drain oil and refill with fresh oil (LT)

Best Practices: Into Storage – Pneumatic System

- Air Compressor
  - Take air compressor oil sample for analysis (ST, LT)
  - Test lube oil for free water with a Crackle Test, and correct if found
  - Drain and replace the oil and filter
  - Remove the blanking plates on the low pressure heads
  - Ensure all water drains out of that part of the head to prevent freezing. Some plates have freeze plugs but history shows they don't always work. Note: this may not be necessary on compressors with the newer cylinder design
- Air Dryers, if equipped (ST, LT)
  - Inspect eye condition, if oil indicated, find source and correct
- Electronic Air Brake Type Systems (ST, LT)
  - Drain condensate from all filters equipped with drains
  - 26L Type Air Brake Systems (ST, LT)

  - Remove P2A and drain condensation
  - Blow out the airline to P2A before reinstalling
- Air Reservoirs and piping (ST, LT)
  - Drain condensate from reservoirs and air lines
  - Drain condensate from coalescing filters
  - Close, drain, MU hose, and brake pipe cocks
  - Clean dirt collectors
- Air Starters (EMD SD70ACe and SD70M-2) (ST, LT)
  - Lubricate pinion gear drive spline and ring gear

Best Practices: Into Storage – Running Gear

- Inspect TM covers for proper sealing and securement (ST, LT)
- Inspect gear pans for proper sealing and securement (ST, LT)
- Motor support bearings (non Bearing Tapered Roller) (ST, LT)
  - Drain water from support bearing boxes
  - Clean wick top plate, remove wick assembly, test wick for proper function and presence of no water
  - Inspect brass and axle for unusual conditions
  - Reapply wick with new gasket, apply fasteners and locking tabs. Wire journal support drain plug in the closed position
  - Fill with fresh oil to proper level
- Drain water from Hyatt journal boxes, apply drain plug and wire closed, and fill with oil to proper level (ST, LT)
- Inspect traction motor lead boots for sealing and securement (ST, LT)

Best Practices: into Storage – Miscellaneous

- Drain condensate from crankcase (ST, LT)
- Do not top off oil (ST, LT)
- Cover exhaust stacks using adequate covers (ST, LT)
- Clean all engine sumps and water drain holes (ST, LT)
- Clean generator aspirator ensuring proper operation (ST, LT)
- Drain retention tank and close retention tank valve (ST, LT)
  - While in storage drain retention tank at an appropriate interval dependent on weather conditions
- Make notation “Do Not Start” tags, date stored and apply to isolation switch and to start button (ST, LT)
- Empty and clean refrigerator, block door open (ST, LT)
- Clean and drain the toilet and water supply tank (ST, LT)
- Close and lock all doors and windows (ST, LT)

Best Practices: Return to Service – Prestart

- Perform required maintenance (FRA, RR) (ST, LT)
- Inspect for and remove all debris (ST, LT)
  - Rodents, snakes, insects, nests, leaves, trash, etc.

- Inspect and repair missing components/vandalism (ST, LT)
- Remove exhaust stack covers and inspect stack (ST, LT)
- Conduct visual truck and brake rigging inspection (ST, LT)
- Change all HVAC filters (ST, LT)

Best Practices: Return to Service – Fuel System

- Drain condensate from fuel tank (ST, LT)
- Change all fuel filters and clean or replace fuel suction strainer, if equipped (ST, LT)
- Fill tank with diesel fuel (ST, LT)
- Clean and inspect engine fuel sight glass (ST, LT)
  - Replace rubber seal as required
  - Check for proper bail ratchet operation (if equipped)
- Clean fuel tank sight glasses as required (ST, LT)
- Pressurize fuel system and inspect for leaks (ST, LT)

Best Practices: Return to Service – Cooling System

- Open all cooling fan shutters (ST, LT)
  - Reconnect the “Fail open” shutters
- Install water pump drain plugs (GE units only) (ST, LT)
- Fill the cooling system with raw water (ST, LT)
- Flush and test auto dump valves (ST, LT)
- Add an appropriate amount of cleaner to remove the “filming” corrosion inhibitor (ST, LT)
  - Obtain approval of your Environmental, Safety, and Health Department prior to the use of any corrosion prevention additives

    - Include MSDS data precautions into work planning
    - Conduct appropriate training
    - Ensure proper PPE is available and used

Best Practices: Return to Service – Engine and Engine Oil

- Inspect engine baggy filters and change as required (ST, LT)
- Change all oil filters (LT)
- Inspect Michinana Tank Seal groove for corrosion(ST, LT)
    - Corrosion can lead to seal failure and oil spray and fire

- Drain condensate from crankcase (ST, LT)
- Open power assembly compression relief valves (ST, LT)
- Pre-lube engine, do not overfill (ST, LT)
- Bar engine over 2 revs during pre-lube process (ST, LT)
    - EMD: Inspect liners and pistons for rust and corrosion
    - EMD: Spray 2 to 4 ounces of clean engine oil into each cylinder liner and piston to prevent scuffing and assist in engine starting
    - GE: Observe free rotation and listen for unusual sounds/noise
- Conduct EMD top deck valve train inspection (ST, LT)
- Inspect GE cams and spray with clean engine oil (ST, LT)
- Conduct Air Box Inspection (EMD) (ST, LT)
- Conduct Crank Case Inspection (ST, LT)

Best Practices: Return to Service – Pneumatic System

- Air Compressor
    - Drain and replace oil and filter (ST, LT)
    - Flush compressor heads with clean water (ST, LT)
    - Reinstall all blanking plates on the low pressure heads
    - Inspect all air and water lines (if equipped) for damage and deterioration and replace as necessary

- Air Dryers, if equipped (ST, LT)
  - Service per Railroad maintenance instructions
- Electronic Air Brake Type Systems (LT)
  - Change MR, BP, actuating (13), and independent (20) filters
- 26L Type Air Brake Systems (LT)
  - Change brake pipe cutout filter
- Air Reservoirs and piping (ST, LT)
  - Inspect for and correct any degradation
  - Ensure all MU air valves are closed
- Air Starters (EMD SD70ACe and SD70M-2) (ST, LT)
  - Lubricate pinion gear drive spline and ring gear

Best Practices: Return to Service – Running Gear

- Inspect and correct dust guard defects (ST, LT)
- Inspect and correct TM defects (ST, LT)
- Ensure traction motor ground straps are secured ST, LT)
- Inspect traction motor lead boots for sealing and securement (ST, LT)
- Inspect and correct rigging defects (ST, LT)
- Inspect and correct journal box defects (ST, LT)
- Recheck motor support bearings (non BTR) (ST, LT)
  - If water is found repeat process for placement into storage
- Recheck Hyatt journal boxes (ST, LT)
  - If water is found repeat process for placement into storage

Best Practices: Return to Service – Starting Engine

- Remove all “Do Not Start” tags (ST, LT)
- Close all electrical breakers for starting locomotives (ST, LT)
- Close cylinder compression relief valves (ST, LT)
- Verify engine protection operation before starting engine (ST, LT)
- Prime fuel system and inspect for fuel leaks (ST, LT)
- Start engine and bring to normal operating temperature prior to performing any test or moving locomotive (ST, LT)
- Inspect for proper oiling and operation (ST, LT)

Best Practices: Return to Service – Engine Running

- Inspect for fuel, oil, water, air, and exhaust leaks (ST, LT)
- Run self check on applicable electrical systems (ST, LT)
- Check operation of HVAC (ST, LT)
- Verify that engine protection devices operate (ST, LT)
- Verify the MR charges (130 - 140 psi) and brakes set (ST, LT)
- Verify air compressor unloader valve is functioning (ST, LT)

- Load test for 30 minutes (ST, LT)
    - A load box is required for non-self loaders, a 30 minute drag test is an acceptable alternative to a load box test
- Conduct air dryer inspection for proper operation (ST, LT)
- Ensure all air MR blow-downs are functioning (ST, LT)
- Verify proper compressor output with MR orifice test to (LT)
- Conduct shop release air brake test and inspection (ST, LT)
    - Calibrate air flow meter
- Perform stall test and directional test (ST, LT)

Best Practices: Return to Service – Post Engine Running

- Shut down engine and take engine and air compressor lubrication oil samples and submit for analysis (ST, LT)
- Test lube oil for fuel dilution with a lab test or a Fuel Sniffer (ST, LT)
    - If fuel dilution is detected find the source and correct
- Test lube oil for free water using a Crackle Test (ST, LT)
    - If free water is detected find the source and correct
- Drain coolant/cleaner and refill system with water treated with corrosion inhibitor to proper TDS level (ST, LT)
- Take applicable downloads and review fault logs (ST, LT)
- Install radios and FOT devices (ST, LT)
- Release to Service (ST, LT)
- Place on a controlled run, six months preferred with no premium service for the first two months (ST, LT)

Conclusion

To ensure successful locomotive storage and return to service performance factually assess your locomotive storage process and procedures and replace non-value added activities with processes proven by other railroads or related industries. Use the Best Practices discussed in this paper to help develop a lean and standardized storage process. For continuous improvement assess your post storage reliability performance and revise your process as appropriate. Continue to share your success stories and lessons learned with the appropriate LMOA Committees to ensure data sharing amongst the Railroads, OEMs, and component and material suppliers for future improvement of the LMOA recommended Best Practices for locomotive storage and return to service.

Problem Solving Basics

Prepared by:
Tim Standish, Progress Rail Locomotive, Inc.

Many LMOA papers go over current problems impacting locomotive performance or even take a look at future issues that can impact the industry along with offering various solutions based on a combination of problem solving, industry experience and knowledge sharing. The process of going from problem to solution is not often covered in these papers so some basic methodologies will be covered here and will help find solutions in a shorter time frame, be more effective and are sustainable. Other benefits include using facts and data instead of opinions, identification of issues that are systemic and ability to find multiple causes or contributing factors to issues.

There are a number of ways to resolve problems, which will be covered here, but before jumping into a formal procedure, check to see if there are resources that are already available to help get quick solutions such as talking to an expert, opening up a maintenance manual, reading a troubleshooting guide, reviewing past LMOA papers or even going to YouTube. These resources should not be overlooked as someone has gone through some of the same issues and have come up with the most likely cause or take you down a troubleshooting path to that solution. What should not happen is just addressing the symptom by just changing parts as this may result in future more expensive failures. For example, adding oil without addressing a leak or changing a failed component when that component only failed because of another issue. Think of the cost of changing a turbo and not addressing why foreign material damaged the turbine or impeller blades only to fail a second turbo. Stepping back and sitting down and going through a methodical approach should come sooner rather than later to avoid the frustration of failed solutions or problems that linger on. When to use a formal problem solving process depends on a number of factors such as customer impact, complexity of the issue, cost associated with the issue and if the issue is wide spread (systemic). Gathering a team together to address a single instance of a small component failure would not seem a prudent use of resources if there are much larger issues to investigate. So if the issues at hand relative to certain indicators or goals are not acceptable, then it's time for utilizing a formal problem solving process.

There are a number of problem solving processes including Plan Do Check Act, 8D, 7 step, AAR Chapter 7 reporting, DMAIC among others. Regardless of the name, the following steps are key to solving problems:

1. Planning
2. Assigning a team
3. Defining the problem
4. Containing the issue
5. Root cause analysis
6. Corrective action
7. Evaluation and Effectiveness

Planning is often an overlooked important first step in the process. Without up-front planning you may get too far along in the process before you realize that you didn't have a true problem to begin with or the problem didn't need a formal process/team to resolve due to its simplicity. For planning purposes you will need to have some initial information such as what requirement is not being met and what information was given showing that it was not met. With that information you can determine what further information is needed, who can help resolve, who can help contain the issue, what is the time frame to resolve, what is desired state, what is the current state, and what is the impact to customer and organization. Having these questions ironed out at the start of the process will make the probability of success much higher along with resolving the issue quicker.

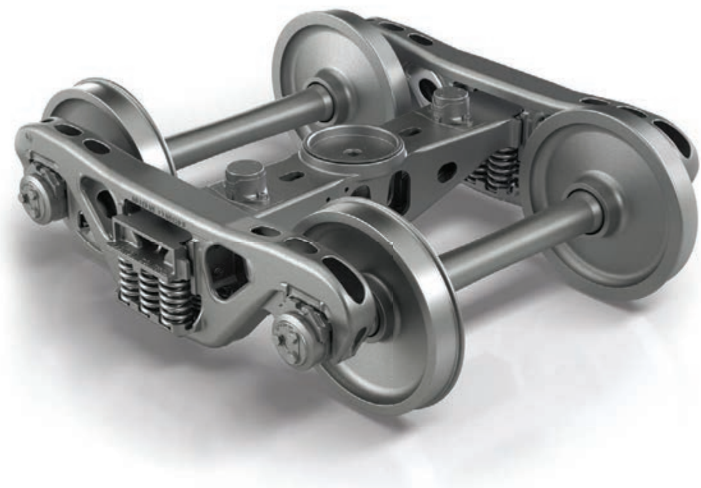
After the planning is completed, you can assign a team to properly address all aspects of the plan. Remember to include the various trades, mechanics and production employees as needed since they work with the various products every day. Having all viewpoints to an issue not only helps clearly identify the issue but is extremely helpful in getting buy in when solutions are implemented. Some questions to answer when deciding who to include: Who can help resolve this issue? Who knows the process best? Who do you need for containment? Who is a key input to the process? Who is the customer or the output of the process? Who can help facilitate this? Sometimes the problem owner is not the best facilitator. Just having someone who has availability to join the team but lacks knowledge of that process may not be a good choice. How many should be on the team? Depending on the size of the issue, anywhere from 4 to 10 people is typical. While working as a team, there are some team norms you should establish such as: speaking with data and facts – not opinions, be an active participant and ask questions if you don't understand and don't be a silent objector. Other items include there are no dumb questions, respecting everyone's opinion, everybody is equal, accepting constructive suggestions, be creative, focus on future, don't get stuck on the past "we've always done it that way". Often new ideas come from building upon other thoughts regardless of being lofty or far-fetched. Once the team is identified it is now time to go into the problem definition phase.

It is important to clearly define the problem to ensure the team is working on the right issue including not working on a symptom of the problem. All facts about the problem is needed to fully define the issue such as what locomotives is this occurring on, when or where is it occurring, what happened, what is the process, what is the defect, why did it happen this time, etc. It should also include the impact the issue is having on fleet performance (current state) and include a goal (desired state) so that you know when the problem has been adequately addressed. When writing out the problem statement, don't include possible cause or solutions as this may limit the investigation or drive the investigation down a wrong path. When defining the problem, you need to make sure that the scope isn't too large as that will increase the time to resolve or discourage the team as there might be items out of their control.

Here's a made up example of a problem going from initial report to a clearly defined problem: *Shop foreman brings up an issue: we are seeing starter motors fail after a short time in the field, must be a new supplier*. Clearly defined statement: *Utex starter motors have failed on 8 of the 30 SD40 locomotives within 4-6 months of overhaul which does not meet the expected life of 3 years. There has been no change in suppliers and based on this failure rate, we will be out of material and have to park units in around 3 months*. By having a clearly defined problem, you can start more of the investigation using facts and knowing a timeframe needed for resolution.

Now that we have identified the problem you need to determine what can be done quickly in the short term to help alleviate the problem. Should parts be quarantined and recalled, bulletins sent out to alert shops, can inspections be done at certain intervals? Containment should take into consideration how fast it can be done, who will coordinate, is the containment activity possible and acceptable to the customer. This containment action can also be used to gather critical data to help define the issue even more. Communication is needed to make sure good parts are not improperly removed, qualified parts in the pipeline are properly identified and instructions for rework are clear and do not create other unintended issues. If material returns are needed, they need to be properly identified so they don't end up back in the store room or back on the supplier's shelf. Tracking is important so that you know when this activity is done so that the same inspections or rework doesn't occur on units that have already been completed. As the containment activity is going on, it is important to monitor the temporary fix to make sure it was effective.

Now the difficult part which is determining the root cause of the issue. This is the process that if performed well will eliminate the problem from occurring in the first place. If the first steps of the problem solving process were thoroughly done, your root cause analysis will focus on the true problem and not a symptom of the problem. There are a number of tools to help determine root cause(s) but will only cover 2 in this paper, the 5 whys and the fishbone diagram. Some other tools include brainstorming, FMEA, Pareto diagrams, design of experiments, control charting,



pictographs, histograms and flow charting among the more popular ones. The tool used can be based on who will be using them (skill level), how complex the problem is (interaction effects or contributing factors) or the amount of data that is available to analyze.

5 Whys – This is a simple tool used to get to the root of the problem by asking why 5 times and helps to deepen the understanding of problem. Note that 5 is picked as the norm for the number of times asked but you could have more or less. If it is less, you might not be driving to something that is actionable. When do you stop asking why? Typically when there is insufficient data or knowledge to continue or the cause is not within our control to correct (example, the weather). An example of a why exercise is below:

1. Why would the engine not start?
   The starter motor pinion would not engage the ring gear
2. Why did the starter motor pinion not engage the ring gear?
   The pinion was not indexing properly
3. Why was the pinion not indexing properly?
   Dirt and debris were inhibiting proper indexing
4. Why was dirt and debris collecting on the pinion
   Too much grease on the pinion was creating a dirt and debris collection point
5. Why was too much grease applied?
   The work instructions were not clearly specified

By having more data in your problem definition, you can narrow down where you start your 5 whys. In this case, engine would not start is a very high level starting point and can take you in multiple directions and based on review of shop input it points you to the pinion won't engage the flywheel (starter abutment). But you can quickly see some limitations in this tool since it is linear and you may run into items that can branch off such as in this example why would the pinion not engage the ring gear. You could say damaged teeth, no chamfer on ring gear, improper backlash too much runout on flywheel, etc. You can branch off into another 5 why and come up with a number of items to investigate as root cause. This is where a fishbone diagram can prove to be more useful.

Fishbone diagram – This tool gets its name from the way it looks when filling it out. The problem statement will be put in a box to the right and then major branches (bones) are drawn to the left with each branch labeled with high level headings to investigate. Traditional fishbone diagrams will use man, material, method, machine, measurement and environment to prompt thinking about different categories of potential cause. See figure 1 showing a diagram filled out with the starter motor issue. These headings are a good starting point since you may not know what direction to start at first, but you can also use systems or parts of a process as headings. For example, for the starter motor issue, you can use the various parts of the system as the headings: pinion, ring gear, maintenance, batteries, etc. as shown in figure 2. Regardless of the path you take, once you have the top headings, you can start to brainstorm various ideas of the failure mode and add them to each branch which become items that are more actionable; see figure 3. From there you can use the data already gathered from your problem definition along with consensus from the group as to which items would be the most likely to investigate first (data usually wins this battle) and then prioritize (such as priority 1 – 3) as shown in figure 4. Start with priority 1 items and analyze information to see if issues uncovered are the part of the root cause and can be verified as such. The 5 why method can be used as you investigate each potential root cause. If it is found not to be a cause, cross it off the list, include why it was crossed off and retain data collected in case you have to revisit that item. Note, the below examples were done with Minitab Quality Companion which is a nice tool to brainstorm a list, move around items on the diagram and to set priorities. It also allows comments to be added so you can include notes on why an issue was crossed off.

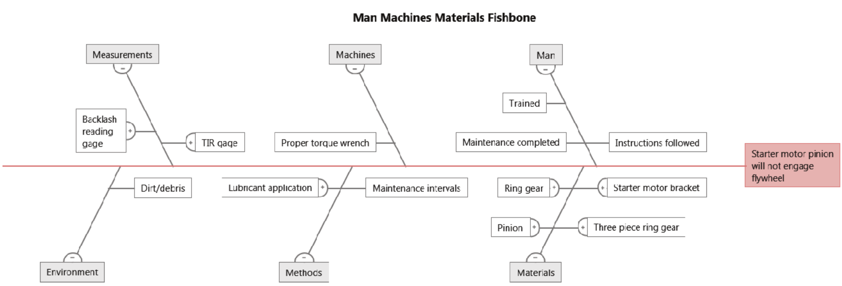


Figure 1: Fishbone using typical heading starting points

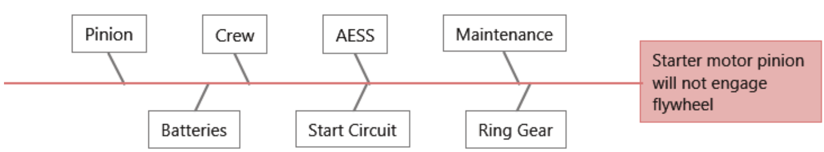


Figure 2: Fishbone headings using system parts

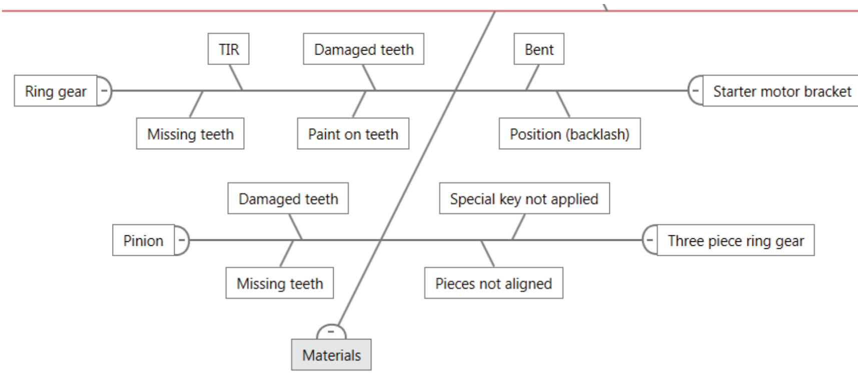


Figure 3: Breaking out branches into more details that are actionable

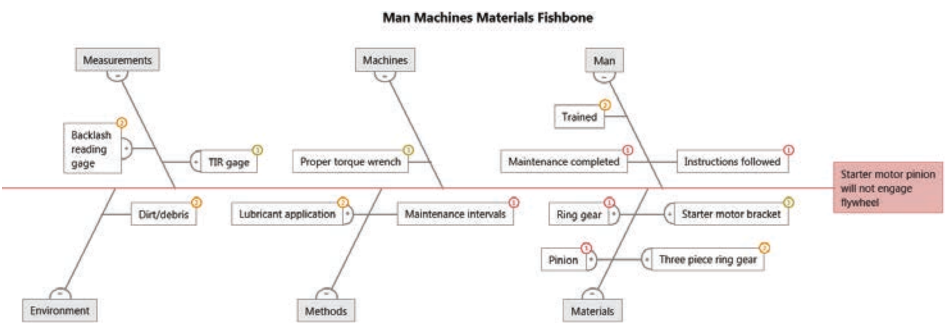


Figure 4: Example of putting priority rankings to what to look at first

After verification of the root cause, you can start to put corrective actions in place. This includes what is going to be implemented by whom and when. There can be a number of corrective actions that need to be implemented such as a design change, process change, and maintenance changes along with mistake proofing so the issue does not reoccur. You need to make sure there is a good plan for implementation such as clear instructions, a material plan, training, etc. You also need to make sure the corrective action is acceptable to process owners and customers. Make sure that if there are any long lead items to implement that the current containment is adequate while waiting. Weak corrective actions that show that the true root cause was not found or actions that are really only containment item include: we retrained the employee, we added another inspection point, check sheets were updated, replaced the broken tool or talked to the employee about the issue.

Following implementation you need to evaluate that the corrective actions are in place and also if they are effective. Evaluation means you are verifying that each of the corrective actions are in place and are being used. Check to make sure the new process instructions are in place, old ones removed, new tools or fixtures were implemented, confirmation that training was held, etc. Effectiveness is done after some period of time has passed to see if what was implemented is correcting the issue and is meeting the goals established. The period of time depends on the issue, how long it takes to gather data and how long it took for the failure in the first place. Also, do another check on the corrective action to make sure the items are still in place so that the issue will not reoccur. Based on the success of implementing these corrective actions, it is a good idea at this point to see if these solutions can be applied to other areas.

By following the steps outlined here along with using some basic tools many of the problems you may run across can be methodically solved. It is not a simple task but needs to be a planned, regimented activity in order to achieve permanent corrective action.

Locomotive Emissions Labeling

Prepared by:
Prepared by Mark Duve, Norfolk Southern Corporation

Background

As part of the initial locomotive emissions regulations as found in 40 CFR part 92 and the current 40 CFR Part 1033 regulations, emissions labels are a requirement for a locomotive that is emissions certified. After nearly 20 years of emissions labeling this paper will discuss the challenges in applying the labels and the issues in maintaining them.

This paper concentrates on some of the label regulations of 40 CFR 1033 that causes some challenges, and does not cover all the details. It is advised that each individual read the regulations and consult their legal staff.

Regulations

There are two types of required emissions labels one each for the locomotive and engine. Both label specifications are stated in 40CFR1033.135.

Locomotive Labels

All locomotive labels must be applied by the manufacturer or remanufacturer when the locomotive is made or remanufactured and the physical label must meet the following criteria:

1. Permanent
2. Written in English
3. Legible
4. Affixed in a position that is readily visible
5. Attached to a part of the locomotive that is normally not replaced during the service life.
6. Locomotive label is prohibited from being attached to the engine.
7. The label shall be attached such that it can't be removed without destroying or defacing.
8. For Tier 0 and Tier 1 more than one label is allowed as long as all the pieces are permanent.

The specific information on the label should be as follows:

1. Labeled heading, "Original Locomotive Emission Control Information." Manufacturers may add a sub label to distinguish from the engine label.
2. Manufacturer's full corporate name and trademark.
3. Date of original manufacture of locomotive.
4. The emissions standard or Family Emissions Limit (FEL) for which the locomotive is certified.
5. The statement, "THIS LOCOMOTIVE MUST COMPLY WITH THESE EMISSIONS LEVELS EACH TIME THAT IT IS REMANUFACTURED, EXCEPT AS ALLOWED BY 40CFR 1033.750.
6. Separate labels must be used by each fuel filler that designates the allowable fuel used to maintain emissions compliance (consistent with 1033.101.) For instance, Tier 4 Locomotives should be labeled, "ULTRA LOW SULFER DIESEL ONLY."

Engine Emissions Label

The engine label must be applied at the time the engine is assembled or remanufactured in the emissions configuration. If an engine has after treatment, the label should be applied after the after treatment devices are installed. The engine labels have very similar physical specifications to the locomotive label. These specifications are:

1. Durable throughout the useful life of the engine
2. Legible.
3. Affixed to the engine in a readily visible location after installation of the engine in the locomotive
4. Attached to an engine part that is not normally replaced during the useful life.
5. The label shall be attached such that it can't be removed without destroying or defacing.

The specific information found on the engine label is as follows:

1. Label heading, "ENGINE EMISSION CONTROL INFORMATION."
2. Full corporate name of the manufacturer and remanufacturer.
3. The engine family and configuration identification which is specified on the emissions certificate for either new or remanufactured.
4. The "prominent" unconditional statement that of EPA compliance for the appropriate emissions tier certification. For instance, for Tier 3 Line Haul Certification the statement would read, "This locomotive conforms to US EPA Regulations Applicable to Tier 3 Line Haul Locomotives."
5. The useful life of the locomotive as specified in 40 CFR 1033.901 (g)
6. The standards (either 40 CFR Part 92 or Part 1033) and FEL (if applicable) for which the locomotive was certified.

7. The regulations also allow for the following optional information:
    1. Other emissions standards such as international standards.
    2. Information to ensure proper maintenance.
    3. Features to prevent counterfeiting, such as the engines serial number.

The regulations also allow an organization to request for modified labeling requirements if it can be shown to be necessary.

Engine Family

The engine family is a 12 digit name that is based upon a code as follows:

First Digit: Model Year Code: The model starts with 1 in 2001 and runs up to 9 for 2009. Beginning in 2010 an alphabetical character is used for the year. Model year 2010 uses the letter "A"; 2011 uses letter "B" and so on.

2nd through 4th Digit: Manufacturer Code: The EPA's code for the manufacturer common codes are as follows:

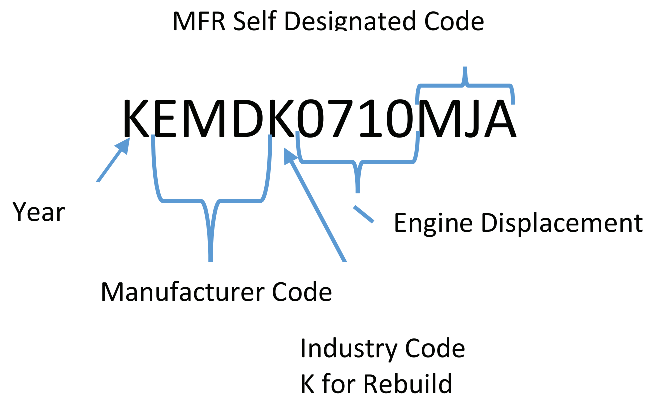
GMX: General Motors (EMD until 2005)
EMD: Electromotive Diesel and Progress Rail (2005 until present)
GET : GE Transportation
KBI: Hatch and Kirk
TER: Thoroughbred Emissions Research
ECT: EcoTrans

5th Character: Industry Code: For locomotives, there are two industry codes, which are the letters G and K. The letter "G" signifies a newly built engine, and the letter "K" signifies a rebuilt engines.

6th through 8th Characters: Engine Displacement: In the locomotive market, both major builders Progress Rail (EMD) and Wabtec (GE) use displacement in cubic inches per cylinder. For EMD engines, 0710 and 0645 are used for the 710 and 645 engines respectively, and for GE engines 0668 and 0958 are used for the 7FL and EVO engines respectively.

9th through 12th Characters: Manufacturers Self-Designated Code: These three characters are selected by the certificate holder for which there are no regulatory rules.

Example of Engine Family Designations are as follows:



Family Emissions Limits

Any time a certificate holder wishes to generate credits by certifying a locomotive below the legally required emissions levels as stated in 40 CFR 1033.101 or if the credits are used in the certification the locomotive will have a Family Emissions Limit (FEL). These FELs must be stated on the locomotive and engine labels if the FEL was used in the certification.

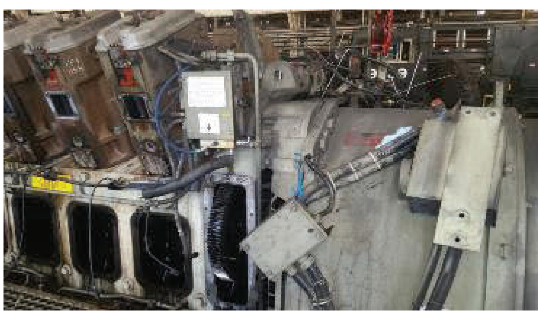
Location of the Labels:

The law does not state where the labels are to be located on the engine and the locomotive; it is up to the manufacturer. When a label is provided as part of a kit, it must be placed in the location as stated in the kit instructions.

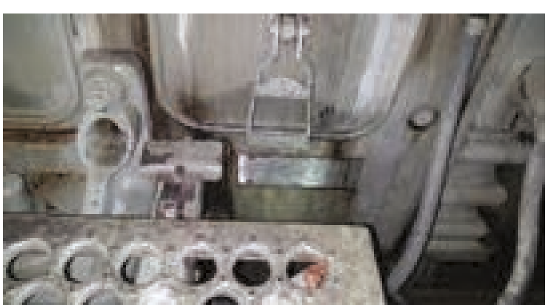
On GE locomotives, the locomotive label is on the exterior of the engineer's side of the cab for both new and overhauled locomotives. The L engine emissions label on the Dash 8 and 9 is found on the crankcase section that mounts to the alternator as pictured on next page. On the EVO engine, the label is located under the crankcase door on the left rear side of the engine.

GE Locomotive Label Location
Engineer's Side of Operators Cab

GE Dash 8 and Dash 9 Location
Near Locomotive Engine Start Station
Engine Blocks Alternator Mounting Face



GE EVO Engine Location
Under Crankcase Door – Left Rear Side

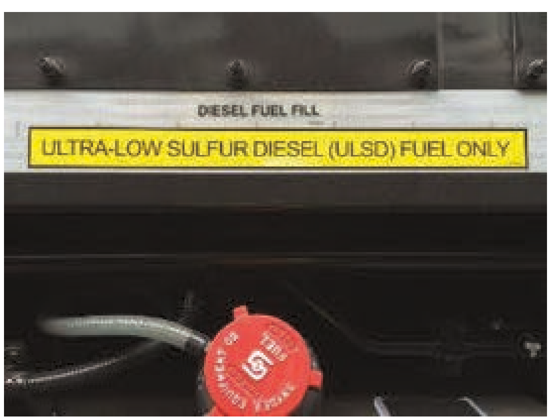


On new EMD locomotives, the label is also on the exterior of the engineer's side of the cab. However, for EMD locomotives that were produced prior to emission regulations taking place and brought into the emissions regulations through overhaul, the locomotive emissions label can be located on the upper counsel in the cab or on the underframe side sill on either side. The engine label is typically located on the right side (conductor's side) of the engine below the engine build plate.

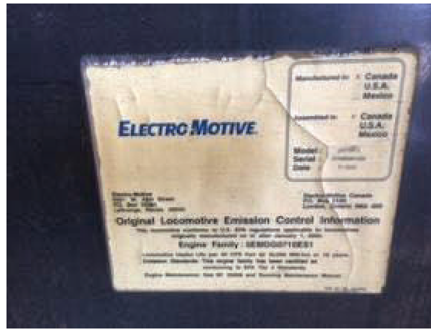
In addition, there should be another decal stating the anti-idling device, and for Tier 4 locomotives there must be a label near each fuel filler that states, "Ultra Low Sulfur Diesel Only."

GE Idle Reduction Label Location
Above or beside the Locomotive Label

Ultra-Low Sulfur Diesel Fuel Label
Required for Tier 4 Locomotives (including Tier 4 Credit Locomotives)



New EMD Locomotive – Label Location
On the nose of the Operator's Cab

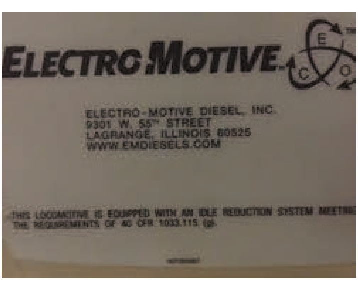


Rebuild EMD Rebuild Locomotive Label
On the Under Frame Side Sill (either side)

Alternative EMD Rebuild Locomotive Label Location
Inside the Operator's Cab

EMD Engine Label Location
Under or Beside the engine badge plate

EMD Idle Reduction Location
EMD's Idle reduction label can be in various locations, shapes and wording.



Label Findings

Norfolk Southern has an emissions auditing process where locomotive mechanical staff inspect locomotives for emissions compliance. This section details the findings of the inspections.

Environmental Issues

All emissions labels are subjected to harsh environments. The labels mounted externally to the locomotive are subjected to wind, rain, sun and debris. Over time the labels will deteriorate, become cracked, damaged or completely fall off. The labels on the engine are also subjected to a harsh environment with wide temperature variations and oil soaking. Those labels that are installed in the cabs are subjected to vandalism by the crew, and in some cases removed by the crew members. Over time most labels will either become illegible or fall off. Examples of labels are shown in the pictures below:

Deteriorated and Damaged EMD Label

Deteriorated GE Label

Soot Covered Locomotive Label

Missing Locomotive Label

Oil Soaked 7FDL Engine Plate

Oil soaked EMD Engine Label

Deteriorated GE Engine Plate

Double Labeling

It is common to see locomotives that were either built or brought up to 40 CFR Part 92 standards eventually overhauled and then brought up to 40 CFR Part 1033 standards. In this case, there is no guidance in the emissions regulations on removing the locomotive labels that were applied under Part 92, and there are many locomotives with both the Part 92 and Part 1033 labels. At an LMOA meeting, an EPA representative stated it is acceptable to have the dual labels; however, some railroaders would prefer to see that statement in writing.

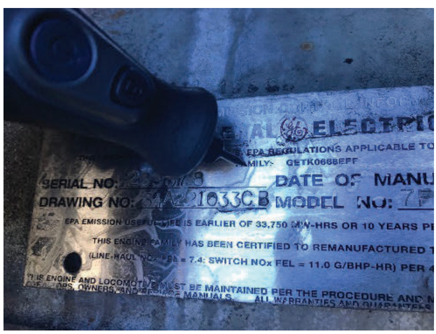
Examples of both Part 92 and Part 1033 Labels on the same locomotive

Filling In Labels

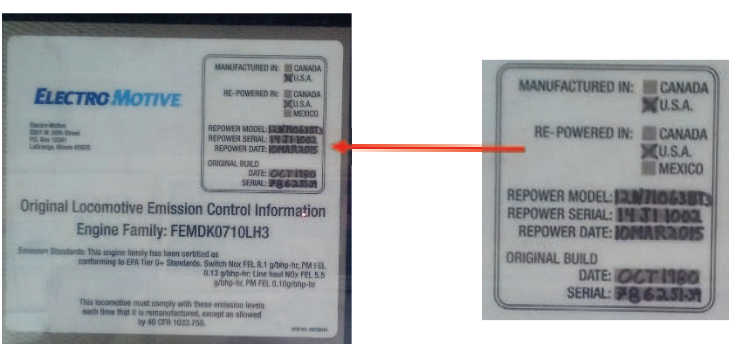
Because of the many variations of emissions kits, many labels are produced with blank spaces that need to be filled in. These labels are filled in by craft people that may not have all the information necessary to accurately fill in the label. In addition, it takes some skill to fill in the label legibly. Typically on the GE label, the first year character must be filled in with the use of a scribing tool or punch. On the EMD repower label a marker must be used. The methods of the scriber and the marker makes it a challenge to produce a legible label. Care must be taken to ensure the employee filling in the label has a steady hand or best penmanship and has the correct information. As seen in the pictures below, not only railroads have struggled with this issue but also the locomotive builders.

As an alternative to filling in labels, some manufacturers have supplied pre-filled in labels. This solution works until the end of the year and beginning of the next year at which time there is a frantic purge of old labels and new labels must be expedited.

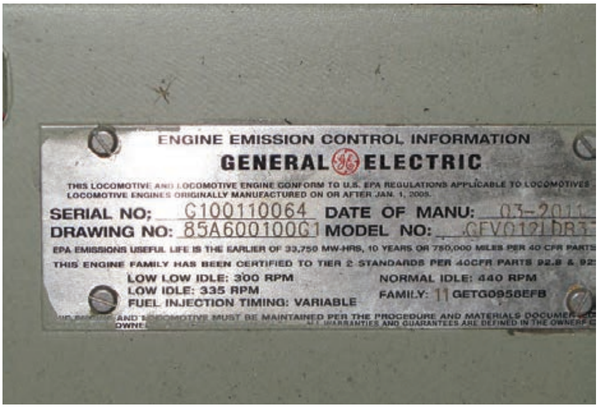
Challenges of filling in Labels



Scribing the Date Character on the GE Engine Label



Filling in the Information on the EMD Repower Label with marker



Incorrect Date Character (Per 1033, the Date Code should be letter “B” instead of 11)

Replacement Labels

Both manufacturers struggle with providing replacement labels in a timely manner. A replacement label from GE has a two month lead time and an EMD label has a month lead time.

Once the replacement label is received it is another challenge to get it to a particular shop location where it can be applied. A locomotive label can be applied at one of 45 shop locations on Norfolk Southern. The basic problem is knowing which shop the locomotive will head to for servicing since servicing is done at the closest shop on an as needed basis. In addition, through interchange, locomotives can be off line on a foreign railroad for months.

Record Keeping

Due to the variations in engine families and the leading year character the Norfolk Southern has 167 emissions kits for 4,000 locomotives. In 2020, it is expected the number will increase to over 200 kits. For a majority of the kits, the engine components are the same; the difference is caused by the labels.

Conclusion

The current emissions kits which include labels with many variations of engine families and date codes are a major concern in keeping the fleet in compliance. The locomotive operating environment is not conducive to any current label. Also due to the many variations in engine families, date codes and locomotive fleet size, the task of getting the correct information on the label is quite cumbersome. A better method of documenting the correct emissions information as required by the regulations previously noted is seriously needed.

DEF Systems for Locomotives

Prepared by:
Allen Meek, Cummins, Inc.

Introduction

With the 2015 adoption of the US EPA Tier 4 Locomotive regulations, engine manufacturers have opted to utilize various technologies to meet these requirements. The nitrogen oxide (NOx) levels decreased 76% with the new Tier 4 regulations, which has led to the adoption of Selective Catalytic Reduction (SCR) aftertreatment by some engine manufacturers. To complete the chemical reaction and reduce NOx levels, Diesel Exhaust Fluid (DEF) is injected into the exhaust prior to the SCR.

Figure 1 shows some components used to store and transfer DEF (Urea) in a typical SCR aftertreatment system. These components are new to the locomotive industry and require special attention to ensure proper DEF delivery to the exhaust stream.

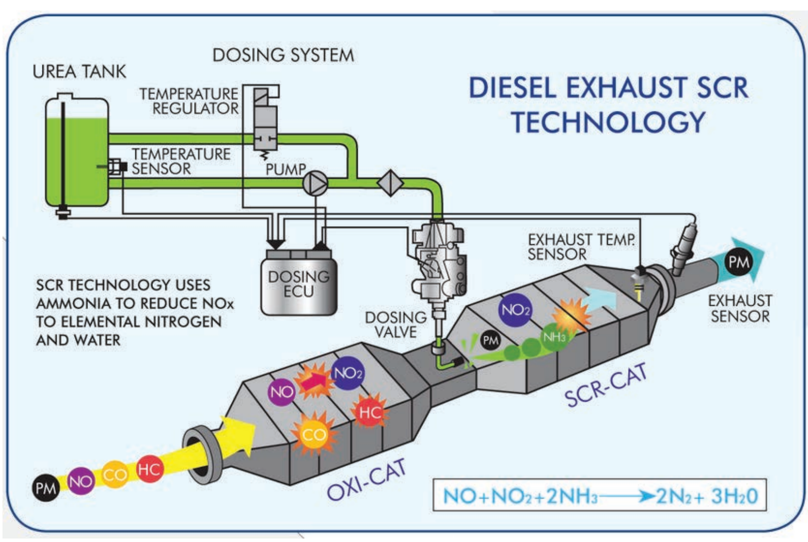


Figure 1: Example SCR System

Challenges with DEF (Urea)

The 2011 LMOA paper "*Diesel Exhaust Fluid Properties & Technical Information*" by Joseph Hiznay of Colonial Chemical Corp was the first LMOA paper written on the topic of DEF. Some key points from this paper regarding DEF include:

Temperature:

DEF freezes at 12° F, but freezing does not affect DEF quality. Once thawed, it returns to a homogenous solution ready for dosing into the exhaust stream. Frozen DEF expands approximately 7%, so some aftertreatment systems are designed to purge the DEF lines with compressed air, while others allow the DEF to freeze in the lines and be thawed by electric heaters.

Quality:

The purity of DEF is critical for locomotive performance, and purity is mostly reliant on the supply chain. DEF requires proper storage and handling to assure quality. DEF is a water based solution composed of 32.5% urea.

Shelf Life:

When DEF is stored at an average temperature between the recommended temperature range of 15-80° F, the shelf life will be between 1-3 years. The graph in Figure 2 shows the effect of temperature on DEF shelf life. Proper storage of DEF is critical to maintain its quality.

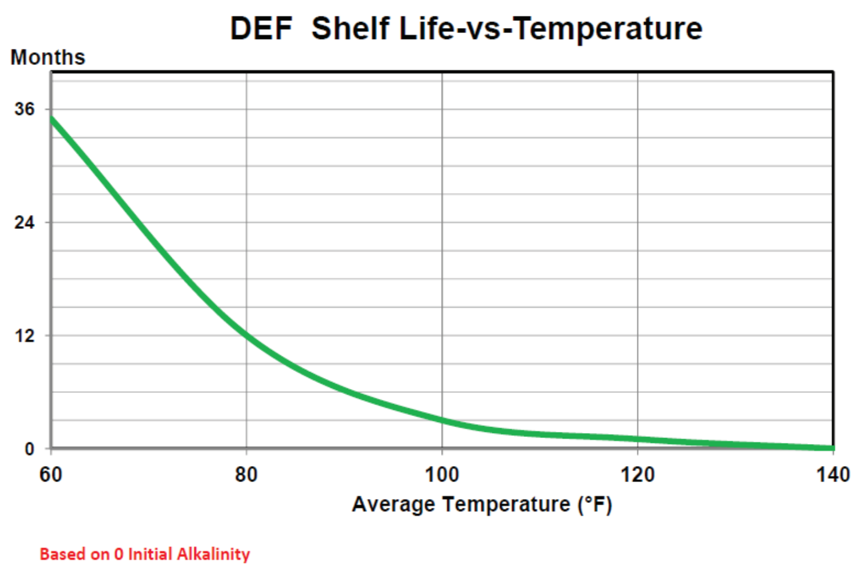


Figure 2: DEF Shelf Life

Corrosiveness:

Since DEF is mostly an aqueous solution, it is not considered a hazardous material. DEF may cause minor skin irritation on some individuals, but in general there are not any special handling considerations. DEF will however react to certain materials and potentially corrode some types of metals. Therefore, it is very important to only use compatible materials to store or dispense DEF. Figure 3 lists some material recommendations.

Materials compatible with DEF

To avoid contamination of DEF and to resist corrosion, all containers, valves, fittings, gaskets, hoses, etc. in direct contact with DEF must be compatible with DEF.

Examples of materials recommended for use with DEF are:

a) Stainless steel 304 (S30400), 304L (S30403), 316 (S31600)
b) High Density Polyethylene, free of additives (HDPE)
c) Titanium
d) Some Epoxy resins
e) Polytetrafluoroethylene (PTFE), free of additives

The following is a partial list of incompatible materials:

a) Carbon steels, zinc coated carbon steels, mild iron
b) Non ferrous metals and alloys (copper, zinc, lead)
c) Solders containing lead, silver, zinc or copper
d) Aluminum, aluminum alloys
e) Magnesium, magnesium alloys

Figure 3: Material Compatibility with DEF

Typical Systems

In 2018 the LMOA paper from Kelle Ravn "*SCR for Locomotive NOx Reduction*", Kelle described some of the current SCR systems in locomotives. While the hardware in these systems vary, they all use DEF with the SCR to reduce NOx emissions to acceptable levels. Typical DEF systems include the following components:

- Tank
- Pump
- Doser
- Lines
- Electronic Control Modules
- Sensors

Depending on the manufacturer's design, the DEF can be allowed to freeze in the system or purged after engine shutdown. There may also be a Pre-Oxidation Catalyst prior to convert as much of the NO to NO_2 prior to the DEF injection on some systems. These catalysts are often used to improve NOx conversion efficiency in the SCR. Figure 4 shows a few examples of DEF systems.

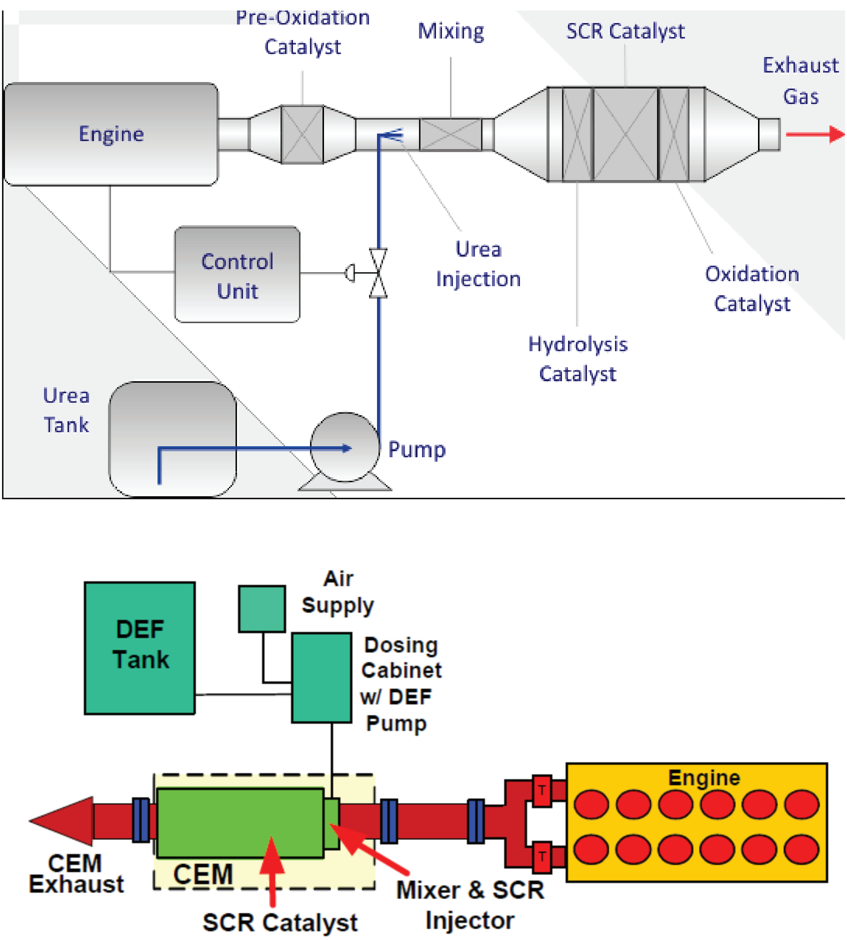


Figure 4: Example DEF Systems

Tank

DEF tanks are typically made of stainless steel or plastic, with most locomotive installations utilizing a stainless-steel design due to the location of the tank. Another common design is to use a plastic tank inside a heavy steel plate box to mount the tank and protect it from damage. Most DEF tanks are located next to the fuel tank on the underside of the locomotive frame, as shown in Figure 5.

Figure 5: Locomotive DEF Tank

The tank is usually sized for a 1:1 ratio of DEF consumption to fuel consumption for common fill events. Depending on the DEF dosing rate, the DEF tank will be between 3-10% of the fuel tank size.

Figure 6: Stainless Steel DEF Tank

Headers in the tank are usually mounted on the top and contain multiple fluid connections and sensors. DEF supply and return lines are included in the header and extend to bottom of the fluid level. Attached to the DEF supply line is a filter to prevent debris from entering the DEF system. Multiple sensors are included on the header as well, including level, temperature, and quality sensors. Depending on the design of the tank, the coolant heating lines or electric heaters could be included on the tank header.

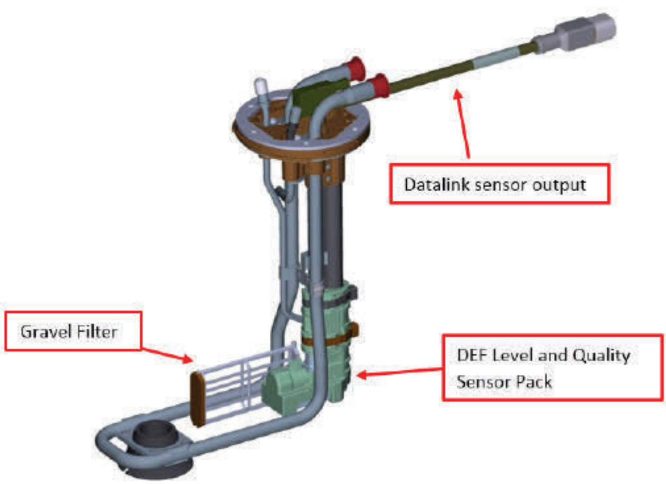


Figure 7: DEF Tank Header

Since DEF freezes at 12° F, consideration for freezing and thawing of DEF needs to be incorporated into the design of the tank. DEF tanks are designed with enough expansion space above the fluid level for the entire capacity of DEF to freeze. Heaters inside the DEF tank are used for thawing the DEF and freeze prevention. These heaters can either be electric or use the engine coolant. With coolant heating systems, a control valve meters the coolant depending on the temperature of the DEF in the tank. Figure 8 shows the fluid flow in a DEF tank.

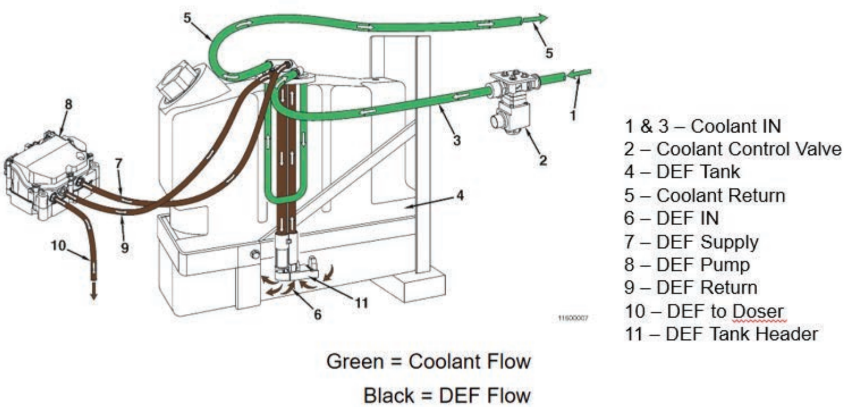


Figure 8: DEF Tank Fluid Flow Details

Fast fill necks are available for DEF tanks to minimize the fill time. Tanks should always have a blue cap and label next to the cap indicating the tank is for DEF.

Pumps

Pumps are used to transfer DEF from the tank to the doser. Depending on the manufacturer, there could be one pump for all dosers or multiple pumps. The pump can be powered electrically or use compressed air to transfer the DEF. Heaters are also incorporated into the pumps to ensure DEF doesn't freeze. Pumps use either electric heaters or engine coolant for freeze prevention or thawing.

Figure 9: DEF Dosing Cabinet

Figure 10: DEF Supply Module (Pump)

Dosers

Dosers are used to inject DEF into the exhaust upstream of the SCR catalyst. Dosers can inject the DEF with an air assisted injector or electronic actuator valves. Because of the location of the doser, they need to withstand high temperatures. Some systems maintain temperatures by circulating DEF through the doser. In systems that use DEF to cool the dosers, the DEF tank has a reserve volume of DEF below the EMPTY level to use for cooling the DEF when it is returned to the tank.

Figure 11: DEF Dosers

Lines:

DEF lines are used to transfer DEF from the components in the overall system. The lines can be constructed of braided stainless steel, Nylon, or EPDM. EPDM hoses have been designed to expand when DEF freezes in the line. If required, the lines can have electric heaters built in. Lines will be sized to maintain the required fluid pressure without causing excess restriction.

Figure 12: EPDM DEF Line

Connections with the components can use standard stainless-steel adapters or SAE J2044 style quick connectors. DEF compatible materials are required.

Electronics & Sensors:

Electronic Control Modules (ECM) are used to control all aspects of the SCR system, from DEF pumping rates, valve actuation, dosing rates, emissions levels, temperatures, pressures, etc. Most of this information is transmitted via SAE J1939 CAN communications.

NOx sensors are added to the exhaust stream before and after the aftertreatment to measure emissions and allows the ECM to determine appropriate DEF dosing rates. NOx sensors typically have their own ECMs to analyze the data and then transmits the data to the SCR control ECM via CAN communication link.

Figure 13: NOx Sensor

Multiple temperature sensors are also required to provide inputs to the control system. Exhaust gas temperature sensors are installed in the exhaust stream to determine when the SCR has reached the required temperature to support the chemical reactions and allow DEF dosing. An ambient air temperature sensor is included to determine when heating of DEF components is required.

DEF quality sensors are also incorporated in the tank header to determine if the DEF quality is adequate. The ECMs also uses the various sensors to determine if there is inadequate DEF in the system and will generate fault codes as necessary.

Additional cab equipment will be required as well for the DEF system. A DEF tank level gauge will be in the cab to ensure DEF tank is filled. For DEF fault codes a new warning lamp will be displayed on the control screen.

Figure 14: DEF Fault Lamp

Maintenance Requirements

With the added components within a DEF system, there are added maintenance requirements. Added filters are designed to align with existing locomotive maintenance intervals. The following additional filters will need regular replacement:

- DEF tank filter
- DEF pump filter
- Compressed air filters

Unlike other Industrial machinery, Locomotives will not be shut down or disabled due to DEF faults. When the aftertreatment system is preventing the proper conversion of exhaust emissions, an electronic timer is used to record the amount of time the system is out of compliance. It is the responsibility of the locomotive owner/operator to report this out of compliance time to the EPA.

Conclusion

While DEF is a relatively new fluid for locomotives, it has been used extensively on other diesel-powered equipment in the rail industry for many years. With increased DEF usage and infrastructure development in rail yards, the management and maintenance of DEF and components on locomotives will become common practice.

References:

Hiznay, Joseph, “Diesel Exhaust Fluid Properties & Technical Information”, LMOA, September 2011

Caterpillar, Inc., “Cat Clean Emissions Module Application & Installation Guide”, LEBM0023-04, 2016

Nott, Dennis, “Pacific Harbor Line Tier 3+ and Tier 4 Re-Powered Locomotive Emissions After-treatment Experience”, LMOA, 2013

Ravn, Kelle, “SCR For Locomotive NOx Reduction” , LMOA, 2018

BNSF & GE Pilot Hybrid Locomotive Consist Using a Battery Electric Locomotive

Prepared by:
Michael Cleveland, BNSF

Abstract

As a part of their commitment to technology, service, and environmental stewardship, BNSF is investing in the development of multiple types of battery electric equipment. This project is highlighted by a partnership with GE Transportation (a Wabtec Company) to pilot a battery electric locomotive, which will form a hybrid locomotive consist. The battery electric locomotive will work collaboratively with the conventional diesel locomotives in the consist to deliver the tractive and braking effort in the most energy efficient manner. This partnership aims to develop a locomotive platform and subsystem with the latest generation of battery technology that can be utilized.

By rethinking the behavior of locomotives within a consist, BNSF & GE expect to reduce the fuel consumption across all locomotives within the consist while also reducing carbon, oxides of nitrogen, and particulate matter emissions. Through integration with the Trip Optimizer system, the locomotive consist will evaluate the battery state of charge, trailing tonnage and upcoming terrain, to determine the optimal train handling strategy that yields the most fuel efficient operation.

To reduce local emissions surrounding train yards, the locomotive consist will be able to operate in a "low emissions" mode which idles or shuts down the conventional diesel locomotives. In this mode, all yard operations (train arrival, departure, and locomotive hostling) will be performed by the battery electric locomotive. To evaluate the effectiveness of charging, a wayside charging station at the origination terminal will be installed.

This development is a part of BNSF's larger Flexible Solutions for Freight Facilities Initiative, which is funded in partnership with San Joaquin Valley Air Pollution Control District via California Air Resources Board's Zero and Near Zero Emissions for Freight Facilities grant program.[1]

1 Marruffo, Amanda, and Dan McNair. "Flexible Solutions for Freight Facilities." *NorCal Clean Fleet Expo*, 17 Oct. 2018, norcalcleanfleetexpo.com/program/2018presentations/Marruffo_McNair.pdf.

Introduction

Since the introduction of diesel electric locomotives in the 1930s, improvements have been focused on sub-system performance. Traction systems have more torque and engines are more reliable producing more power and use less fuel than ever. Years of hard work and good engineering focused on iterative improvements has made the North American locomotive platform the gold standard worldwide. These improvements have not dramatically changed locomotive architecture and locomotive consists, but with few exceptions, multiple locomotives simply follow the instructions given to all locomotives in the consist. This demonstration project aims to change locomotive consist behavior through the application of modern battery technology.

In the past 20 years, the automotive industry has made significant advancements in the application of batteries to improve the total cost of ownership of passenger vehicles. These advancements are driven largely by the vehicle application of battery technologies traditionally reserved for consumer electronics. Hybrid cars were the first commercially viable example of this trend, which currently manifests as the plethora of battery electric car and truck projects. The cost, power, and energy density of the batteries used in these vehicles is now attractive enough to consider their application in high power applications such as freight locomotives.

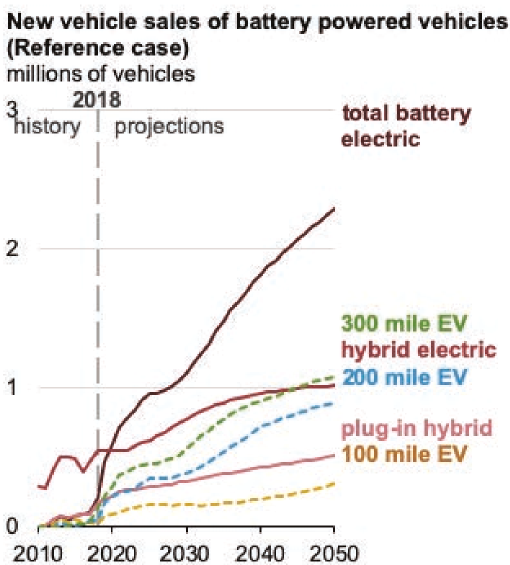


Figure 1 New vehicle sales of battery powered vehicles[2]

2 "2019 EIA Annual Energy Outlook." *2019 EIA AEO*, U.S. Energy Information Administration, www.eia.gov/outlooks/aeo/.

This project aims to apply lithium ion battery technologies from the automotive industry in the locomotive space. Similar to the development path of the automotive industry, this project will use a battery electric locomotive to create a hybrid locomotive consist. This paper will describe the motivation, approach, and recommendations for the development of this concept.

Previous Battery Electric Locomotives (BELs)

The concept of a battery electric locomotive is not new with the first battery electric locomotive being produced in Scotland in 1838.[3] Michael E. Iden in his 2014 ASME paper, identified 126 locomotives using batteries as a propulsion mechanism. Mr. Iden points out that with the exception of two locomotives all of these locomotives are lower power switching locomotives and none remain in service. The two line-haul locomotives were both experimental concepts built by GE to test the concept of energy recovery from dynamic braking.[4]

Figure 2 GE Hybrid Locomotive

The most notable example of battery electric hybrid locomotives is the Railpower Green Goat locomotives. Fifty-five were produced by Railpower and operated from 2005 to 2012. They were battery operated, with lead acid batteries packs providing all the tractive energy, and a 224kW diesel generator recharging the batteries. They were capable of 1492kW of power and had nameplate energy capacity of 806kWh.[5]

3 Middleton, William D. *When the Steam Railroads Electrified*. Indiana University Press, 2001.

4 "GE Unveils Hybrid Locomotive." *Railway Gazette*, www.railwaygazette.com/news/single-view/view/ge-unveils-hybrid-locomotive.html.

5 Iden, Michael E. "Battery Storage of Propulsion-Energy for Locomotives." *ASME 2014 Joint Rail Conference*, 2014, doi:10.1115/jrc2014-3805.

Figure 3 UPY 2319 Green Goat Locomotive[3]

To date all major examples of battery electric or hybrid locomotives have functioned either as single locomotives or operated in the conventional locomotive manner. With the exception of mother-slug sets, power sharing across the consist has not been widely employed. Consist power sharing is a key enabling technology for the hybrid consist as it allows energy to be used most efficiently. For the purposes of this demonstration the power sharing will be done virtually through the energy management software.

It is useful to compare and contrast the BEL presented in this demonstration against the previous examples discussed here. Firstly, the BEL presented here is not a hybrid locomotive; all of its energy comes from the lithium ion batteries making it a true battery electric locomotive. In the case of the Green Goats or the GE experimental locomotives, there were multiple modes of energy production (batteries and diesel). The demonstration BEL alters the consist's operation to form a hybrid consist. In operation the consist has the ability to provide tractive effort via battery or diesel energy. Secondly, this is the first locomotive to use lithium ion batteries for energy storage. Lithium ion batteries represent a step change in power and energy density over other common battery types. Use of the latest technology batteries allow the locomotive to operate at a significantly higher power output than previous battery powered locomotives. This demonstration

represents a new direction for locomotive design, operation, and performance. While this demonstration shares some similarities with previous locomotives it should be considered independently of these efforts.

Motivation

Diesel fuel represents one of the largest expenses for North American freight railroads. This cost is largely driven by line haul freight locomotives. Taking a cue from the automotive industry, locomotive fuel costs may be reduced through the use of battery energy storage systems in a hybrid arrangement. In order to reduce fuel consumption and associated emissions, efforts to create a hybrid locomotive should be focused on line haul applications.

As discussed in the previous section, battery locomotives are not a new concept. However, previous efforts have focused primarily on switcher or intermediate locomotives. The higher power capabilities of lithium ion batteries allow for systems that produce power levels required by modern high horsepower line haul locomotives. Given the space and weight restrictions on locomotives and relatively low energy density of lithium ion batteries (when compared to diesel fuel), full replacement of diesel powered locomotives is not practical currently. Instead, augmenting diesel performance through the use of a hybrid battery system allows for a true long haul locomotive solution.

By rethinking the operation of locomotives and introducing battery technology, the options for locomotive operations are significantly improved. In a modern diesel locomotive there are relatively few design elements that can be controlled. In practical terms, the power output of the engine, number of powered axles, and fuel tank size are the major limiting factors in diesel locomotive performance. By introducing tractive batteries to locomotives, significantly more degrees of design freedoms are created. Battery power and capacity can be varied similar to engine power and fuel tank size but now with this design additional new choices can be explored. By having both diesel and battery power available, the batteries can be reserved for use in specific geographic regions and charging can be done strategically (both statically and dynamically). The flexibility afforded by this combination of diesel and battery power allows railroads to target locomotive performance to specific operating challenges across their networks. For example, low noise and emissions operation can be used for rail yards in densely populated areas (potentially at the cost of reduced fuel savings on mainline train traffic). Alternatively, high fuel consumption routes can be targeted for early implementation to reduce system fuel costs. To determine the optimal solutions to these scenarios, modeling combined with pilot testing will inform future decisions.

Approach

In order to achieve a battery electric hybrid locomotive consist, many subsystems must be developed and tested. Each of these sub-systems is complex and requires integration with the locomotive and locomotive consist in a novel manner.

The most fundamental component of the hybrid consist is the battery electric locomotive. For the purposes of development and technology demonstration, the GECX 3000 will be converted to a 4400 HP four powered axle all battery locomotive. The tractive system on the locomotive is similar to the ES44C4 or ET44C4 locomotives common to BNSF's fleet except that each axle has its own DC link fed by the batteries instead of the common DC link on standard C4 locomotives.

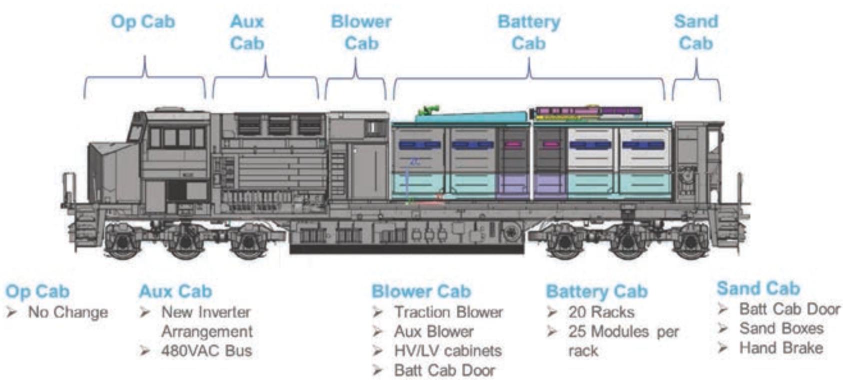


Figure 4 BEL Arrangement Description[6]

The battery system is comprised of modular subcomponents as is common in other electric vehicles, albeit at a larger scale. Each powered axle is fed by several battery strings. Each battery string is made up of between twenty to thirty battery modules. These battery modules are the minimum service replaceable unit and repairs are not expected on individual cells. Contained within each battery module are cells arranged into stacks. For the purposes of this demonstration, the lithium ion cells are a standard automotive pouch type cell.

6 "BEL Demo Overview." GE Transportation, 2019.

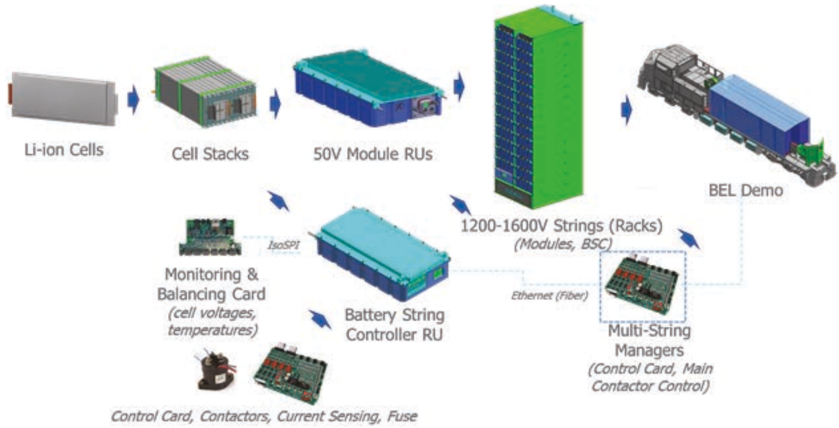


Figure 5 Battery System Breakdown[7]

In this demonstration, eighteen thousand battery cells provide three megawatts (~4400 HP) of power expected out of a modern high horsepower freight locomotive. Their energy capacity is 2.4 megawatt-hours, which is roughly equivalent to the usable energy of about one hundred fifty gallons of diesel fuel. While insufficient for traditional locomotive operations, in a hybrid consist the BEL may reduce total consist fuel consumption by 15% or more.

It should be noted that a key attribute of this demonstration is iterative design; the cell, module, string and locomotive are all expected to change as pilot learnings are incorporated into future versions. Throughout the design of these battery locomotive subsystems, ensuring the ability to incorporate future technology improvements is a key consideration. The battery cells are a common form factor with a long predicted development lifetime. The modules can be adapted from air to liquid cooling as needed. The battery strings and string controllers are adaptable to future versions of modules and locomotive control systems. This means that future versions of the locomotive can be adapted as technology advances and most importantly learnings from this project can be rapidly integrated.

At a consist level, the battery electric locomotive will supplement the performance of the conventional diesel locomotives to provide fuel and emissions reductions. When the consist is using dynamic braking, braking energy will be shifted to the BEL to be recovered until the batteries are sufficiently charged. This "en-route charging" is expected to be the primary method of charging the BEL's batteries. When tractive effort is required, the batteries will use this recovered energy to offset the tractive energy required from the whole consist. This is the fundamental operation of the hybrid consist.

7 "BEL Demo Overview." GE Transportation, 2019.

To create the hybrid consist, the lead locomotive must communicate with the other locomotives. Communication includes understanding locomotive capabilities, state of charge for the BEL or BELs, and issuing operating commands. The lead locomotive will communicate using Ethernet over MU (eMU). This system transfers high speed digital signals over the low speed digital pins on the MU cable. This provides seamless operation to the train crews; no additional wires or cables are required. During the initial demonstration the BEL will have two "mate" locomotives equipped with the hardware and software to support the BEL's operation. Once widespread implementation of this technology is achieved, all locomotives in the consist may be equipped with the hardware and software to take advantage of the BEL's energy savings.

Figure 6 Hybrid Consist Demo Arrangement[8]

To maximize the benefits of the BEL within the consist, the lead locomotive will run a modified version of Trip Optimizer (TO). TO uses route and train analytics to plan the optimal throttle notch schedule to minimize fuel consumption. In the hybrid consist, the TO system will also plan for the battery state of charge and will shift dynamic braking and tractive effort to the BEL based on the route terrain and power needs. The BEL will charge under dynamic braking and reduce demand from diesel locomotives in the consist. The planning and optimization is to be seamless to the operator and the system will ensure that in all cases sufficient tractive or braking effort is being delivered to safely manage train speed.

While in the rail yard, the consist can operate in a "low emissions mode" where all tractive effort is delivered by the BEL and the diesel locomotives idle or shut down. This has the effect of reducing local emissions while not negatively impacting train operations. In Stockton California, a wayside charger will charge the BEL prior to departure. This allows for testing the impact of way side charging on fuel reduction. Additionally, it will allow testing of the procedure, ergonomics, and system integration of "plug-in" locomotive chargers. While automatic charging of the locomotive through overhead catenary, third rail, or inductive charging is likely to be an important aspect of future BELs, it would have added an additional layer of complexity and cost for this demonstration.

8 Cleveland, Michael. "BNSF's Alternative Fuels." DOE, *H2@Rail Conference*, 2019.

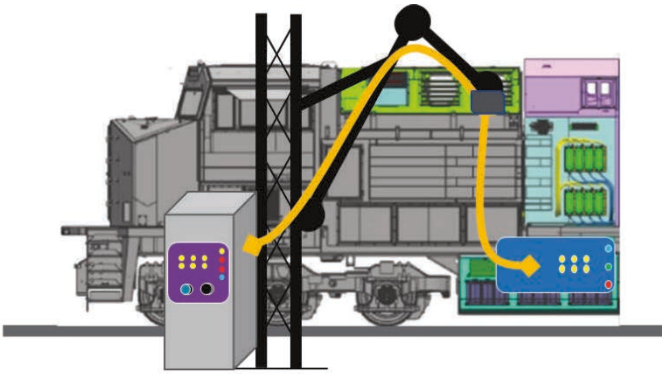


Figure 7 BEL Charger Concept[9]

Testing of the BEL and hybrid consist will be on mixed manifest trains operating between Stockton and Barstow California. This route was selected due to its high dynamic braking usage from Tehachapi pass as well as being a controllable and captured service for testing.

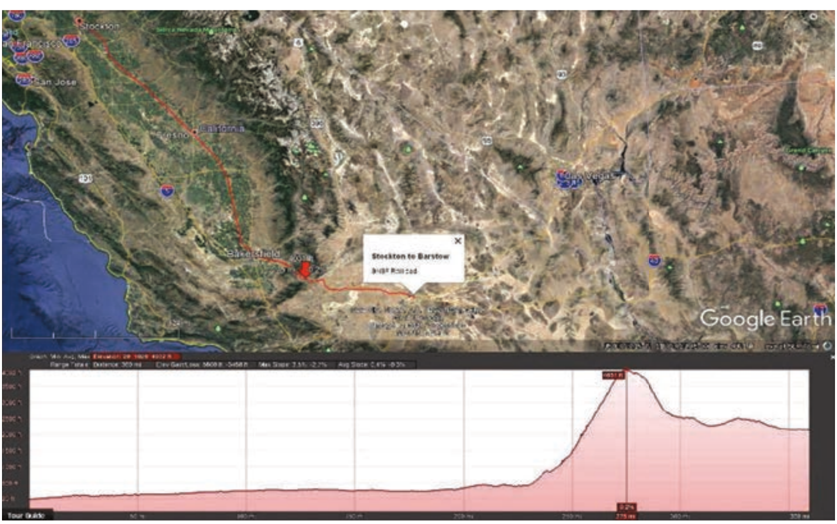


Figure 8 Demonstration Route[10]

9 "BEL Demo Overview." GE Transportation, 2019.

10 "Flexible Solutions for Freight Facilities - San Joaquin Valley Zero and Near-Zero Emission Enabling Freight Project." *San Joaquin Valley Zero and Near-Zero Emission Enabling Freight Project*, San Joaquin Valley Air Pollution Control District, 19 July 2018.

Once initial testing is complete and consist performance has been successfully proven, additional testing and routes have been planned. Future testing will be focused on areas where the most benefits of hybrid consists will be realized. Examples may include mountain grade helpers, captured “basin”, unit train, or tunnel operations, all areas where BELs provide a unique advantage over diesel only units.

Future Work

Since this is the first of its kind demonstration there is a long list of opportunities for future work. The design of the locomotive, intended operation and early learnings will guide future development. This locomotive is intended to be the first version upon which future versions evolve and is intended to be a development platform more than a production ready locomotive.

This testing is critical to inform areas of development; including operations, maintenance, locomotive software & design. The operational impact of the BEL will be tested initially from Stockton to Barstow, California. The planned testing will focus on operational capability, i.e. can the locomotive generate tractive effort when requested, does the consist communication work correctly, etc. Once operational confidence is built the demonstration can be expanded to other routes. Throughout testing, key parameters will be monitored to determine the impacts of fuel consumption and emissions. Operator feedback can lead to improvements in locomotive handling and consist operation. The charging system requires careful design, handling, and process development. Issues such as: who does the charging, what level of protection (blue flag, LOTO, etc.) is required, what charging notifications are required, and etc. still need to be determined at an industry level.

Maintenance of the battery system is a major area of consideration. While maintenance aspects should be considered at this early phase, most maintenance considerations will be developed once the locomotive is available for technicians to provide guidance. For example, battery replacement requires both good design and field feedback. The battery modules are the minimum service replaceable unit and should be considered analogous to a power assembly on a diesel locomotive. They require special lifting equipment and lock out tag out procedures. The modules are designed to be removed from the battery string. The actual method of removal from the locomotive is still in development. For example, a lifter concept has been developed but locomotive testing will refine it and determine the exact module replacement procedures. Other development topics include battery life/ wear rate, consist duty cycle impacts, cooling air flow cleanliness needs, contactor wear, and vibration related impacts on battery modules to name a few. Iterative design is critical to the BEL’s development and having a solid early first concept is key to this process.

Locomotive software and design will rapidly develop based on the learnings from this demonstration. BEL route planning with TO requires understanding of actual hybrid consist behavior to be learned through this demonstration. As an example, the battery electric locomotive is expected to have a very fast load rate. The impacts this has on the tractive effort needed, particularly at low speeds, is unknown and may produce favorable impacts on the consist's duty cycle. Fortunately, the BEL software and hardware is designed to be modular and adaptable, so early learnings can be quickly incorporated in the current and future versions.

Beyond this demonstration, the application of battery technologies in the locomotive space is an area ripe for development. The potential for battery electric switching, regional, and passenger locomotives is encouraging. In many respects these are logical starting places for further development of battery electric locomotive systems. They offer captured service with dedicated home locations for charging. Further development of battery electric switching locomotives would be a logical step and could benefit from colocation with the "home terminal" of BELs used in line haul hybrid service as charging infrastructure could be shared. Fortunately, any development related to locomotive battery systems benefits the entire sector due to the modular nature of battery systems.

Passenger locomotives and battery electric multiple unit consists presents a very appealing application of this technology. The routes are well defined, typically relatively short, and often in environmentally sensitive areas. Their schedules often have layover periods at night and mid-day to allow for opportunistic battery charging. Battery electric dual mode locomotives may be used to transition between electrified and non-electrified territories while retaining the benefits of full electrification. Transit agencies may find the lower operating costs, available grants, and reduced maintenance costs of battery electrics more appealing than diesel powered units both initially and on a lifecycle basis.

Charging systems will enable dramatic improvements to the operational effectiveness of BELs. Once automatic charging systems are developed and implemented the benefits of opportunity charging may be realized. In the electric bus market, automatic charging generally comes in one of three forms: overhead catenary/pantograph, ground based contact charging, or inductive charging. These systems are potentially applicable for locomotives and in the case of catenary or ground charging are well established in European, passenger, or transit rail applications. Safe and reliable automatic charging systems will further reduce dependence on diesel and local emissions and air BEL adoption.

Energy management software development is a key enabler and multiplier of battery electric locomotive technology. These technologies are mature and providing significant benefits to railroads today and as locomotive technology improves these improvements inform the energy management software. Adding battery electric locomotives to the consist opens additional degrees of freedom for train operations and the energy management software is key to managing this complex relationship between variables like battery state of charge, locomotive output, and train route.

Conclusions

The use of battery electric locomotives to form hybrid consists has the potential to reduce locomotive fuel consumption and emissions through the use of dynamic brake capture. Fuel economy improvements will be dependent on a wide variety of factors including BEL specifications, route geography, train makeup, train handling, and consist communication. As with many new technologies, additional study will be required to determine how much can be realized in terms of practical savings. Coupling advanced modeling techniques with pilot operations will provide the greatest insight on the potentials of this technology.

This novel approach unlocks many degrees of freedom in the design and operation of future locomotives. New factors such as battery size and density, charging solutions, and consist communications should to be considered in the physical design of locomotives. Emissions modes, locomotive consist make up, route planning and charging locations all need to be reconsidered in train operations. Furthermore, when considering the design of future rail improvements, partial electrification and en-route charging should be considered as a means to reduce the total system operating cost.

For areas where local air emissions are particularly sensitive, the ability to use batteries to offset locomotive emissions presents a particularly appealing solution. Using dynamic brake energy to charge the traction batteries adds no additional emissions and wayside charging may dramatically improve BEL effectiveness. While much development is required hybrid consists represent another path for the reducing the footprint of rail emissions, fuel consumption, and improving locomotive performance.

Acknowledgements

The author would like to recognize and sincerely thank James Bunce (Wabtec), Dan McNair (Wabtec), Daniel Bellemare (DLL), and James Taylor (BNSF) for their contributions, review, and patience throughout the development of this paper.

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Report on the Committee on Fuel, Lubricants and Environmental

Monday, September 23, 2019 at 11:00 AM

Chair

Corey Ruch

Assistant Director-Technical Research & Development

BNSF Railway, Topeka, KS

Vice Chair

Don Mattey

Sales & Rail Manager, OEM & Key Accounts, Energy Division

Alfa Laval, Incorporated, Hermitage, PA

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PERSONAL HISTORY

Corey Ruch

Assistant Director
BNSF Technical Research & Development

Corey was raised in a small town south of Kansas City, Missouri. Upon graduating High School, he moved to Springfield, Missouri to attend Southwest Missouri State University (SMSU) where he earned a BS in Chemistry and minored in Plastics and Industrial Technology.

During college, Corey interned for Technical Services Laboratories (TSL), a company providing research and development services to the Burlington Northern (BN) railroad. Upon graduation, he was offered a position at TSL and began full time employment in fall of 1995.

By winter of 1996, the Burlington Northern and Santa Fe Railroads were completing their merger to become the BNSF Railway. Shortly afterward, all laboratory operations were being consolidated at the former Santa Fe TR&D Lab in Topeka, KS.

Corey was extended an offer to work at the consolidated "BNSF TR&D Lab" and moved to the Topeka, KS area in 1998. After gaining experience in fields such as Fuel and Environmental Testing, Metallurgical and Mechanical Examination, Failure Analysis, Electronics Testing, Derailment Investigation and many other areas, Corey was promoted to Assistant Director – Lab and Testing Services. He currently oversees a group of dedicated scientists and engineers performing a wide array of testing and examination for the railroad.

Corey enjoys running, hiking, cycling and adventure racing with his wife, Kjrsten as well woodworking, metalworking and other DIY projects.

The LMOA Fuel, Lubricants and Environmental Committee would like to sincerely thank Hillary Parker and the Union Pacific Railway for hosting their winter meeting on February 20, 2019 at Union Pacific Center in Omaha, NE. The committee was also treated to Hors d'oeuvres at the pre-meeting dinner, lunch on the day of the meeting and a tour of the Union Pacific Harriman Dispatch Center in downtown Omaha.

The work presented on the following pages is the result of numerous conference calls, face-to-face meetings and sub-committee conversations as well as concessions of professional, personal and travel time by the individual members of the committee throughout the past year. The committee, as a whole, would like to thank the authors and presenters as well as each individual member for their guidance, input and support of the committee.

The Effects of a Hydrogenation-Derived Renewable Diesel (HDRD) Fuel Surrogate on Fuel Consumption and Emissions from a GE Tier 2 Locomotive

Prepared by:
Dustin Osborne, Jerainne Heywood, Doug Glenn, Michael Cleveland

ABSTRACT

Hydrogenation-Derived Renewable Diesel (HDRD) is an emerging biofuel entering the North American rail fuel supply. Although minimal locomotive testing of HDRD has been performed to date, this paper uses past test results of Fischer-Tropsch (FT) diesel, a fuel with similar composition and properties, to help guide expectations in the impact of HDRD on locomotive fuel consumption and emissions. Featured in this paper are results from exhaust emissions testing of a Tier 2 GE ES44DC line-haul locomotive operating on conventional ULSD and FT blends of 10, 20, 50, and 100 percent by volume (i.e. FT10, FT20, FT50, and FT100, respectively). The results indicate regulated pollutant emission levels were reduced and the volumetric fuel consumption increased relative to ULSD base fuel for blend concentrations of at least 20% FT diesel by volume. Compared to the ULSD baseline, NO_x emission reductions of 4% and 13% were observed for FT50 and FT100 respectively over the EPA Line-Haul Locomotive Duty Cycle. Reductions of Particulate Matter (PM) emissions over the EPA Line-Haul Cycle of at least 12% were observed for all blends except FT10. Compared to the ULSD base fuel, an increase in volumetric fuel consumption over the EPA Line-Haul Cycle of approximately 2% was observed for FT20, 3% for FT50, and 6% for FT100. Locomotive fuel injection became volume limited at Notch 8 during FT100 testing, resulting in a 3% reduction in brake power.

INTRODUCTION

Hydrogenation Derived Renewable Diesel (HDRD) is a synthetic diesel fuel produced from renewable biomass feedstock. Motivated by HDRD's potential for Green House Gas (GHG) reduction when used in place of petroleum diesel, the U.S. EPA Renewable Fuel Standard, along with government agencies in California, Oregon and Canada, have mandated and incentivized the introduction of HDRD into the transportation sector, including the off-road sector. As a result, HDRD is currently being blended into diesel fuel markets in select areas with target blending levels increasing each year.

With locomotive exposure to HDRD growing, there is a definite need to understand the effects of this new biofuel on locomotive engine performance and emissions. To date, there are no locomotive HDRD test trial reports publicly available. However, the composition and properties of HDRD are similar to Fischer-Tropsch (FT) diesel (Table 1), a synthetic diesel that has been studied and utilized in the past. Although the feedstock and processes are different between HDRD and FT diesel, the end products are nearly indistinguishable such that the expectation is that engine emissions and fuel consumption effects should be similar for both fuels. This allows for the use of a past locomotive FT fuels study to provide insight on the impact of HDRD utilization on locomotive engine emissions and fuel consumption.

Table 1. Select Fuel Properties of typical HDRD, FT Diesel, and ULSD

Property	Typical neat HDRD*	FT Diesel used for testing**	ULSD used for testing**
Cetane Number	70 – 95	>76	48.6
Density at 15°C lb/gal	6.43 – 6.59	6.42	7.01
Sulfur, ppm	< 1.0	0.8	1.0
Aromatic content, %	< 1.0	0.9	21.5
Lower Heating Value BTU/lb BTU/gal	 18,960 123,423	 18,975 121,904	 18,478 129,592

* table values from Neste Renewable Diesel handbook[1]
** table values are actual fuel analysis results from the test program featured in this paper

Featured in this paper are results from exhaust emissions testing of a Tier 2 GE ES44DC line-haul locomotive operating on conventional ULSD and FT blends of 10, 20, 50, and 100 percent by volume (FT10, FT20, FT50, and FT100, respectively).

TECHNICAL APPROACH

Presented below is an overview of the experimental methods used to evaluate the effects of Fischer-Tropsch (FT) fuel blends on exhaust emissions and fuel consumption of a Tier 2 ES44DC locomotive.

Test Locomotive

The locomotive used for testing was BNSF7736, a General Electric (GE) ES44DC locomotive manufactured in 2005 and certified to U.S. EPA Tier 2 locomotive emission standards. BNSF7736, shown in Figure 1, was equipped with a GEVO-V12 diesel engine. Engine details are provided in Table 2.

Figure 1. BNSF7736 GE ES44DC Test Locomotive

Table 2. Locomotive Specifications

Manufacturerand Model	**GE ES44DC**
Road Number	BNSF 7736
Engine Model	GEVO12LDB5
Year of Manufacture	2005
Rated Traction Power (kW)	3,280
Rated Engine Brake Power (kW)	3,356
Operating Cycle	Four-Cycle
Cylinder Arrangement	45° V-12
Bore	250 mm
Stroke	320 mm
Displacement/ Cylinder	15.7 L
Rated Engine Speed	1050
Fuel Injection	Direct Inject Electronic Unit Pump System

Test Fuels

Commercially available Ultra Low Sulfur Diesel (ULSD) was used for baseline testing and as the base fuel for blends of 10%, 20% and 50% Fischer-Tropsch by volume. Fischer-Tropsch fuel used for this program was Syntroleum S-2 Synthetic Diesel Fuel, produced by Syntroleum Corporation using the patented Syntroleum Process.[2] A lubricity additive (Unichem 7542) was added to the FT fuel prior to blending. For blending nomenclature, FT10, FT20, FT50 and FT100 refer to the fuel blends of ULSD with additions of 10%, 20%, 50%, and 100% Fischer-Tropsch by volume, respectively. The blending of test fuels was completed at SwRI in 500-gallon batches. The blending process for each batch consisted of first filling a tote with the respective volume of ULSD base fuel, then adding the appropriate volume of neat FT fuel to obtain target concentration. Finally mixing the batch for 30 minutes using a pump to circulate fuel from the bottom outlet of the stainless steel tote to the top of the fill opening. After blending, fuel samples were collected and analyzed. A summary of fuel analysis results from this test program is presented in Table 3.

Table 3. Test Fuel Analysis Results

Determinations	ASTM Test Method	ULSD	FT10	FT20	FT50	FT100
API Gravity @ 15 °C Specific gravity Density (lb/gal)	D4052	36.8 0.8408 7.01	38.1 0.8342 6.96	39.6 0.8268 6.90	44.0 0.8063 6.73	52.2 0.7702 6.42
Viscosity @ 40°C (cSt)	D445	2.4	2.3	2.3	2.2	2.1
Sulfur (ppm)	D5453	1.0	1.8	1.3	0.9	0.8
Cetane Number	D613	48.6	49.8	53.1	61.0	>76
Cetane Index	D4737	47.5	49.7	52.8	61.8	81.1
Heat of Combustion HHV (BTU/lb) LHV (BTU/lb) HHV (BTU/gal) LHV (BTU/gal)	D4809	19,705 18,478 138,198 129,592	19,740 18,513 137,362 128,818	19,795 18,544 136,523 127,890	19,977 18,672 134,356 125,582	20,358 18,975 130,789 121,904
wt % Carbon wt % Hydrogen Hydrogen/Carbon	D5291	86.38 13.45 1.86	86.24 13.46 1.86	86.00 13.72 1.90	85.37 14.30 2.00	84.38 15.16 2.14
Lubricity (HFRR at 60°C) Wear Scar Diameter (μm)	D6079	375	455	455	465	465
Pour Point (°F)	D97	-22.0	-16.6	-16.6	-16.6	-22.0
Cloud Point (°F)	D2500	-7.6	-7.6	-9.4	-9.4	-11.2
Cold Filter Plugging Point (°F)	D6371	-16.6	-9.4	-13.0	-22.0	-22.0
Hydrocarbon Type Aromatics (vol %) Olefins (vol %) Saturates (vol %)	D1319	21.5 1.3 77.2	14.9 3.1 82.0	15.8 1.8 82.4	10.5 2.1 87.4	0.9 0.9 98.2
Aniline Point (°F)	D611	154	150	155	171	196
Flash Point (°F)	D93-80	166	160	166	157	145
Copper Corrosion Strip	D130	1B	1B	1B	1B	1B
Water & Sediment (vol %) Description	D2709	0.01 Clear & Bright	0.01 Clear & Bright	0.01 Clear & Bright	0.01 Clear & Bright	0.01 Clear & Bright
Ash Content (mass %)	D482	<0.001	<0.001	<0.001	<0.001	<0.001
Carbon Residue 10% (wt %)	D524	0.11	0.09	0.07	0.03	0.04
Distillation	D86 % Recovered IBP 10 50 90 FBP	Temp. °F 375 418 487 567 616	Temp. °F 355 409 485 569 616	Temp. °F 360 404 485 573 617	Temp. °F 339 388 486 582 624	Temp. °F 333 373 488 598 629

Test Procedures

Exhaust emission tests were performed using the EPA Locomotive Federal Test Procedure (FTP) described in Part 92 of CFR Title 40.[3] Gaseous emission measurements of hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) were conducted using Part 92 raw gaseous emissions sampling procedures.

Hydrocarbon concentrations in the raw exhaust were measured using a California Analytical Instruments Model 300 heated flame ionization detector (HFID), calibrated on propane. NO_X concentration in the raw exhaust was measured using a California Analytical Instruments Model 400 heated chemiluminescent detector (HCLD). NO_X correction factors for engine intake air temperature and ambient air humidity were applied as specified by EPA in Part 92. Concentrations of CO and CO_2 in the raw exhaust were determined by non-dispersive infrared (NDIR) instruments made by Horiba.

Gaseous mass emission rates were computed using the measured concentration, the observed (measured) fuel consumption rate, and calculated engine airflow. Following the FTP, engine airflow was not directly measured in this test program. Instead, engine airflow was determined using a carbon balance of the carbon-containing constituents in the exhaust (CO_2, CO, and HC) to compute the fuel/air ratio (f/a). Engine airflow rate was then computed using the measured fuel consumption rate and the computed f/a ratio.

Particulate Matter (PM) emissions were sampled using a partial flow dilution system (PFDS) consistent with Part 92 requirements. A dilute exhaust particulate sample was extracted from the dilution tunnel through a sample probe, and particulate was accumulated on two 90 mm fluorocarbon-coated glass fiber filters (Pallflex T60A20) at a target filter face velocity of 70 cm/sec. The two filters were mounted in series, each in a stainless steel filter holder and connected to the sample probe. Particulate filters were preconditioned and weighed before and after testing, following the FTP. The particulate mass emission rate was computed using the increase of mass on the filters, the volume of dilute exhaust drawn through the filters, and dilution air and raw exhaust flow parameters.

Smoke opacity was measured using the light extinction method in accordance with Part 92 of CFR Title 40. A modified Public Health Service (PHS) full-flow opacity meter (smokemeter) was mounted above the locomotive exhaust stack, and smoke opacity was continuously monitored during the EPA Locomotive Test Sequence.

Test cycle

A single FTP test was completed for each of the five test fuels. The ES44DC was equipped with dynamic brake grids capable of dissipating full engine power, and they were used to load the engine during stationary testing via the locomotive self-load feature.

Power was determined by measurement of the main alternator voltage and current, and measurement of the auxiliary power. GE supplied alternator efficiencies were used to calculate brake power. Power and fuel rates were recorded as observed values, and the observed power was used to report brake-specific exhaust emissions in g/HP-hr. Fuel consumption was measured on a mass basis, using a mass flow meter. The laboratory fuel system was equipped with a heat exchanger to control fuel supply temperature. Hot return fuel, which would normally return to the locomotive on-board fuel tank, was cooled before returning to the fuel measurement reservoir ("day tank") to assure a consistent fuel supply temperature at the engine.

The ES44DC has two engine idle speeds, and discrete test modes included operation at both idle operating points, a simulated dynamic brake condition, and operation at all eight throttle notch settings. For the dynamic brake test mode, the locomotive dynamic brake control was activated resulting in Notch 2 engine speed with a reduced engine load to simulate dynamic braking during revenue service.

Table 4 presents the duty cycles that were applied to the individual steady-state notch data points to compute the EPA Line-Haul and Switch duty cycle weighted composite results. The duty cycles were constructed by the EPA from actual event recorder data collected from in-use locomotives.

Table 4. EPA Locomotive Line-Haul and Switch Duty Cycles used to compute weighted averages

Throttle Notch Setting	EPA Line-Haul Cycle	EPA Switch Cycle
Low Idle	19.0 %	29.9%
Idle	19.0 %	29.9%
Dynamic Brake	12.5 %	0.0%
Notch 1	6.5 %	12.4%
Notch 2	6.5 %	12.3%
Notch 3	5.2 %	5.8%
Notch 4	4.4 %	3.6%
Notch 5	3.8 %	3.6%
Notch 6	3.9 %	1.5%
Notch 7	3.0 %	0.2%
Notch 8	16.2 %	0.8%
TOTAL	100.0 %	100%

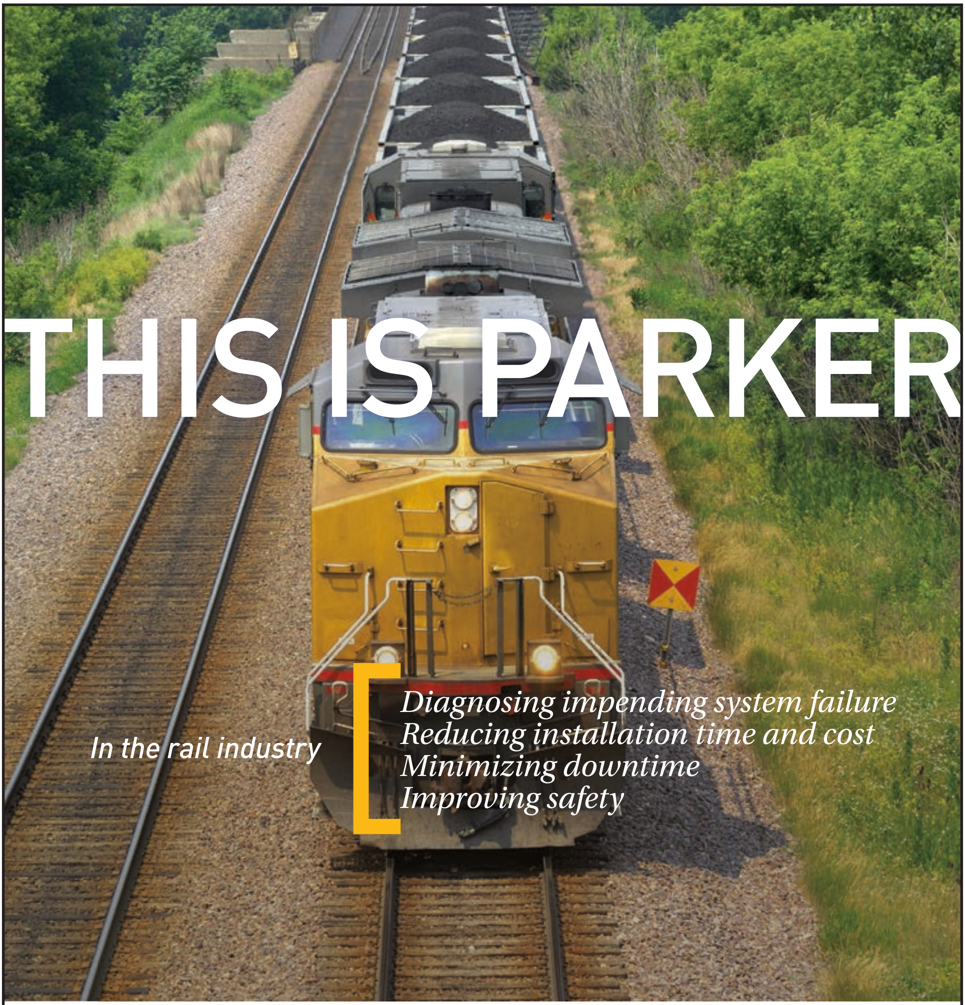
TEST RESULTS

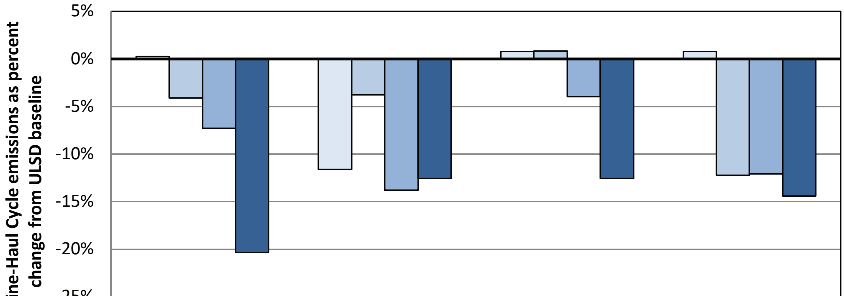
Regulated brake-specific exhaust emissions weighted over the EPA Line-Haul and Switch Locomotive Duty Cycles are listed in Table 5, and relative changes in duty cycle weighted emissions as compared to ULSD base fuel are listed and plotted in Figure 2 for the EPA Line-Haul Locomotive Duty Cycle, and in Figure 3 for the EPA Switch Locomotive Duty Cycle.

FT10 showed little to no change in emissions over the EPA Line-Haul Cycle, as compared to the ULSD baseline. Although NOx reduction benefits over the EPA Line-Haul Cycle were negligible for FT10 and FT20, FT50 showed a 4% NOx reduction from baseline, and FT100 nearly a 13% reduction. FT100 was the only fuel to show a significant NOx reduction from baseline over the switch cycle. Significant PM reductions over the line haul and switch cycles were observed for all fuels except FT10. However, there does not appear to be additional PM benefits for blends above 20% FT by volume. All fuel blends showed CO reductions from baseline for both duty cycles. A progressive reduction in HC was observed for each blend above FT10, and FT100 HC results were approximately 20% lower than baseline. Smoke test results, displayed in Figure 4, indicate FT fuel did not significantly affect smoke opacity.

Table 5. Summary of brake specific emissions weighted over EPA Locomotive Duty Cycles

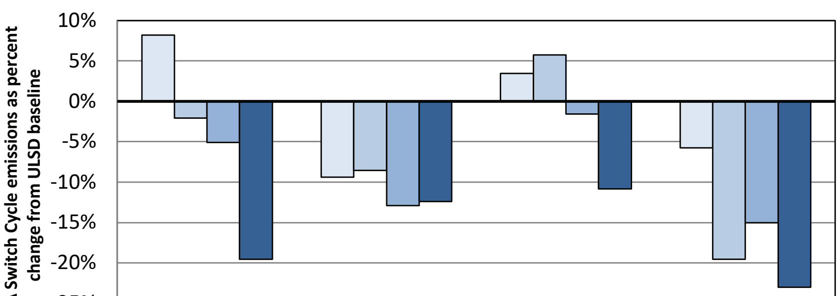
Fuel Blend	EPA Line-Haul Cycle, g/HP-hr				EPA Switch Cycle, g/HP-hr			
	HC	CO	NO_x	PM	HC	CO	NO_x	PM
ULSD	0.15	0.25	4.59	0.087	0.18	0.36	5.34	0.138
FT10	0.15	0.22	4.63	0.088	0.20	0.33	5.53	0.130
FT20	0.14	0.24	4.63	0.077	0.18	0.33	5.65	0.111
FT50	0.14	0.22	4.41	0.077	0.17	0.31	5.26	0.117
FT100	0.12	0.22	4.01	0.075	0.15	0.31	4.76	0.106


THIS IS PARKER
In the rail industry
Diagnosing impending system failure
Reducing installation time and cost
Minimizing downtime
Improving safety



	HC	CO	NOx	PM
FT10	0.2%	-11.6%	0.8%	0.8%
FT20	-4.1%	-3.8%	0.9%	-12.2%
FT50	-7.3%	-13.8%	-4.0%	-12.1%
FT100	-20.3%	-12.6%	-12.6%	-14.4%

Figure 2. EPA Line-Haul composite emissions expressed as percent change from ULSD baseline



	HC	CO	NOx	PM
FT10	8.2%	-9.4%	3.5%	-5.8%
FT20	-2.0%	-8.6%	5.7%	-19.6%
FT50	-5.1%	-12.9%	-1.6%	-15.0%
FT100	-19.5%	-12.4%	-10.8%	-23.0%

Figure 3. EPA Switch cycle composite emissions expressed as percent change from ULSD baseline

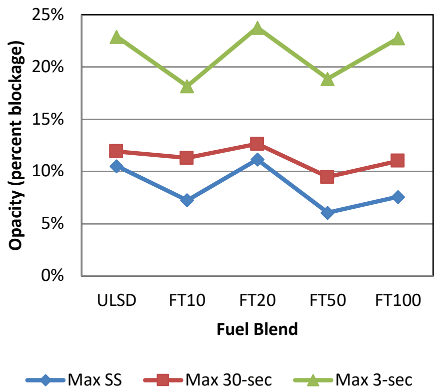
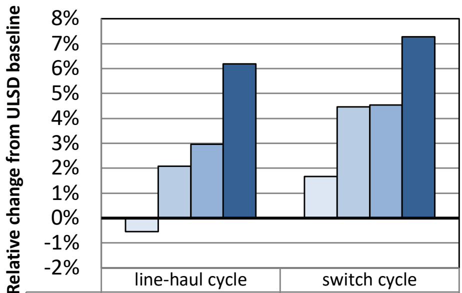


Figure 4. Smoke Test results For ULSD and FT blends

The relative change in brake specific volumetric fuel consumption for each fuel blend as compared to the ULSD base fuel is shown in Figure 5. Compared to ULSD baseline, an increase in volumetric fuel consumption was observed over the EPA Line-Haul and Switch Cycle for each FT blend, with the exception of FT10. For blending levels above 10%, fuel consumption increased progressively with FT concentration. FT20 showed a 2.1% increase relative to ULSD over the Line-Haul Cycle, and 4.5% over the Switch Cycle. FT100 fuel consumption over the Line-Haul and Switch Cycle was 6.2% and 7.3% greater than ULSD. The fuel energy density penalty associated with renewable diesel has negative implications for locomotives, such as the need for more frequent fueling and possibly reduced peak power. In this study, the ES44DC locomotive controls compensated for the lower density test fuels, achieving target power during all of the fuels testing except at Notch 8 during FT100 testing, where fuel injection became volume limited and the resulting brake power was approximately 3% below target.



	line-haul cycle	switch cycle
FT10	-0.5%	1.7%
FT20	2.1%	4.5%
FT50	3.0%	4.5%
FT100	6.2%	7.3%

Figure 5. Change in specific volumetric fuel consumption relative to ULSD base fuel

CONCLUSIONS

Testing of a Tier 2 GE ES44DC line-haul locomotive has shown that there are observable changes in key parameters when FT fuel is substituted for ULSD fuel. Given FT fuel is a close analog for the HDRD fuel currently being introduced into the market, similar changes are expected with introduction of HDRD Fuel. Two key areas were evaluated in this test:

Fuel Consumption – An increase in volumetric fuel consumption was measured. Depending on duty cycle, the engine consumed roughly 2 to 7 percent more fuel for blends of FT diesel ranging from 10 to 100 percent.

Emissions - NOx emissions over the Line-Haul duty cycle were negligible for FT10 and FT20 blends but dropped between 5 and 9 percent for FT50 and FT100 respectively. FT100 was the only fuel that showed significant NOx reduction over the Switch cycle. PM reduction of 12 to 20 percent was observed for all blends above FT10, with the full PM benefit observed at FT20. Unburned hydrocarbons (HC) and carbon monoxide (CO) were also generally reduced with increasing substitution of FT diesel.

While the results presented here give insight into the expected performance of HDRD, it is recommended that more research and testing be done on heavy-duty diesel engines to understand the full implications of running HDRD fuel blends in locomotives.

NOMENCLATURE

μm	micrometer
BNSF®	BNSF Railway Company
BTU	British Thermal Unit
BTU/gal	BTU per gallon
BTU/lb	BTU per pound
CFR	Code of Federal Regulations
CO	Carbon monoxide
EPA	Environmental Protection Agency
g/kW-hr	grams per kilowatt-hour
FT	Fischer-Tropsch diesel fuel
FT10	10% Fischer-Tropsch diesel fuel in balance petroleum diesel fuel
FT20	20% Fischer-Tropsch diesel fuel in balance petroleum diesel fuel
FT50	50% Fischer-Tropsch diesel fuel in balance petroleum diesel fuel
FT100	100% (neat) Fischer-Tropsch diesel fuel
FTP	Federal Test Procedure
GE®	General Electric Company
GHG	Greenhouse Gas
HC	Hydrocarbon
HCLD	Heated Chemiluminescent Detector
HDRD	Hydrogenation Derived Renewable Diesel
HFID	Heated Flame Ionization Detector
HFRR	High Frequency Reciprocating Rig
kW	Kilowatt
kW-hr	Kilowatt-hour
lb/gal	pounds per gallon
mm	Millimeter
NDIR	Nondispersive Infrared
NO_x	Oxides of Nitrogen
PFDS	Partial flow dilution system
PM	particulate matter
ppm	parts per million
THC	Total Hydrocarbons
SwRI®	Southwest Research Institute®
ULSD	Ultra Low Sulfur Diesel

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Used Oil Analysis – Is It Reliable? (2018 Railroad Used Oil Test Laboratory Evaluations)

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Introduction: One of the objectives of used engine oil testing is to determine if unscheduled engine maintenance is required, or if additional engine inspections are required at scheduled maintenance intervals. If the oil test data is not accurate and precise, it in turn can affect locomotive availability, durability, reliability, and failure rates, in other words - cost money.

This is a summary of the findings of six completed evaluations of North American Railroads' used oil testing programs. Railroads closed their internal oil laboratories starting in the late 1990s. Over time, they became more reliant on commercial laboratories not only for the testing of the oil but other functions. Those functions often included oversight of which tests are being performed, which test methods are being used, what calibration/crosscheck methods are being used, how results are being interpreted and reported, what is actually found during a shop inspection vs what was reported in the analysis, as well as many other functions. Also, note the laboratories' inputs may not keep pace with the rate of locomotive technology development.

Background: The purpose of the evaluations were to first determine if the reported used oil test results were acceptable from the aspect of both repeatability (within laboratory) and reproducibility (between laboratories). This was accomplished by running several round robin tests with multiple used oil specimens being collected. Each specimen was split into two or more samples. Those samples were forwarded on to the railroads' contracted laboratories, an OEM's reference laboratory, and some round robins included an oil additive company's laboratory. If there was not a round robin, there were reviews of used oil tests results from multiple locomotives over several months.

In addition to evaluation of the results, the used oil specimen collection frequency was calculated from the specimen dates. Furthermore, analytical test methods used by the contracted laboratories were evaluated to determine if the OEM required analytical test methods and reporting limits were applied.

During the evaluation phase, communication between the OEM's, railroads, and when permission was granted, direct communications with the testing laboratories was established. This provided a more complete understanding of the laboratories exact methodology and instrumentation, as well as discussion of analytical differences in tests results to help improve the test programs. When suggested changes were made, additional round robins were undertaken to validate those changes.

The remarks detailed below are summaries of the studies. Detailed bullet point lists are provided at the end of this paper:

Railroad A:

The oil analysis lab employed by Railroad A chose to determine pentane insoluble (PI) 'soot' levels in the oil using an infrared spectrometer 'surrogate method' as opposed to the prescribed ASTM D7317 chemical analysis method. The infrared spectrometer allowed faster analysis of samples and did not require solvent (pentane) use and disposal after the examination.

Unfortunately, an adequate 'transfer function' was not developed. This meant there was no method to equate the results obtained by the infrared spectrometer to those of the ASTM D7317 standard method. This provided generally inaccurate results for several years.

However, when the spectrometer was replaced, a different calibration and correction method was used. This created an additional issue of erroneously increasing all results. The railroad only became aware of the issue after a significant increase in locomotives flagging for high 'soot' levels in the oil. This created a substantial amount of extra work and expense for the requested oil changes.

Recommendation: Any time a 'surrogate method' is used in place of a standard test, rigorous testing and analysis should be performed to establish a valid 'transfer function' and make sure results of the surrogate test agree with the standard test across the expected range of samples and results. Anytime any component of the 'system' is changed (i.e. - locomotive make/model, oil manufacturer, additive package or test instrument, etc.) the entire transfer function should be re-tested to make sure results still agree with the standard test.

Railroad B:

Railroad B employed a 'main oil laboratory', which used up to three separate subsidiary analysis laboratories to perform testing of oil samples. At any given time, some samples were reported with flags for some criteria by some of the laboratories. However, no clear trend, such as an excessive amount of flags from any one lab, was apparent. All appeared 'normal' at casual inspection.

To gain better insight, a 'round robin' test was performed by sending identical samples to each of the three subsidiary laboratories as well as to a fourth reference laboratory. As results were accumulated, it became clear that some of the laboratories results were out of range when compared to the results of the identical sample returned from other laboratories.

Performing a more in depth review, it could be determined if the results from any given laboratory were good, consistently incorrect, randomly incorrect, etc. This information helped address the underlying issues at the laboratories.

Recommendation: Periodic 'round robin' testing between a minimum of two laboratories, and ideally three or more, can help identify small variations in repeatability and/or reproducibility. These variations can often be large enough to cause unscheduled maintenance/downtime in a locomotive, but may not be apparent with casual examination of an oil analysis program – or in a case where no firm 'reference result' is available.

Railroad C:

A full data review was performed for Railroad C. During the review, many oil analysis parameters were noticed to be inconsistent. For example, elemental analysis would indicate the presence of water, but a physical 'crackle test' would 'pass' with no water detected. Viscosity results were consistently reported much too high for the oil the railroad was using. Various elemental results were inconsistent. For example, wear metals, which tend to accumulate at a consistent rate in the oil, were found to jump high to low, low to high in various samples. Base number (BN) results, which tend to drop as the oil ages and the additive is 'used up', appeared to be 'flat' or very consistent even as the oil aged. Lastly, a calculation of oil samples across a fleet of locomotives indicated an average collection frequency of 38 days vs the OEM recommendation of 10 to 15 days.

Recommendation: To provide the most accurate and beneficial results, oil sample frequency should be maintained in the 10-15 day range as recommended by the OEM's. Once the sample frequency is correctly established, a round robin test could be conducted between the incumbent oil laboratory and one, or ideally more, reference laboratories. This would help establish which tests are producing good results and those tests, which are producing erroneous results.

Railroad D:

Review of 119 used oil test results were evaluated. Results generally indicated the oil was performing satisfactory at 184 days. A more in-depth review indicated newer Tier locomotive oil was generally in better condition relative to the older Tier locomotives. Trend lines generated from data plots of oil age vs base number (BN) and insolubles (PI) had good correlations i.e., high R^2 values. However, it was noted the best-fit curves are very flat! There was very little change in the oil parameters relative to time. Essentially all oil samples were always reported as "good" oil.

Recommendation: Even though tests and transfer functions were established and 'best fit' curves were generated with exceptionally good correlations, on close inspection, the data did not pass a sensibility 'gut check'. As a natural consequence of oil lubricating an engine, certain additives are 'used up' and the value decreases (i.e. Base Number), while contaminants such as soot (Pentane Insolubles) and wear metals (iron, lead, copper, etc.) naturally increase. If a 'best fit' curve is only capable of reporting a very small range of "good" values over the entire life of the oil, additional investigation should be performed to determine if the test is actually valid.

Railroad E:

A data review and round robin oil test was performed specifically to focus on soot (Pentane Insoluble) values in the oil analysis. As with other cases, a surrogate method (infrared analysis) was used in place of the standard physical/chemical analysis (ASTM D7317). In completing the analysis, it was noted the laboratory was not reporting soot in the correct units - i.e. weight percent of insoluble material.

Recommendation: Standard units should be used across all reporting. This helps reduce issues with conversion factors and/or misunderstanding of numerical values due to implied or non-standard units.

Railroad F:

A round robin was completed in April of 2019. Twenty locomotives had one specimen collected and divided into two identical samples. This ultimately produced two identical groups of 20 samples each. One locomotive had 1 specimen collected and divided into 10 samples to produce two identical groups of 5 identical samples.

Within the round robin test, the reference laboratory was determined to be producing data with a good degree of repeatability and reproducibility. However, the railroad contracted laboratory failed to provide data with reasonable repeatability or reproducibility. In short, the data could not be relied on to make predictions of locomotive engine health.

Recommendations: Because no valid data was being produced by the laboratory, a recommendation was made to put the fleet on a fixed 92-day oil drain cycle, immediately. This was an effort to prevent both costly mechanical issues due to 'missed' flags in the oil analysis and to prevent costly un-needed service due to 'false' flags in the oil analysis.

Further recommendations, including better communication, a communication feedback loop between the OEM, railroad and spectrograph lab, as well as using processes established in the peer reviewed Locomotive Maintenance Officers Association 2001 paper on how to select a test laboratory, were made.

Full Details:

Railroad A: Because of differences between the testing laboratory, the OEM's reference laboratory and the oil additive company's results, several round robin tests were performed. After each round robin, reports were issued. The reports highlight analytical differences with emphasis on understanding why there were differences in the results and making recommendation for improvements. The major differences of the findings are as follows:

- Pentane Insoluble materials, LMOA PI:
  - No determination of pentane insoluble materials (PI) was made by ASTM D7317 per the OEM Maintenance Instruction (MI)
  - Instead, "soot" was inferred from an infrared spectrometer spectra (IR) surrogate method
  - No transfer function developed between infrared spectrometer spectra (IR) surrogate "soot" method to PI method ASTM D7317
  - Pre December 2015, the infrared spectrometer method was using an "empty cell/background" correction
  - Infrared spectrometer was replaced
    - New instrument's spectra were determined without using empty cell correction (background correction) without changes to the limit
    - Methodology not using empty cell correction started approximately January 2016
    - Resulted in a major shift up (increase) in the reported "soot" values from the previously reported results
    - Resulted in many locomotive units falsely being flagged for contaminating soot concentrations exceeding limit
  - Locomotives had the crankcase oil drained unnecessarily
  - OEM stopped utilizing "soot" parameter indirectly determined from IR spectra (surrogate test method)
  - Not utilizing insoluble materials increases the risk of engine failures
- Recommended corrections for "soot":
  - For "soot" parameter, laboratory to use the empty cell correction (background correction)
  - OEM developed a transfer function between the railroad laboratory "soot" surrogate IR results to OEM's reference laboratory results from ASTM D7317
  - OEM must add the developed transfer function (algorithm) into their system to calculate the pentane insoluble materials from the IR spectra absorption results

- Base Number:
  - Base Number (BN) inferred from an IR surrogate method
  - The BN transfer function from the IR BN to titrated base used the wrong ASTM reference method
  - Used ASTM D2896 which is recommended for new oils
  - Should use ASTM D4739 which is recommended for used oils
  - Resulted in over reporting the used oil base protection available
  - Risk corrosive attack
- Recommended correction for base values:
  - Validated railroads infrared spectrometer surrogate base number generated result using the correct reference ASTM method, i.e., ASTM D4739 and not ASTM D2896
- Significance:
  - "Soot" or insoluble materials were not being included as an important parameter, and base was being over reported. Together they are increasing risk of failure from third body wear, corrosion, and/or the combination of the two.

In the Appendix: Figures 1 to 5 are examples of the need to understand how the laboratory's instrumentations are set up, and to understand the differences in the analytical methods used.

Railroad B: As with railroad A, there were several round robins and reports to understand the lack of repeatability (within laboratory) and reproducibility (between laboratories). The reports included detailed analysis and recommendation for improvements. The major differences of findings are as follows:

- Data reviewed:
  - First evaluation was a review of over one year of used oil data from 26 locomotives (not a round robin)
  - The older specimens (starting early summer 2016 to late summer 2016) were tested by laboratory AA
  - The more recent specimens (late summer 2016 to late winter 2017) were tested by one of three BB's laboratories
  - The second evaluation was a round robin starting early 2018 that included the three BB's laboratories, and OEM's reference laboratory
- First evaluation (data review)
  - Laboratory AA's results were acceptable
  - Results from the 3 BBs laboratories were not acceptable, the three laboratories lack a consistent reproducibility (between BB's three laboratories)
  - Some of BB's results for pentane insoluble (PI) were not realistic, e.g., one specimen was reported at 36 weight percent, others in the 20% range.

        - The limit is 4%, which is approximately 120 Lbs. of contamination, the reported contaminates in the oil of 36% by weight is over 1000 Lbs.
        - No one reported concerns of the very high unrealistic PI values
    - BB's reported results from two laboratories base numbers (BN) also had reproducibility issues
- Second evaluation (round robin)
    - BB's results still were not acceptable, the three laboratories still lack a consistent reproducibility (between BB's three laboratories)
- Recommendations:
    - With railroad B's approval (pending):
        - OEM's discuss requirements with the oil testing laboratories
        - Offer to help the testing laboratory improve their results

In the Appendix: Figures 6 through 9 shows the lack of reproducibility between railroad B's 3 laboratories.

Railroad C:

- Data Review:
    - 221 used engine oil specimens collected from 22 different locomotives
    - The average specimens' collection frequency of 38 days
        - Recommended 10 to 15 days
    - Maximum of 219 days between specimen collection
    - Elemental results look to be inconsistent in time and relationship to the other elements
    - Relationships of sodium (Na) to boron (B) to the water crackle results are inconsistent.
    - Viscosity recorded at the 100^0C the maximum values of 19.7 cSt and average value of 16.6 cSt appear to be too high
    - Base number (BN, TBN old term) results appear to be too flat
    - No pentane insoluble materials reported, only "soot"
- Recommendation:
    - Conference call to discuss the path forward
    - Round Robin needed after a complete understanding of the laboratory's methods

Conference call should be scheduled with the laboratory to discuss the analytical methods and steps to improve consistency. After the discussion an agreement on a path forward could be made. It should include increase specimen collection frequencies, and a round robin. The round robin protocol could be modeled after the OEM's existing protocol.

Railroad D:

- Data Review:
  - Based on the 119 used oil specimen's results evaluated; the crankcase oil appeared in satisfactory condition at 184 days.
  - The newer Tier locomotive's crankcase oils are in better condition relative to the older Tier locomotives.
  - The trend lines generated from the plots of days and/or dates vs base number (BN) and insolubles (PI) had good correlations i.e., high R^2 values
  - However:
    - The best-fit curves are very flat!
    - Little change of oil parameters relative to time.

Because of the lack of the typical expected rate changes in the oils' parameters, a review of the laboratory methods and transfer functions are strongly recommended!

It was also noted the long-time gap in specimen collections, i.e., too infrequent. Because of the time gap in specimens' collection, there is introduction of uncertainty in interpretation of the oils trend over time, i.e., changing condition.

Round robin would be recommended after a discussion with the laboratory has occurred. This is to discover why the trend linear regression is so flat. The round robin could possibly validate the existing data from the testing laboratory. That would require an understanding of the decay rate and contamination rate of the oil. Low utilization (low mega-Watt Hours), ultra-low sulfur fuels, oil temperatures, engine condition, and other factors all contribute the oil's parameter decay rates.

Figures 10, 11, and 12 are in the Appendix showing the low rate of change.

Railroad E:

- Data Review:
  - This evaluation was a review of 25 E's locomotive crankcase used oil specimens.
  - The results of the round robin, from three different laboratories testing the same oil specimens with the same methods, were mixed, i.e., the correlations were reasonable except the IR surrogate "soot" determinations
  - *Additionally*, one important parameter was not tested
  - The missing parameter is the weight percent of insoluble materials.
    - The method is ASTM *D7317 (Standard Test Method for Coagulated Pentane Insolubles in Used Lubricating Oils by Paper Filtration (LMOA Method))*.

- Railroad's data column identified as PI GE and PI EMD infrared results are not correlated to OEM's reference laboratory or the oil additives company results

- Recommendations:
    - Discussion with the laboratory of the findings on IR "soot"
    - If needed make improvements to IR method
    - Round robin testing that includes both IR "soot" and PI method

Railroad F: Round robin was completed April of 2019.

- Data review:
    - 20 locomotives had 1 specimen collected and divided into 2 samples (total 40 samples)
    - 1 locomotive had 1 specimen collected and divided into 10 samples
    - Total of 50 samples
    - Railroad laboratory and the reference laboratory received the same 25 samples
    - 20 unique samples, and 5 samples that were from the same specimen
    - Samples were not identified by loco numbers, but assigned numbers for a blind test
    - Both laboratories were to process/test the samples as they would using their current standard methods
    - Railroad's contracted laboratory failed to provide data with reasonable repeatability (within laboratory) based on the 5 duplicate specimens
    - Railroad's contracted laboratory failed to provide data with reasonable reproducibility

See appendix for table 1 for railroad contracted repeatability (within laboratory) results, and table 2 for reference laboratory for their repeatability results.

- Recommendations:
    - Move to a fixed 92-day oil drain cycle
        - until improvements in the oil test program
    - Schedule a conference call between OEM and the railroad
    - If railroad agrees, schedule a conference call between railroad, their contracted laboratory, and the OEM
    - Railroads should use the process in the peer reviewed Locomotive Maintenance Officers Association 2001 paper on how to select a test laboratory

Tables 1 and 2 in the Appendix summarize the results on three of the oil parameters evaluated.

Comments:

If all of the oil analysis investigations detailed above are considered as a whole, one common trend does tend to emerge. Oil analysis laboratories are continuing and expanding the use of 'surrogate methods' instead of performing the OEM recommended standard physical/chemical methods.

Often the standard methods require physical measurement/handling of the sample through multiple stages of analysis and employ various chemical reagents. The additional handling steps along with purchasing and disposal of the reagents add overall cost and complexity to the test which may be passed along to the railroad as a higher 'per sample' price.

When used properly, 'surrogate methods' can provide a quick, 'one step' method to determine various properties of the oil and often require no reagents or additional treatment of the oil. This should result in a lower per sample cost as well as a cleaner and more environmentally sound test regimen due to the reduced use and disposal of reagents.

However, problems can result if surrogate test methods are used which have not been correlated to OEM recommended used oil analytical methods, or if the correlation has been performed incorrectly.

Further, the interpretation of results obtained from surrogate methods can be problematic if not correlated to OEM recommended methods through a round robin oil analysis. In some instances noted above, a test was always returning 'good' results while other tests returned 'mixed' or 'random' results, but only the round robin test could establish the 'true' values and provide a basis to identify actual incorrect sample values.

Ultimately, the analytical approved test methods, and surrogate test methods need to be reflective of the engine and oil condition.

Recommendations:

- Organize yearly Railroad Used Oil Round Robin, between railroads
- Railroads require their contracted laboratory to participate in a yearly oil round robin with a standard organization such as the ASTM or similar highly regarded organization and provide the results to the railroad
- When selecting an analytical oil laboratory, the recommendation in a 2001 LMOA paper on a method to select a laboratory should be followed[1]
- Railroads' test laboratories should run OEM required tests
- If the laboratory cannot run required tests, the laboratory should develop transfer functions
- If the laboratory cannot develop such transfer functions independently, guidance from the OEMs should be requested
- Railroads should maintain adequate specimens collection frequency
- Railroads should maintain clear understanding of the results and the significance on engine operation

- Increased communication and feedback between OEM's, Railroads and Oil Analysis Laboratories regarding technical parameters of oil analysis.

Summary:

- All laboratories included in this evaluation have room for improvements.
- The laboratories have substituted their surrogate analytical methods for some of the OEM's methods
- These surrogate methods should undergo rigorous testing using scientific methodology and statistical data analysis when they are initially established
- Additionally, the surrogate methods should undergo routine round robin cross checking and testing to insure continued validity even as engines, engine component materials, oils, oil additives, fuels, test instruments and other factors in the industry change.
- One of the railroad's contracted laboratories has implemented all the recommended changes after the evaluation
  - Resulted in improvements to both repeatability and reproducibility

With improvements to the used oil results more advanced analysis, e.g., Incipient Engine Failure Detection[2] could be utilized to predict engine failures up to 6 months in advance – with high confidence.

References:

1. D. McAndrew, Evaluation of Locomotive Engine Oil Analytical Laboratories 2001, Locomotive Maintenance Officers Association, September 2001 Proceedings of the 64th Annual Meeting
2. Manoj Kumar Prabhakaran, Dennis McAndrew, Abhijith Jain, Prashant Kumar, Dariusz Oracz, Krzysztof Korycinski, Najeeb Kuzhiyil, Diesel Engine Health Prediction with integrated Lube Oil Analysis, Locomotive Maintenance Officers Association, September 2012 Proceedings of the 74th Annual Meeting

Acknowledgements: The authors would like to thank James Schreiner (GE Transportation) for coordinating the crankcase oil round robins, the railroads for all their effort in collecting the specimens, and GE Transportation field service personnel for their assistance. We would also like to acknowledge the Fuels, Lubricants and Environmental Committee for their input on the several reviews of the drafts.

Appendix:

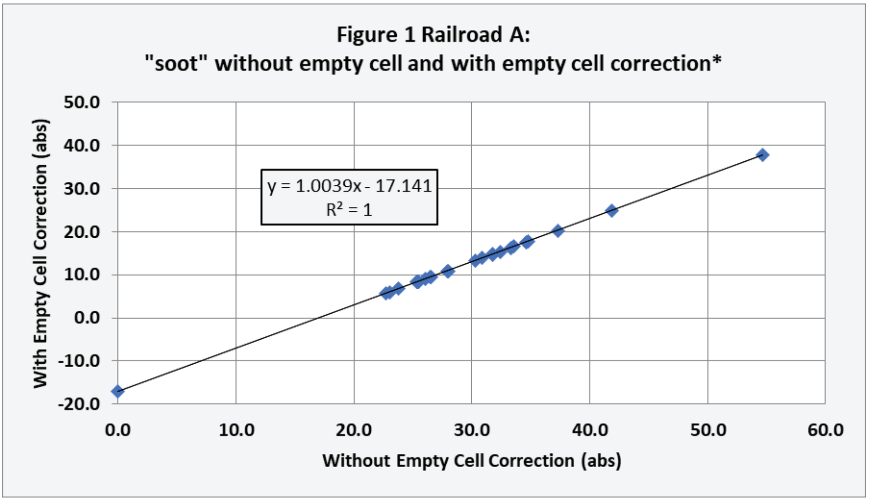


Figure 1 Notes: Units are absorbance infrared units (abs): slope 1.0039, R^2 1, however intercept is not close to the origin. There is an off set of -17.141 which resulted in reporting high "soot" values.

* Point 0, -17.141 was added to highlight offset in the plot. The ideal relation would pass through the 0, 0 point (green line)

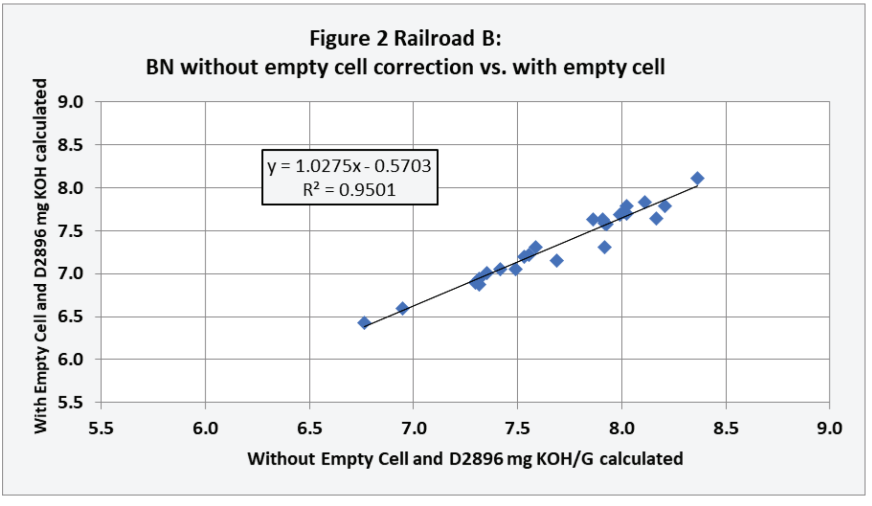


Figure 2 Notes: units are mg KOH/g calculated from a transfer function absorbance infrared units (abs): slope 1.03, R^2 0.95, however intercept is not at origin. There is an off set of -0.5703 which resulted in over reporting available/ useful base protection

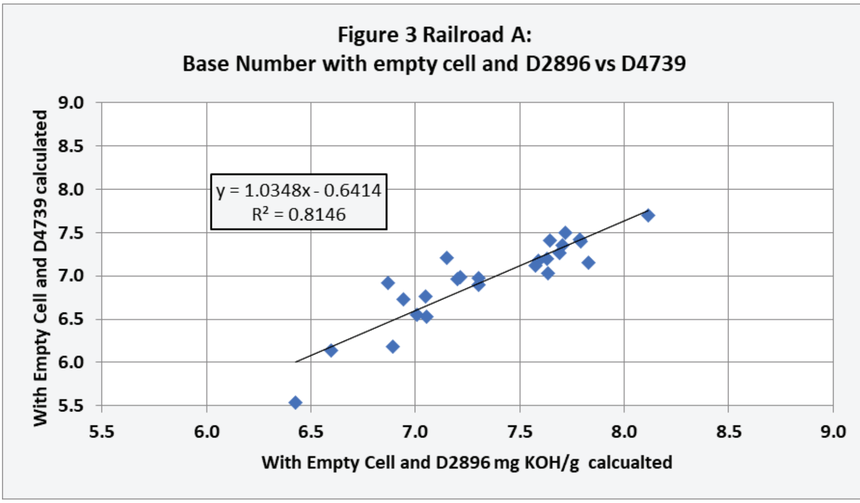


Figure 3 Notes: units are mg KOH/g calculated from a transfer function absorbance infrared units (abs): slope 1, R^2 0.81, however intercept is not at origin. There is an off set of -0.6414 which resulted in over reporting available base protection when D2896 is used rather that D4739

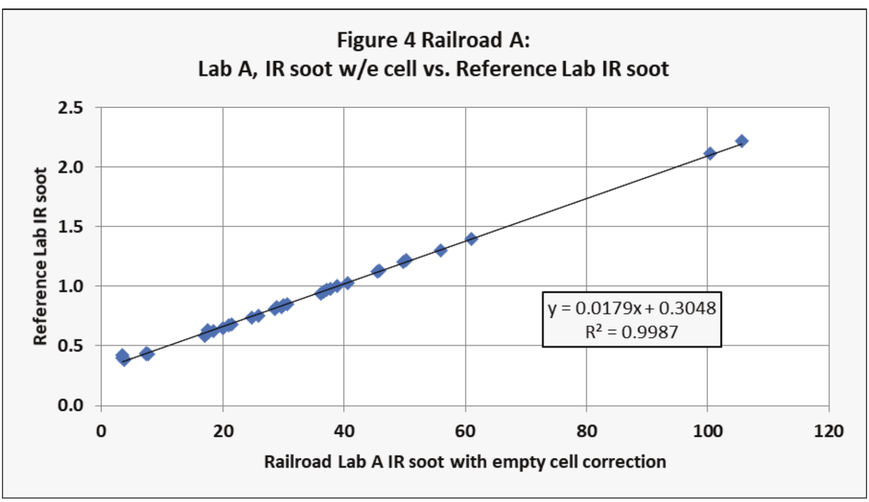


Figure 4 Notes: units are absorbance infrared units (abs): slope 0.0179, R^2 0.9987, intercept 0.3048. The slope is very different! The reference lab is using units directly from their instrumentation per ASTM E163[3]. The railroad lab is using a thicker cell, applying a multiplication factor, or something internal to their infrared spectrometer.

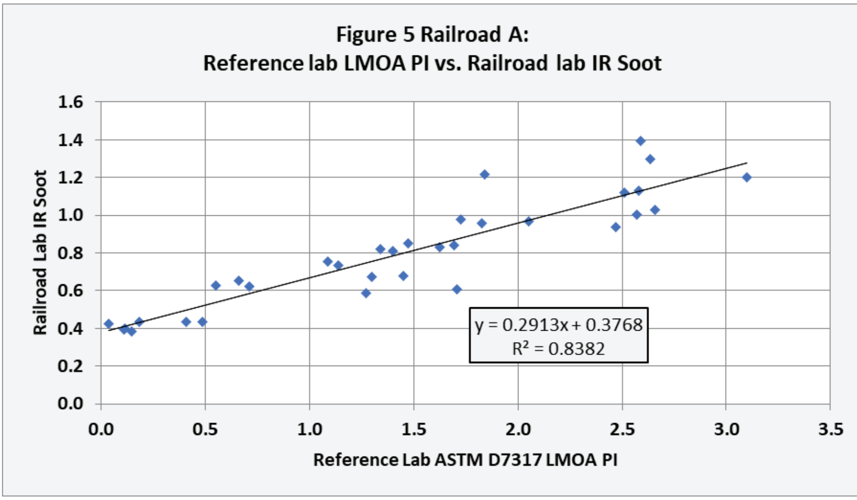


Figure 5 Notes: Reference lab units are weight percent per ASTM D7317. Railroad unit are absorbance infrared units (abs). With an R^2 of 0.8382, the above could be used to help develop a transfer function between the two methods.

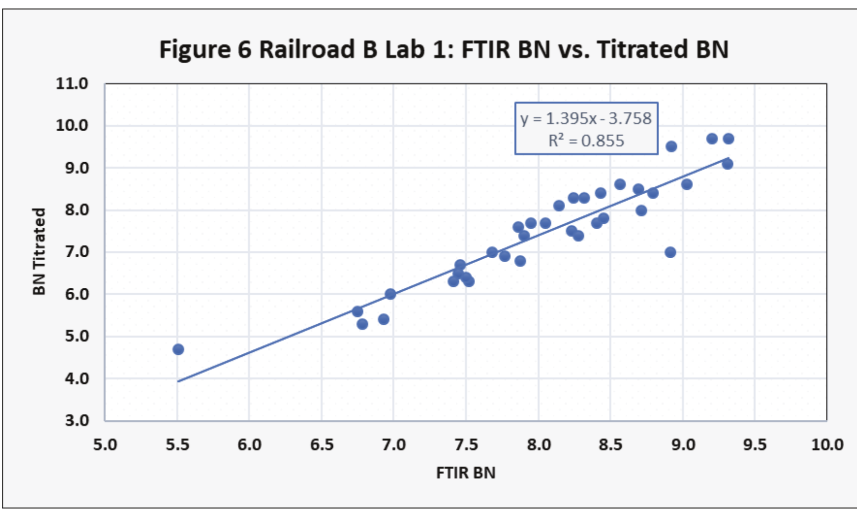


Figure 6 Notes: The infrared spectra generation values could be used to develop a transfer function of a base number. A perfect fit: the slope 1, intercept 0, and a very high R^2. However, the slope is 1.398 and the intercept is -3.758. The result is the FTIR is over reporting low base values.

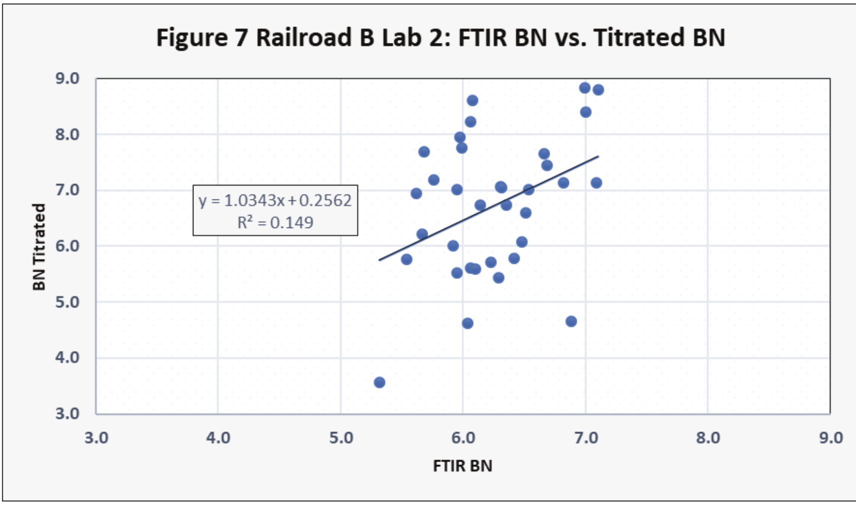


Figure 7 Notes: The infrared spectra generation value could be used to develop a transfer function of a base number. However; the <u>correlation is very low</u> with a R^2 only 0.149

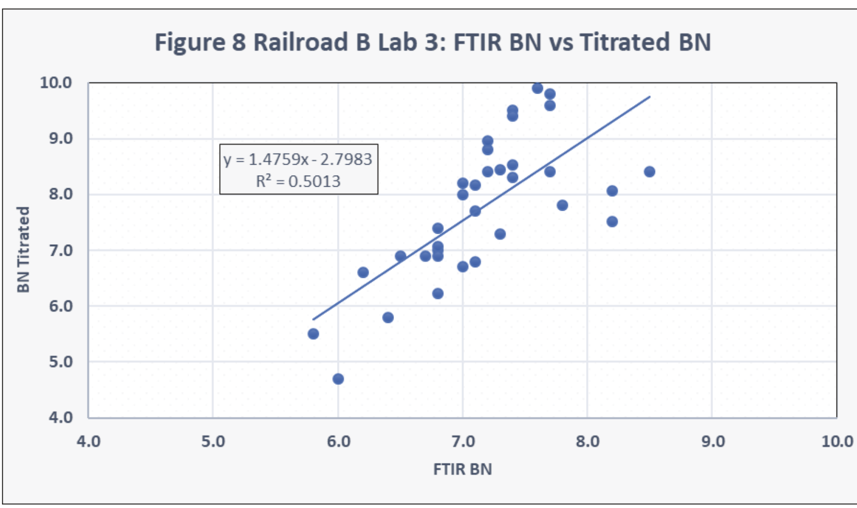


Figure 8 Notes: The infrared spectra generation value could be used to develop a transfer function of a base number. However: the slope is 1.4759, the intercept is -2.7983, and the R^2 is only 0.5013

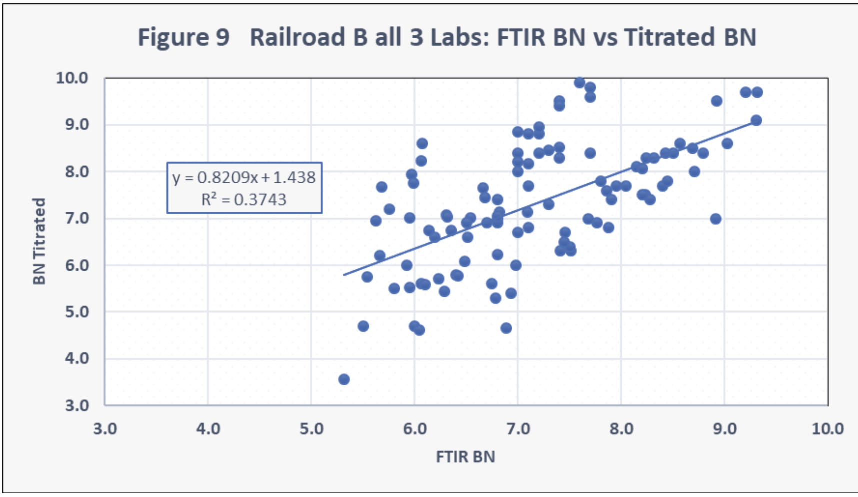


Figure 9 Notes: The infrared spectra generation value vs. base numbers titrated show low confidences in the result of the correlation, R2 = 0.3743.

The four figures (6, 7, 8, and 9) show different problems with the three testing laboratories

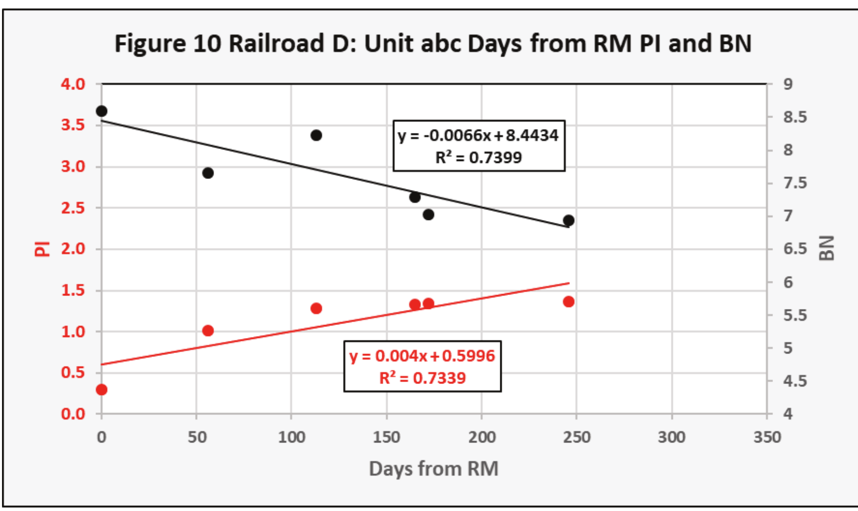


Figure 10 Notes: after 250 days, the insoluble only increased 1% by weight, and the base was reduced only by 1.5 mg KOH/g

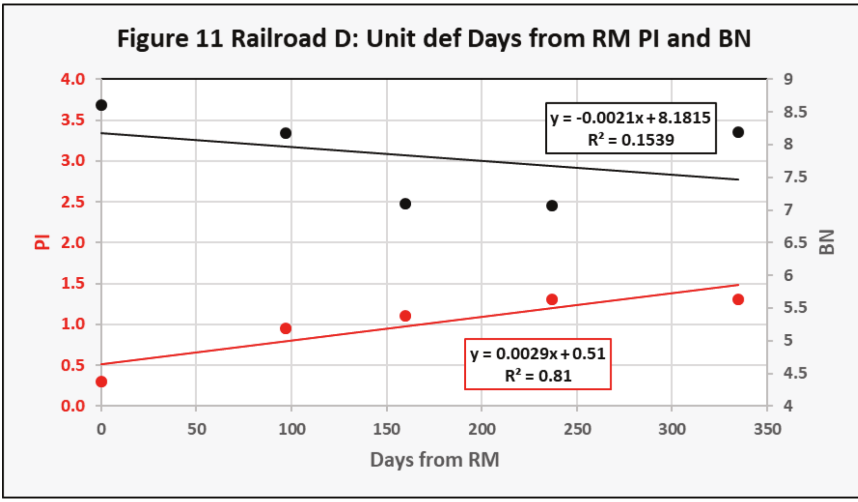


Figure 11 Notes: after close to 350 days, the insoluble only increased 1% by weight, and the base was reduced only by 1.0 mg KOH/g. Note low specimen collection frequencies

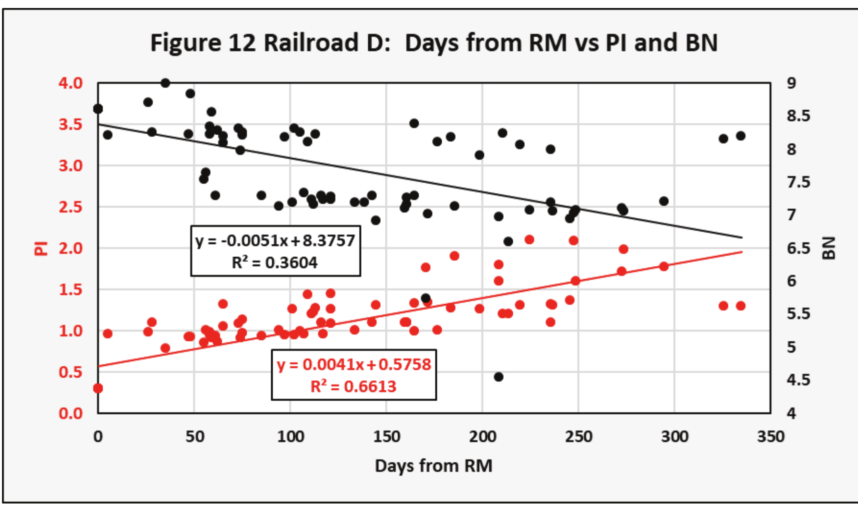


Figure 12 Notes: Composite of the locomotives included in the review. From day zero to after close to 350 days, the insoluble only increased 1.5% by weight, and the base was reduced only by 1.5 mg KOH/g

Railroad F:

<u>Tables:</u>

Table 1: 5 specimens collected from one locomotive, however UP's lab only reported 4																		
Unit	Vis	soot	TBN	Al	B	Ca	Cr	Cu	Fe	Pb	Ni	Si	Ag	Na	Sn	Zn	H2O	FUEL
1a	15.18	1.10	7.89	2	25	2884	2	13	17	27	0	0.0	0	5	0	0	0	0
1b	15.45	0.60	7.14	1	24	2824	1	13	16	24	0	0.0	0	4	0	0	0	0
1c	14.39	0.90	5.10	1	28	2622	1	12	16	25	0	0.0	0	4	0	0	0	0
1d	16.04	1.00	3.25	1	26	2466	2	12	17	25	0	0.0	0	4	0	1	0	0
1e																		
Avg-->	15.27	0.90	5.85	1	26	2699	2	13	17	25	0	0.0	0	4	0	0	0	0
Min-->	14.39	0.60	3.25	1	24	2466	1	12	16	24	0	0.0	0	4	0	0	0	0
Max-->	16.04	1.10	7.89	2	28	2884	2	13	17	27	0	0.0	0	5	0	1	0	0
Stdev->	0.69	0.22	2.09	0.50	1.71	191.54	0.58	0.58	0.58	1.26	0.00	0.00	0.00	0.50	0.00	0.50	0.00	0.00

Table 1 Notes: the range/differences from the minimal to maximum values for viscosity, "soot", and base numbers. The BN the minimal was 3.25 and the maximum was 7.89 mg KOH/g. The expected range should be approximately 0.2 mg KOH/g.

Table 2: Reference lab, 5 specimens collected form the same unit, 6572																							
	Viscosity cSt		Infrared			LMOA P	TBN	TAN	Spectrometric analysis ppm														
Unit	40 C	100 C	Soot	Oxid	Sulfate	% WT.	D - 4739	D - 664	Al	B	Ca	Cr	Cu	Fe	Pb	Ni	Si	Ag	Na	Sn	Zn	P	Mo
1a	148.6	15.85	1.33	0.412	0.471	3.0	6.43	3.52	2	40	3640	1	14	21	28		8.1		0	3	0	6	49
1b	151.3	15.96	1.34	0.419	0.478	3.0	6.44	3.51	2	42	3725	1	15	22	29		8.0		1	3	0	5	50
1c	149.9	15.39	1.34	0.417	0.475	3.5	6.31	3.31	2	41	3632	1	14	21	28		8.0		1	3	0	5	48
1d	150.5	15.98	1.33	0.414	0.474	3.3	6.58	3.54	2	40	3594	1	14	21	28		7.8		0	3	0	6	48
1e	150.8	15.95	1.34	0.416	0.474	3.1	6.65	2.99	2	40	3689	1	14	21	28		8.0		0	3	0	6	49
Avg-->	150.2	15.83	1.33	0.42	0.47	3.2	6.48	3.37	2	41	3656	1	14	21	28		8.0		0	3	0	6	49
Min-->	148.6	15.39	1.33	0.41	0.47	3.0	6.31	2.99	2	40	3594	1	14	21	28		7.8		0	3	0	5	48
Max-->	151.3	15.98	1.34	0.42	0.48	3.5	6.65	3.54	2	42	3725	1	15	22	29		8.1		1	3	0	6	50
Stdev->	1.04	0.25	0.01	0.00	0.00	0.21	0.13	0.23	0.16	0.89	51.30	0.02	0.30	0.40	0.33		0.11		0.22	0.11	0.00	0.36	0.67

<u>**Table 2 Notes:**</u> the range/differences from the minimal to maximum values for viscosity, "soot", and base numbers are significantly lower, i.e., better

From Table 1 RR F			
	Vis	soot	TBN
Avg-->	15.27	0.90	5.85
Min-->	14.39	0.60	3.25
Max-->	16.04	1.10	7.89
Stdev->	0.69	0.22	2.09

From Table 2 Ref			
	Vis	soot	TBN
Avg-->	15.83	1.33	6.48
Min-->	15.39	1.33	6.31
Max-->	15.98	1.34	6.65
Stdev->	0.25	0.01	0.13

Tables from 1 and 2: the two above tables highlight the differences in the two laboratories

3. Infrared Spectrometry: E168 *Standard Practices for General Techniques of Infrared Quantitative Analysis*

Theory for a Single-Compound Analysis

Quantitative spectrometry is based on the Beer-Bouguer-Lambert (henceforth referred to as Beer's) law, which is expressed for the one component case as:

$$A = abc$$

where:
A = absorbance of the sample at a specified wavenumber,
a = absorptivity of the component at this wavenumber,
b = sample path length, and
c = concentration of the component.

Since spectrometers measure transmittance, T, of the radiation through a sample, it is necessary to convert T to A as follows:

$$A = -\log T = -\log P/P_0$$

where:
P_0 = input radiant power at the sample, and
P = radiant power transmitted through the sample

Review of AAR M-963-84 All-Year Journal Box Lubricating Oil Specification

Prepared by:
Anju Singla, Dave Tuttle, Jerainne Heywood, Shaji Koshy,
Dennis McAndrew, Corey Ruch

Abstract:

The specification for *Association of American Railroads (AAR) M-963-84 All Year Journal Box Lubricating Oil* was last revised in 1985, and last appeared in AAR Manual of Standards and Recommended Practices (MSRP) Publication in 2002. However, several lubricants are available in the current marketplace, which continue to bear only an "AAR M-963" specification. Other lubricants bear the AAR M-963 specification in addition to other advanced specifications.

At least one Traction Motor Support Bearing (TMSB) failure has been attributed to the use of a lubricant carrying only the AAR M-963 Journal Box Oil (JBO) specification when a lubricant with a more advanced Traction Motor Support Bearing (TMSB) specification should have been used.

Based on this failure, a request to review the AAR M-963 specification and provide input on the current state of lubricant specifications was made of the Locomotive Maintenance Officers Association (LMOA) Fuel, Lubricants and Environmental (FL&E) Committee.

The following report details background, research, discussion and recommendations of the LMOA FL&E Committee regarding the various JBO and TMSB lubricants and specifications available in the market place.

Background:

A short-line railroad experienced failure of a locomotive traction motor support bearing (TMSB). Subsequent examination and failure analysis concluded the root cause of the failure was due to a combination of excessive surface roughness of the axle finish in combination with plugging of the lubricating wick due to use of an oil with elevated levels of zinc and calcium. The oil reportedly in use carried the AAR M-963-84 All Year Journal Box Lubricating Oil specification.

The traction motor support bearing failure and subsequent discussion led to a request for the LMOA FL&E committee to review the AAR M-963-84 specification and make recommendations.

Additional key factors stated by the requesting railroad included:

SERVICE DELIVERY PRICE QUALITY

POWERRAIL

CREATIVE INNOVATIONS...CONTINUING TRADITION

Journal Boxes

Cooper Bearings Inc., a member of the PowerRail Family of Companies, and a certified AAR M-1003 Quality facility, specializes in NEW and Remanufactured Hyatt and GG Journal Boxes for EMD and GE locomotives. In addition, we offer Unit Exchange and Return & Repair programs, including conversion from Hyatt to GG.

Hyatt Journal Box

All PowerRail Hyatt Boxes are modified with the 3N1 Liner Standard

Hyatt Converted to GG Standard

GG Box

PowerRail, Inc.
570-883-7005
Sales@ePowerRail.com
www.ePowerRail.com

AAR M-1003 CERTIFIED

MADE IN USA

- Most locomotives operated by the short line railroad industry are equipped with wick lubricated traction motor support bearings.
- Short line Railroads have very few locomotives equipped with the newer roller style traction motor support bearings.
- Many short line maintenance personnel do not have the latest guidance available to assist them as to what specific lubricants should be used in certain applications.
- The thought process is that if the oil meets the AAR specification for lubrication of journal boxes it should be good enough for a similar locomotive "journal bearing" application.
- The short line (as well as many others in the industry) would like to consolidate to one product for "all applications" (within a certain category) so only one lubricant would need to be purchased.

Terms / Definitions:

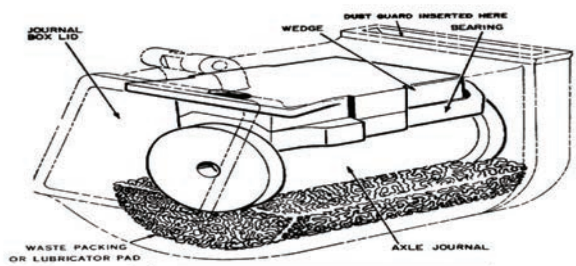
Several common terms and acronyms are defined and clarified below in order to remove ambiguity from additional discussion.

"Journal Box Bearing" (JBB)

A journal box bearing (JBB) is placed at the end of a freight car or locomotive axle to provide support for the truck set side frames and ultimately the weight of the freight car or locomotive. The Journal Box Bearing can be sub-divided into two main types:

Roller Bearing Journal Box – This bearing typically consists of a hardened inner and outer race with hardened cylindrical roller bearing elements and a brass cage.

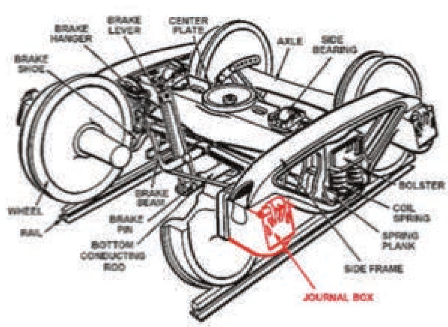
Friction Bearing Journal Box - This bearing typically consists of lead babbitt over a brass bearing shell.



Freight Car Journal Box (JB)

AAR M-963 is required

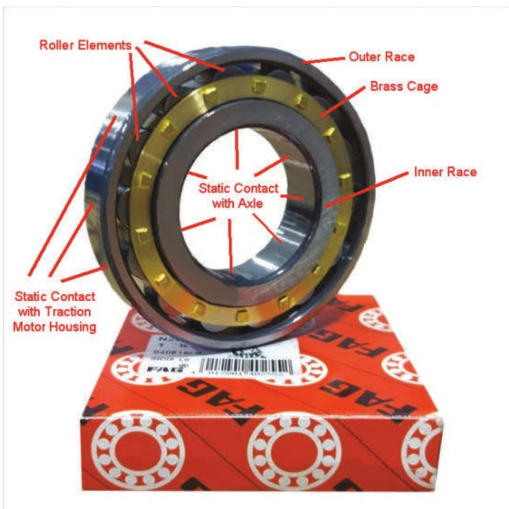
"D50E14, EMS 1002, AAR M-963" oil is acceptable

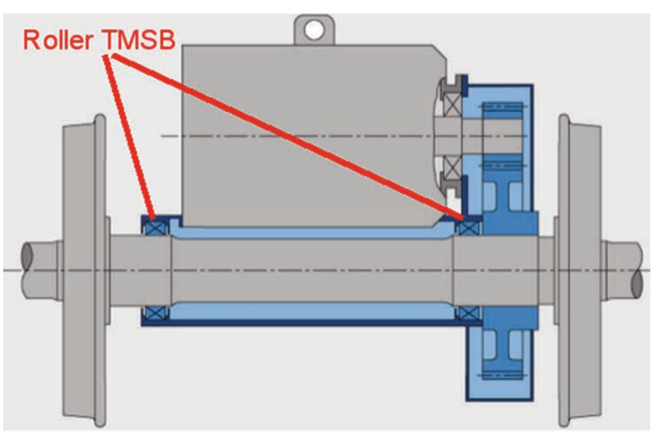


"Traction Motor Support Bearing" (TMSB)

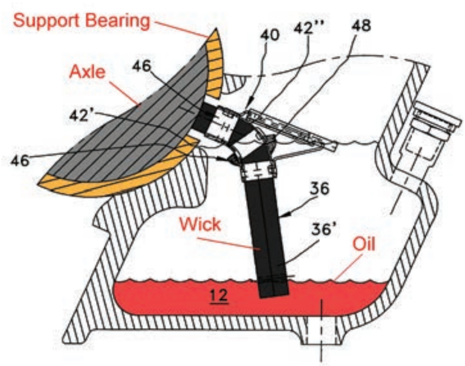
Traction Motor Support Bearings (TMSB) are placed inboard of the locomotive wheels to support the traction motor and can typically be subdivided into two additional categories:

A Roller Traction Motor Support Bearing - Defined as a device with hardened steel inner and outer races, containing a series of round or cylindrical hardened steel roller elements. The inner race is in static contact with the axle and the outer race is in static contact with the traction motor housing. This bearing is typically lubricated with grease in traction motor applications and as such, is not considered in the scope of this review.





Traction Motor Support Bearing aka "Journal Support Bearing" or "Journal Bearing" – A traction motor support bearing or sometimes colloquially called a "Journal Bearing" is typically defined as a bearing with leaded brass base and lead babbitt overlay. The inner lead babbitt surface is in sliding contact with the axle and the outer brass case is in is in static contact with the traction motor housing. This bearing is typically lubricated with a wick drawing oil from a reservoir.



Preliminary Research:

In review of the lubricants applicable to each of the bearing types discussed above, three main specifications were identified. As previously discussed, AAR M-963-84 is an 'all year' lubricant for journal box bearings. GE D50E14 is described by General Electric as a traction motor support bearing oil and EMD EMS1002 is listed by EMD, also as a traction motor support bearing oil.

Each of the three main lubricant specifications, AAR M-963, GE D50E14 and EMD EMS1002 were reviewed. The text of each specification is presented below with additional remarks to follow.

Association of American Railroads
Mechanical Division
Manual of Standards and Recommended Practices

M-963

SPECIFICATION M-963-84

STANDARD

ALL-YEAR JOURNAL BOX LUBRICATING OIL

Adopted: 1978, 1979 Revision Superseded 1984
Latest Revision Effective: March 1, 1985

1.0 SCOPE

These specifications cover the requirements for an all year journal box lubricating oil with rust inhibitors for use in saturating lubricating devices, free oiling of journal boxes or other uses.

PROPERTIES AND TESTS

2.0 PROPERTIES

The all year journal box lubrication oil shall conform to the following:

	Items	Methods of Test*	Requirements
2.1	Flash, min.	ASTM D-92	177°C (350°F)
2.2	Kinematic viscosity at 99°C (210°F) SSU	ASTM D-445	53 - 58
2.3	Viscosity Index, min.	ASTM D-2270 Table XI	100 min.
2.3.1	Viscosity Index for Base or Re-refined stock, min.	ASTM D-2270 Table XI	90 min.
2.4	Pour Point, Upper max.	ASTM D-97	−37°C (−35°F)
2.5	Moisture, max.	ASTM D-95	0.10%
2.6	Pentane Insolubles, max.	ASTM D-893 Procedure B	0.10%
2.7	pH	ASTM D-664	pH 6.5 to 9
2.8	Ash, %, max.	ASTM D-482	0.10%**
2.9	Rust-Preventing Characteristics Test	ASTM D-665 Procedure A-24 hr., min.	No Rust
2.10	Corrosion-Humidity Cabinet	Note (1) ASTM D-1748 100% RH-100 hr.	No More Than 3 Dots

*Means to the latest ASTM test method.

**Ash content of base or re-refined stock prior to addition of additives.

Note (1) = The apparatus to be used shall be of such design and construction as to satisfy the conditions of the test. The test cabinet shall consist of a chamber which will provide support for the specimens and include the necessary means for control of temperature and relative humidity. The temperature to be maintained during testing period shall be 120 ± 2F (48.9 ± 1.10C) and a relative humidity of 100%.

GE specification for Traction Motor Support Bearing Oil – GE D50E14 – Basic Requirements

Table 14. GE Specification D50E14 - Traction Motor Support Bearing Oil

PROPERTIES	AAR-M-963	D50E14	TEST METHOD
Flash Point, COC, °F	350 minimum	350 minimum	ASTM D-92
API Gravity at 60°F	-	27 to 31	ASTM D-287
Pour Point, °F	-35 maximum	-35 maximum	ASTM D-97
Viscosity (Kinematic) cSt at 40°C cSt at 100°C SUS at 100°F	 - 8 to 9.4 -	 52 to 66 8 to 9.4 260 to 340	 ASTM D-445 ASTM D-445 ASTM D-2161
Viscosity Index	100 minimum	100 minimum	ASTM D-2270
Ash,%	0.10 maximum	0.10 maximum	ASTM D-482
Sulfur,%	-	0.80 maximum	ASTM D-129
Load Wear Index, Kg	-	37 minimum	ASTM D-2783
Weld Point, Kg	-	200 minimum	ASTM D-2783
Lubricity, Four-Ball, mm 40 Kg, 1 hr., 75°C, 600 RPM	-	0.35 nominal	GE E4B6 (Similar to ASTM D-2266)
Sources of Supply: Chevron Global Lubricants CITGO Petroleum Corporation			 Texaco Code 674 Journaltex HD57 Journallube SBO

GE specification for Traction Motor Support Bearing Oil – GE D50E14 – Detailed Requirements

Specification D50E14 identifies a refined mineral oil used for lubricating traction motor suspension sleeve bearings with felt wick lubricators. This material meets the AAR-M-693 Specification, but the AAR Specification does not meet Specification D50E14. Oils meeting only AAR-M-963 Specification should not be used for traction motor suspension bearings.

Mineral oils meeting this Specification must contain fatty acid and/or fatty oil additives, or additives that provide equivalent performance to help lubricate the bearings under all load conditions.

Materials meeting this Specification are not to be mixed with other oils unless compatibility tests with and without water contamination, up to 10%, show no deleterious effects.

Compatibility

Materials will be considered compatible (stable) if when mixed with a second journal oil (with and without water), the lubricating properties are not altered. This includes both chemical and physical properties. There shall be no reactions or interactions that cause a precipitation or the formation of other compounds, such as carboxyl salts (soaps). All future lubricant request for approval must demonstrate compatibility with the currently approved materials.

Performance testing requirements:

- A performance or screening test must be performed by the vendor, and observed with the data reviewed by GE Transportation Systems Engineering.
- The test will utilize a full-scale journal and a section of the babbitted bearing lubricated under load and speed conditions to simulate railroad service with felt wick lubricators.
- The test will be a comparative test with an approved oil, and comparative measurements of friction and temperature will constitute the test.
- Engineering may provide temporary approval of a candidate oil for field testing, only after successful completion of performance testing with the precise conditions to be mutually agreed upon at the time of approval.

PROPERTIES	TEST METHOD	AAR-M-963	D50E14
Flash point, COC, F	ASTM D-92	350 min.	350 min.
API Gravity @ 60F	ASTM D-287	---	27-31
Pour Point, F	ASTM D-97	-35 max.	-35 max.
Viscosity (Kinematic)			
cST @ 40C	ASTM D-445	---	52-66
cST @ 100C	ASTM D-445	8-9.4	8-9.4
SUS @ 100F	ASTM D-2161	---	260-340
Viscosity Index	ASTM D-2270	100 min.	100 min.
Ash, %	ASTM D-482	0.10 max.	0.10 max.
Sulfur, %	ASTM D-129	---	0.8 max.
Load Wear Index, Kg	ASTM D-2783	---	37 min.
Weld Point, Kg	ASTM D-2783	---	200 min.
Lubricity, 4-Ball, mm 40 Kg, 1 hr., 75 C, 500 RPM	GE E4B6 (a)	---	0.35 nominal
Compatibility	GE 41A330698	---	Pass

(a) Similar to ASTM D-2266

Manufacture

The oil shall consist of a well-refined petroleum product free from water, sediment and resins, and shall be free from contamination (less than 10 PPM) with calcium and zinc as determined by Spectrometric analysis.

EMD specification for Traction Motor Support Bearing Oil - EMD-EMS1002

REQUIREMENTS:

Test	ASTM Designation[1]	Limits	
		Minimum	Maximum
Viscosity			
SUS 100°F (38°C)	D445[2]	240	340
SUS 210°F (99°C)	D445[2]	53.0	58.0
Viscosity Index	D2270	100	---
API Gravity 60°F (16°C)	D287	26.5	29.5
Ash	D482	---	0.05
Flash Point °F (°C)	D92	380 (193)	---
Pour Point °F (°C)	D97	---	-35 (-37)
Pentane Insolubles, %	D893	---	0.10
pH	D664	6.5	9.0
Water, %	D95	---	0.10
Aniline Point °F (°C)	D611	200 (93)	---
Humidity Cabinet Test 120°F (49°C), 100% R.H., 100 hours	D1748	---	3 dots
Rust Protection in Distilled Water	D665	Passes Test	
Foaming	D892	No continuous layer	
Residuals			
Calcium, PPM	---	---	10
Zinc, PPM	---	---	10
Water Compatibility Test For Oil (Standard Laboratory Practice #117)	---	---	1 ml cream

[1] Latest Date Test

[2] Conversion of kinematic viscosity to Saybolt Universal viscosity based on ASTM D2161.

**No specific brand names are offered within the EMD Specification.*

Specification Review:

In reviewing the details of each specification, two main lubricant properties should be considered - as listed in the following table and discussed below:

	AAR M-963	EMD EMS1002	GE D50E14
Calcium (Ca)	N/S	10 ppm (max)	10 ppm (max)
Zinc (Zn)	N/S	10ppm (max)	10 ppm (max)
Ash	0.10 max*	0.05 max	0.10 max

N/S = No Specification
* Note = Ash of base stock, prior to addition of additives

Zinc and Calcium:

Both GE and EMD Traction Motor Support Bearing (TMSB) oils carry a '10ppm maximum' specification for zinc and calcium, while the AAR M-963 oil does not carry any specified limit for these elements. This means zinc and calcium, which are present in many additives for different functions, could be added far above the 10ppm level in the M-963 oil.

The high levels of zinc and calcium could cause issues with proper wicking of the oil and therefore prevent proper lubrication of the support bearing. Additionally, mixing any two oils together is not recommended as it may result in a gelation effect; which will cause the wicks to clog and fail to distribute the oil properly. Even 'draining and refilling' with a different oil is discouraged as substantial oil can remain in the lubrication wick, leading to the same issues as mixing two oils.

Ash:

Both GE D50E14 and EMD EMS1002 require low ash content of 0.10% and 0.05%, respectively. AAR M963-84 also specifies an ash content of 0.10% maximum – however, a note is included indicating this is the ash content of the base oil, prior to addition of the additive package. Therefore, depending on the additives used, the finished AAR M-963 journal box oil could contain an ash content notably above the 0.05 – 0.10% levels typically specified for TMSB oil.

Bearing Compatibility:

A review of several popular "Journal Lubricants" from the current marketplace was conducted. In each case, the Manufacturer / Name Brand were noted as well as the specifications listed by the oil manufacturer. The data was tabulated as displayed on the next page.

	Specifications			
Manufacturer - Brand Name	**AAR M-963**	**GE D50E14**	**EMD EMS 1002**	**Clarification**
	Locomotive and Freight Car Journal Box Oils	**GE Traction Motor Support Bearing Oils**	**EMD Traction Motor Support Bearing Oils**	
American Refining - Brad Penn No Rust Journal Bearing Oil	Yes	Not Listed [No]	Not Listed [No]	Use in JBB Only
American Refining- Ashless Journal Bearing Oil	Yes	Yes	Yes	Use in TMSB as well as JBB
Chevron - Journaltex HD57	Yes	Yes	Yes	Use in TMSB as well as JBB
Citgo - Railroad Car Journal Oil No. 9	Yes	Not Listed [No]	Not Listed [No]	Use in JBB Only
Interlube - Journal Guard AYG	Yes	Not Listed [No]	Not Listed [No]	Use in JBB Only
Phillips 66 - AAR 963 Oil	Yes	Not Listed [No]	Not Listed [No]	Use in JBB Only
Shell - Cyprina Oil 963	Yes	Yes	Yes	Use in TMSB as well as JBB
Total - Railroad Journal Oil	Yes	Yes	Yes	Use in TMSB as well as JBB

TMSB = Traction Motor Support Bearing

JBB = Journal Box Bearing

Of the eight lubricants surveyed, all were found to carry the AAR M-963 specification, which indicated they could be used as "Journal Box Oil" with standard journal box bearings. However, only four lubricants were found to carry additional specifications, which would be applicable to traction motor support bearings.

Results and Discussion:

The AAR M-963 lubricant specification was developed for journal box bearings (JBB). This use appears to cover locomotive journal box bearings as well as freight car journal box bearings.

The AAR M-963 specification does not appear to include traction motor support bearings of any kind. Confusion may arise as TMSBs are sometimes colloquially referred to as 'Journal Bearings'. This may lead the casual observer to conclude that a journal box bearing oil would be acceptable for traction motor "journal bearing" use. However, due to the 'wick fed' nature of the traction motor versus the 'bath lubricated' nature of locomotive or freight car journal box bearings, this is not necessarily the case.

Further, some oils such as American Refining Group, Chevron HD-57, Shell Cyprina and Total Railroad Journal Oil are formulated to meet GE D50E14 and EMD EMS 1002 specifications for use in traction motor support bearings. These oils also carry the AAR M-963 Journal Box Lubricant specification, which would allow use in either traction motors or journal box bearings. However, lubricants carrying only the AAR M-963 specification should only be used in journal box bearings.

Some of the journal oil, which meets the M-963-84 specification, may be a calcium-based oil, which may also contains zinc. When this type oil is contaminated with water, there is a potential to create a soap, which will plug the lubricating wick and cause loss of lubrication resulting in a failure of a traction motor support bearing. Also this oil may not be able to properly lubricate the traction motor support bearings under high torque, low speed conditions.

Neither of the major locomotive OEM's recommend using oil with calcium or zinc for traction motor support bearing lubrication.

All supplier data sheets we have found indicate the oil meets the specification for journal bearing oil but only some data sheets specify the oil meets the additional requirements for traction motor support bearing oil. [American Refining-Ashless Journal Bearing Oil, Chevron Journaltex HD57, Shell-Cyprina-963 and Total Railroad Journal Oil Tech].

Recommendations:

OEM recommendations should be followed for all oil specification requirements. If a piece of equipment requires a certain oil specification, then an oil carrying (at minimum) that specification should be used.

If a "universal" oil is desired, then an oil meeting ALL applicable specifications for the intended applications should be purchased. These oils currently exist in the marketplace.

Care should be taken to insure all oil products are clearly labeled and/or otherwise identified as to the allowable use and only used for that application. Great care should be taken to keep improper oil out of undesignated applications.

In response to the specific points submitted to the LMOA FL&E Committee for address:

- Most locomotives operated by the short line railroad industry are equipped with wick lubricated traction motor support bearings.
- Short line Railroads have very few locomotives equipped with the newer roller style traction motor support bearings.

Both of these points may be valid. However, the age of the equipment does not alter the OEM recommendation for the required lubrication.

- Many short line maintenance personnel do not have the latest guidance available to assist them as to what specific lubricants should be used in certain applications.

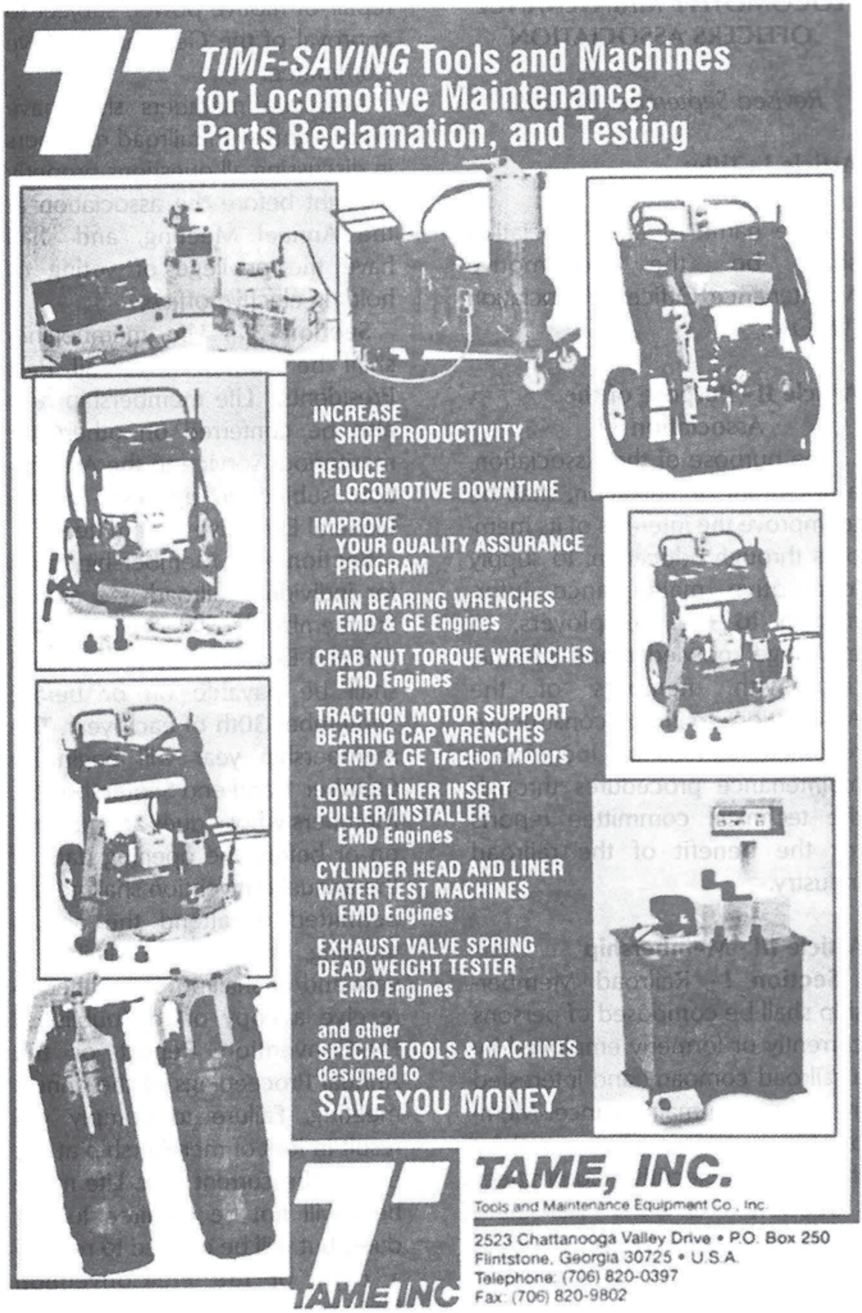
Considering the statements suggesting short line railroads often deal with older equipment - the 'latest guidance' may not be completely relevant. However, guidance is often freely available from many sources such as the OEM, various lubricant manufacturers, 'Ask LMOA' at lmoarail.com, etc. Though again, the FL&E committee would always suggest following the OEM recommendation for the required lubrication.

- The thought process is that if the oil meets the AAR specification for lubrication of journal boxes it should be good enough for a similar locomotive "journal bearing" application.

Unfortunately, there is no basis for this thought process to be correct. Simply because the two applications share the term 'journal' does not guarantee compatibility of lubrication requirements.

- • The short line (as well as many others in the industry) would like to consolidate to one product for "all applications" (within a certain category) so only one lubricant would need to be purchased.

One product for "all applications" may not be achievable for every given category. As mentioned above, the FL&E committee recommends always following the manufacturers recommended specifications for lubrication. However in this instance, at least four oils were identified during the course of this review – American Refining-Ashless Journal Bearing Oil, Chevron Journaltex HD57, Shell Cyprina Oil 963, and Total Railroad Journal Oil – which carry multiple, inclusive specifications and would be applicable to traction motor support bearings as well as journal box bearings.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Engine Oils for Improved Fuel Economy and Oil Consumption to Railroad Services

Prepared by:
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Abstract

This paper was originally published by CIMAC (formerly, Congrès International des Moteurs A Combustion, now the International Council on Combustion Engines) at their 2019 Congress in Vancouver, British Colombia, Canada, June 2019, and is re-printed here with their permission, as this subject will be of interest to the LMOA community.

The paper presents the results of a year-plus long field test comparing two different viscosity engine oils using the same additive package, same base stock slate, same engine and locomotive models, in the same service. The SAE 20W-40 oil resulted in 1.4% lower specific fuel consumption and 37% lower specific oil consumption, compared to the SAE 40 oil.

Commentary

The original paper was peer reviewed by two CIMAC reviewers. Upon review by the Fuels, Lubricants, and Environmental Committee (FL&E) of LMOA, additional points for clarification emerged:

1. The two different viscosity grades – SAE 40 and SAE 20W-40 – were blended with the same additive package in the same base stock slate, (the product line of base stock viscosity "cuts" manufactured by a company using the same crude, process, etc.). The mixture of light-, medium-, and heavy- base stock "cuts" are clearly different for the two oils, as shown in Table 1.
2. The field test comprised 18 locomotives operating on the same route at the same time, with each oil in nine locomotives.
3. The fuel used was low-sulfur diesel (<500 ppm), which was the standard available in the country of the test.
4. Oil changes were performed at approximately six months. For the SAE 40, oil change intervals averaged 188 days (163 minimum / 208 maximum). For the SAE 20W-40, oil change intervals averaged 180 days (165 minimum / 204 maximum).

5. Fuel and oil consumption were reported as a function of engine alternator (volts multiplied by amperes = Watts) and expressed as grams per kiloWatt-hour. In the CIMAC paper, these are named "Brake Specific Fuel Consumption" (BSFC) and "Brake Specific Oil Consumption" (BSOC). Clearly, there are many points through the locomotive system to measure output "power" and various terms which can be applied to any specific point of measurement. However, within the framework of this test, since the locomotives were closely matched and had the same alternators, the fuel economy and oil consumption improvements observed would be valid.

CIMAC 19
CONGRESS
VANCOUVER, JUNE 10-14, 2019

2019/238

Engine Oils for Improved Fuel Economy and Oil Consumption in Railroad Service

10.2 Latest Engine Component Developments – Components & Tribology

This paper has been presented and published at the 29th CIMAC World Congress 2019 in Vancouver, Canada. The CIMAC Congress is held every three years, each time in a different member country. The Congress program centres around the presentation of Technical Papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The themes of the 2019 event included Digitalization & Connectivity for different applications, System Integration, Electrification & Hybridization, Emission Reduction Technologies, Low Carbon Combustion including Global Sulphur Cap 2020, Case Studies from Operators, Product Development of Gas and Diesel Engines, Components & Tribology, Turbochargers, Controls & Automation, Fuels & Lubricants as well as Basic Research & Advanced Engineering. For further information please visit https://www.cimac.com.

ABSTRACT

It has long been known that engine lubricating oils can contribute to the fuel efficiency of internal combustion engines, but measuring these effects with sufficient precision to ensure confidence has been challenging. Procedural changes to improve precision in fuel economy measurements in railroad service, gained by experience, will be presented.

An extended field trial was conducted comparing two oils with different viscometric profiles in ten line-haul units each. The oils were found to give over 1% statistically different specific fuel consumption and over 10% statistically different specific oil consumption. Both results are well fit to classic hydrodynamic lubrication theory.

Wear metal content showed some differences, which are well explained by classical boundary lubrication theory.

Oxidation and its consequences – Acid Number increase, lead corrosion, Base Number decrease, etc. – showed unexpected differences, which were obvious in hindsight by examining how oil components (base stocks and viscosity modifiers) are chosen to achieve the different viscometric profiles.

1. INTRODUCTION

Engine design is certainly the most important factor that determines fuel efficiency, but the engine lubricant also has a role. It has been shown many times, for many different engine types and fuel types, that engine oil can affect engine fuel efficiency through reduction of friction where, in this case friction is meant in the broader sense to include mechanical friction (rubbing) and liquid "friction" (viscosity).

Engine parts rubbing on, or rolling across, each other cause friction – a loss of useful energy – which can be reduced by using the appropriate lubricant. However, that same liquid lubricant creates viscous energy losses, another form of energy loss.

Unfortunately, there is a delicate balance between reducing lubricant viscosity – which lowers the viscous losses, but might increase the mechanical friction losses – and increasing the lubricant viscosity – which might reduce the mechanical losses, but increase the viscous losses.

This balance is captured in the well-known Stribeck Curve, which is shown in Figure 1.

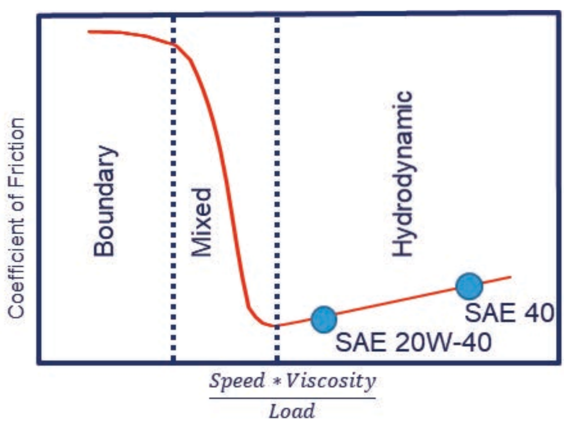

Figure 1. The Stribeck Curve

The Stribeck Curve illustrates that, in the hydrodynamic lubrication regime, lowering lubricant viscosity should lower viscous losses without increasing mechanical losses, resulting in reduced fuel consumption. The points labelled "SAE 20W-40" and "SAE 40" are examples only, and have not been fitted to any particular lubricants.

An engine comprises many parts, and each could be at a different speed, load, and temperature (which affects viscosity). In practice, the measured fuel consumption is a weighted average of all these contributions. It is found, in general, that a well-designed engine operated within its design parameters yields an overall response in the hydrodynamic region (even if specific engine components may not be hydrodynamic).

In consistent service, the speeds and loads should be the same within experimental variation, so the only remaining variable is viscosity. Of course, the oil viscosity at each engine part will be different, due to temperature, pressure, and shear rate but, again, viscosity at a single condition may be used as a surrogate. The question of which condition is the best predictor of engine performance has been the subject of a vast literature over the past 40 years or more [1,2].

This paper presents a field trial demonstration at a North American Class I railroad comparing the fuel efficiency of two railroad engine oils of different viscosities, SAE 40 and SAE 20W-40.

The lower viscosity, SAE 20W-40, oil gave (1.42 ± 0.35) % lower brake specific fuel consumption and (37 ± 20) % lower brake specific oil consumption, compared to the higher viscosity, SAE 40, oil.

2. BACKGROUND

Railroad engine oils conform to descriptions published by the Locomotive Maintenance Officer's Association (LMOA), which categories referenced as "Generations." Currently, Generations 5, 6, and 7 coexist in the market, and are often described by their Base Number (ASTM D2896), although there may be many other differences in the formulations.

Generation 5 is characterised by Base Numbers of 13 and above, and are intended for service with high sulphur diesel (HSD) fuels. Generation 6 is characterised by Base Numbers of 9 or 10, and are intended for service with low sulphur diesel (LSD) or Ultra-Low Sulphur Diesel (ULSD) fuels. Generation 7 is characterised by Base Numbers of 10 or 11, and are intended for service in engines meeting United States Tier 4 emissions (or equivalent), which may only use ULSD fuel.

They meet the specifications of and are approved by two Original Equipment Manufacturer's (OEM's) – Electro-Motive Diesel (EMD) and General Electric (GE). The only approved viscosity grades are SAE 40 and SAE 20W-40. Approval is by field trial.

It is recognised that multi-grade engine oils may give several advantages over mono-grades, similar to on-highway experience, fuel efficiency among them. It is also recognised that the lower viscosity of multi-grade oils could put some engine parts – primarily journal bearings – at risk for greater wear.

It is the purpose of this paper to demonstrate and quantify those differences.

2.1 Expectations

A viscosity-temperature comparison of the SAE 40 mono-grade and SAE 20W-40 multi-grade oils is shown schematically (and non-quantitatively) in Figure 2. An SAE 20W mono-grade oil is shown in gray for reference; it was not part of this field trial.

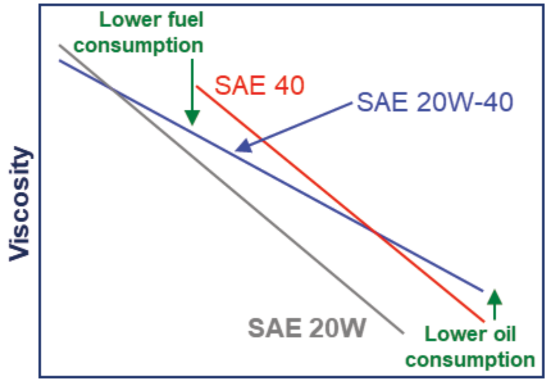

Figure 2. Viscosity-temperature comparison of the two test oils (schematic)

Since both SAE 40 and SAE 20W-40 meet the "40" so-called "summer grade," they have roughly equal kinematic viscosities at 100°C. However, the lower slope of the multi-grade results in lower viscosities at every temperature lower than 100°C. Since most engine parts operate lower than 100°C most of the time, the lower viscosity of the multi-grade at those temperatures should lead to lower viscous losses (also shown as the two points in the hydrodynamic region of Figure 1).

Conversely, due to the lower slope, the multi-grade has higher kinematic viscosity at temperatures higher than 100°C. Since the piston ring zone – in particular, the top ring – operates higher than 100°C, and oil transport around the back of the piston rings is a low shear phenomenon, it is expected oil consumption will be lower for the multi-grade.

Returning to the Stribeck Curve of Figure 1, the lower viscosity multi-grade oil is expected to have lower oil film thickness in hydrodynamic areas, such as journal bearings. This is illustrated schematically in Figure 3, where the lower oil film thickness will lead to more "break-in" of the asperities. The expectation should be that the multi-grade oil will have higher lead content for the first – or maybe even second – oil drain.

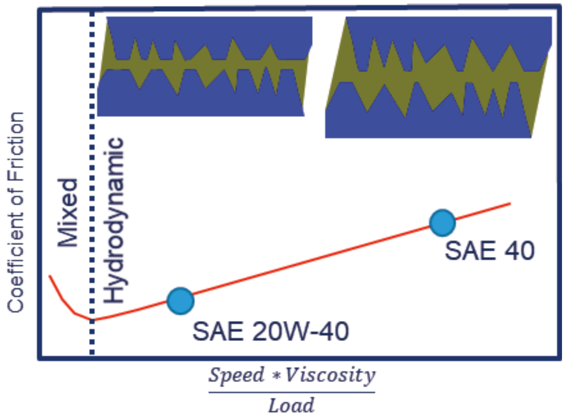

Figure 3. Expectations of break-in wear

3. EXPERIMENTAL

3.1 Test Oils

Two test oils were designed, using the same approved performance additive package and the same API Group I base stock slate, to meet the requirements of the two approved viscosity grades: SAE 40 (mono-grade) and SAE 20W-40 (multi-grade). The multi-grade uses a Viscosity Modifier comprising a di-block polymer. The oil properties are shown in Table 1.

Table 1. Test oils

Property	Mono	Multi
Field test designation	RED	BLUE
Viscosity grade	SAE 40	SAE 20W-40
Viscosity at 100°C, mm^2/s	15.1	15.4
Viscosity at 40°C, mm^2/s	149.6	135.0
Viscosity Index	101	117
Viscosity at -10°C, mPa-s	7690	4140
Viscosity at -15°C, mPa-s	16,800	8430
Viscosity at -20°C, mPa-s	---	19,500
Viscosity at 150°C, mPa-s	4.37	4.20
Viscosity at 100°C, mPa-s	12.7	10.7
Viscosity at 100°C after shear	---	10.7
Bright stock content	8	0
Base oil viscosity at 100°C	13.1	11.4
Base oil saturates	66.2	65.3

Although both oils have similar kinematic viscosities at 100°C (i.e., they are both "40 grade"), notable differences include base oil blend viscosity (-18%), high-temperature, high-shear dynamic viscosity at both 150°C (-4%) and 100°C (–16%).

3.2 Operating conditions

Each oil was charged into nine new GE AC44e locomotives, operating on low-sulphur diesel fuel (<500 ppm S). All units were in similar service on the same line, and were monitored for an average of 440 days; Three mono-grade and two multi-grade units were extended to an average of 568 days (maximum 578).

Engine output, fuel consumption, and oil consumption were recorded daily. Oil samples were taken every two weeks, on average, and analysed for the physical and chemical properties listed in Table 2.

At the end of 16 months, units were opened for inspection, measurements, photographs, and rating by a Qualified Rater (although that is not the focus of this paper). Main journal bearings from several engines were removed for examination, as that is the part most likely to respond to viscosity differences.

Table 2. Used oil analysis properties

Property	Method	Units
Viscosity at 100°C	D445	mm^2/s
Viscosity at 40°C	D445	mm^2/s
Oxidation	FTIR	A/cm
Nitration	FTIR	A/cm
Soot	TGA	mass %
Insolubles (LMOA Method)	D7317	mass %
Base Number	D2896	mgKOH/g
Base Number	D4739	mgKOH/g
Acid Number	D664	mgKOH/g
Fuel dilution	GC	mass %
Water	Karl-Fischer	mass %
Wear elements	D5185	mg/kg
Contaminant elements	D5185	mg/kg

4 RESULTS

4.1 Operational parameters

A field test comparing two oils would not be valid unless the units for each oil were in comparable operations (e.g., engine power output, percent time in service, etc.). Table 3 shows the fleets of nine units each for the two oils were well-matched in service and severity.

This is also shown in Figure 4, where cumulative engine power output is plotted against days on test for each unit, with the mono-grade units in various shapes and shades of red, and the multi-grade units in various shapes and shades of blue.

Each unit was highly linear, indicating consistent service and duty cycle during the test period. The fleets of nine units each for the two oils produced (253.2 ± 6.3) and (255.6 ± 5.3) MW-hr/month for the mono-grade and multi-grade, respectively. There is no statistical or practical difference between the fleets.

Table 3. Operational parameters

Property	Mono	Multi
Field test designation	RED	BLUE
Viscosity grade	SAE 40	SAE 20W-40
Number of locomotives	9	9
Days on test, average	470	418
Days on test, maximum	578	567
Oil change interval, days, avg	188	180
Oil change interval, days, max	208	204
Power output, MW-hr/month	253.2	255.6

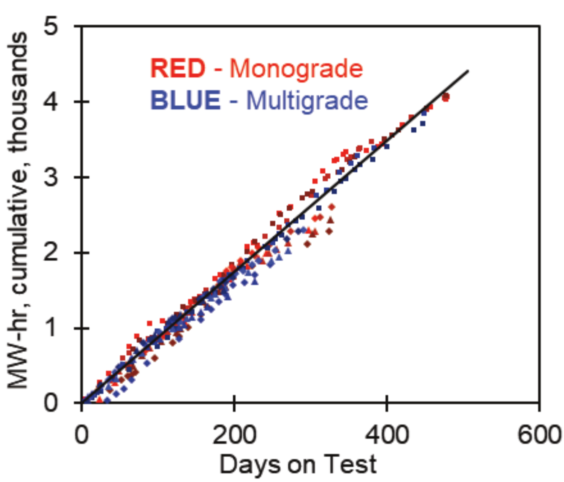

Figure 4. Engine power output

4.2 Brake specific fluid consumption

Fuel consumption was measured by recording the amount added to reach a fill-mark, each time a unit was serviced, on average every four days. Cumulative fuel consumption for each unit is shown in Figure 5.

Oil consumption was measured by recording the amount added to reach a fill-mark, each time a unit was serviced, on average every four days. Cumulative oil consumption for each unit is shown in Figure 6.

Fuel consumption and oil consumption were converted from litres to kg using their measured densities. For each fluid, the cumulative consumption in kg was regressed against the engine power output in MW-hr, using a linear Y=mx + b model. The usual regression diagnostics were performed.

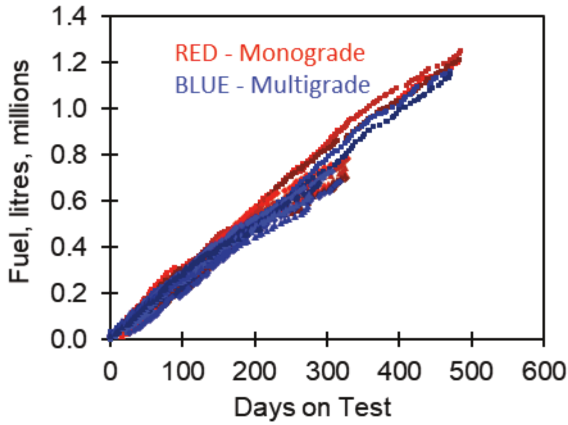

Figure 5. Fuel consumption

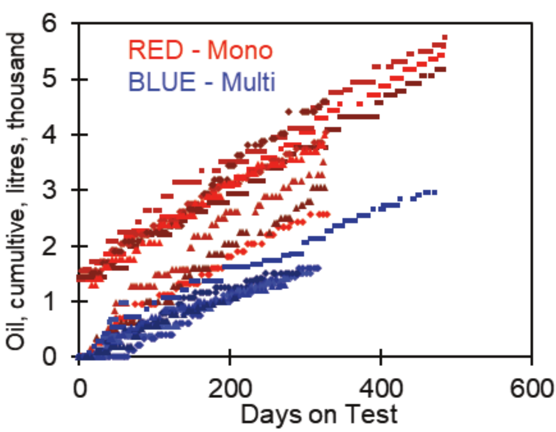

Figure 6. Oil consumption

For each engine, the slope of the linear fit is the brake specific fluid consumption, in g/kW-hr (kg/MW-hr = g/ kW-hr). This method is preferable to taking the average of oil consumed for each measuring period. The results are shown in Table 4.

Table 4. Fluid consumption results

Property	Mono	Multi
Field test designation	RED	BLUE
Viscosity grade	SAE 40	SAE 20W-40
Fuel consumption, g/kW-hr	244.4 ± 0.76	240.9 ± 1.01
BSFC improvement, %	Baseline	1.42 ± 0.35
Oil consumption, g/kW-hr	0.95±0.21	0.60 ± 0.18
BSOC improvement, %	Baseline	37 ± 20

4.3 Used oil properties

There were no significant differences in most of the used oil properties, with the following exceptions: Viscosity increase, oxidation, iron, and lead. These are interpreted and discussed in the next section.

5 DISCUSSION

5.1 Oil stress factors

Before examining the used oil properties, it is instructive to consider the oil stress factors [3] for each oil. Oil stress factor (OSF) is essentially the total amount of energy absorbed per unit mass of oil, and has the units kW-hr/g, or reciprocal BSOC. It depends on the engine power output, the sump volume of oil, and – significantly – the BSOC. As the oil is consumed, and therefore replaced, there is a greater total amount of oil to absorb the engine output, thereby reducing stress on the oil. This is why engines with high oil consumption – for example, old two-stroke trunk piston engines – do not need oil changes: the added oil reduces stress and maintains the in-service oil within condemning limits.

Given the significant difference in oil consumption between the two test oils, the OSF will be different, as shown in Figure 7.

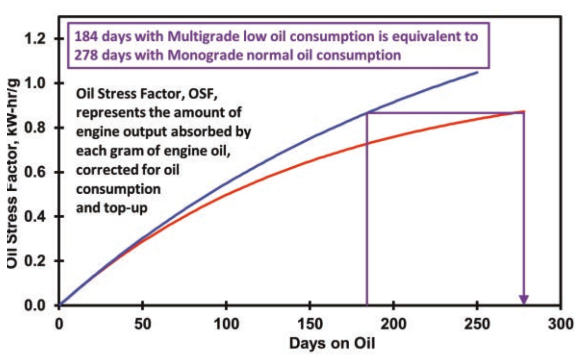

Figure 7. Oil stress factors

5.2 Viscosity increase

As shown in Figure 8, the multi-grade oil had significantly lower viscosity increase, despite having higher oil stress. Soot and insoluble content were similar for the two oils.

Typically, factors that affect viscosity increase are oxidation, inadequate soot dispersancy, viscosity modifier degradation, or a combination of these. As seen in Table 1, the multi-grade uses a shear-stable polymer (e.g., dynamic viscosity before and after shear are the same), and this is not considered a significant contributor to differences in viscosity increase.

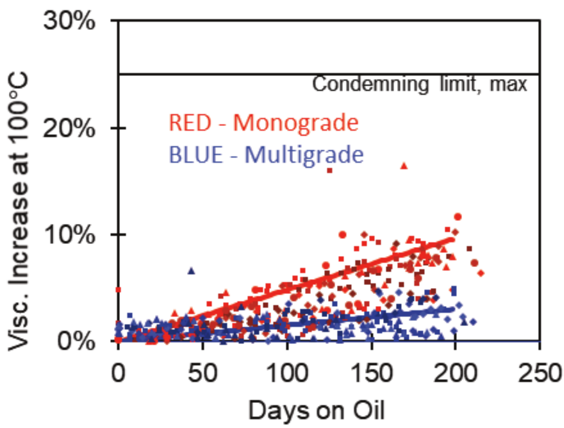

Figure 8. Viscosity increase

Figure 9 shows viscosity increase as a function of used oil soot content, which was found to be more precise than, but highly correlated with, Insolubles by the LMOA paper filtration method.

5.3 Oxidation

Oxidation is shown in Figure 10, demonstrating the multi-grade oil has lower oxidation, despite having higher oil stress. This is assumed to be due to the more favourable base oil mixture, eliminating bright stock and increasing base oil saturates.

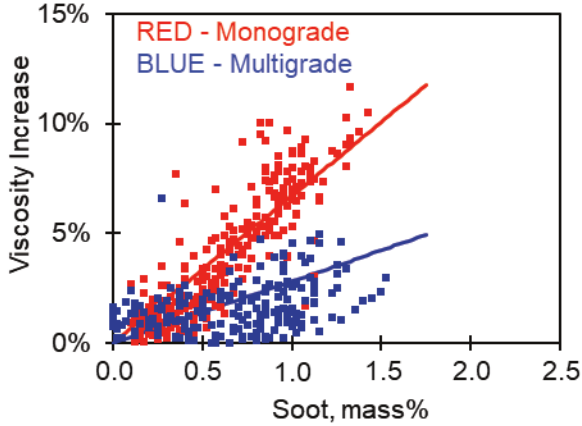

Figure 9. Viscosity Increase vs. Soot

It seems the lower viscosity increase may be a combination of lower oxidation and increased soot-handling ability.

5.4 Iron

It is always a concern when lowering oil viscosity to achieve fuel economy that the engine – or some parts within – will be driven out of the hydrodynamic region into boundary lubrication, and wear will increase. An early signal of this is used oil analysis, particularly wear metals contained in the parts of concern, such as iron in rings, liners, and valve trains. Figure 11 shows iron for the two oils as a function of time on oil, which appears to indicate higher wear for the lower viscosity multi-grade oil, but this is a false conclusion.

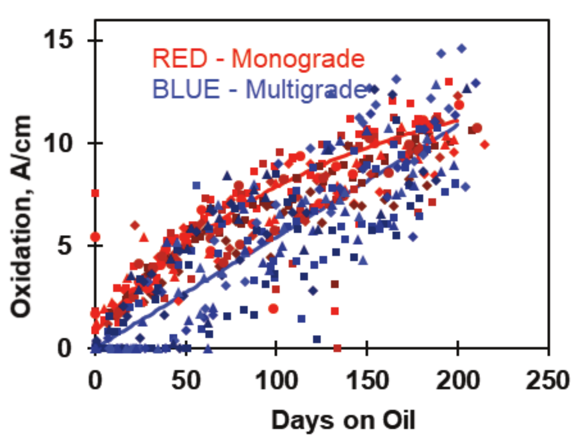

Figure 10. Oxidation increase by Infrared

Keeping in mind the much lower oil consumption of the multi-grade oil, it has less total volume of oil to dissolve any wear particles generated. Figure 12 shows iron for the two oils as a function of Oil Stress Factor (OSF), as explained above. This is essentially used oil analysis corrected for oil consumption. Now it can be seen that the two oils overlap, and there is no difference in their wear protection.

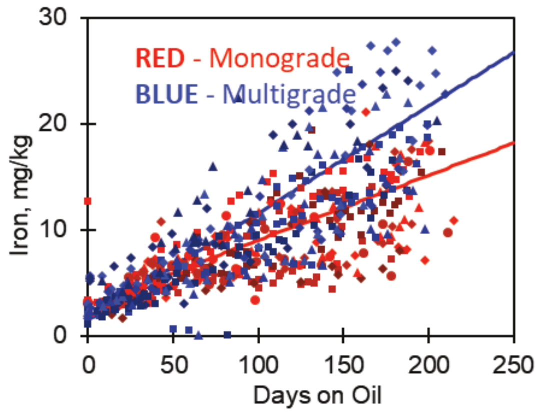

Figure 11. Iron increase

5.5 Lead

Perhaps the most concerning engine parts, when reducing viscosity, are the journal bearings which, for this engine model, have a standard lead overlay.

The results are consistent with lubrication theory and pre-test expectations: the lower viscosity oil will have more "break-in" and take longer to seat the bearings, but then equilibrate to the same low wear rate as the higher viscosity oil.

Figure 13 shows that both oils have high lead during the first oil drain, as the bearings initially "break-in" or "seat." The lower viscosity oil has higher lead during the first drain, since it delivers lower oil film thickness, as illustrated in Figure 3.

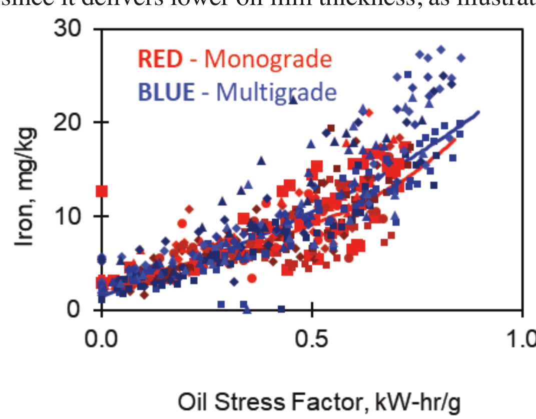

Figure 12. Iron increase vs. Oil Stress Factors

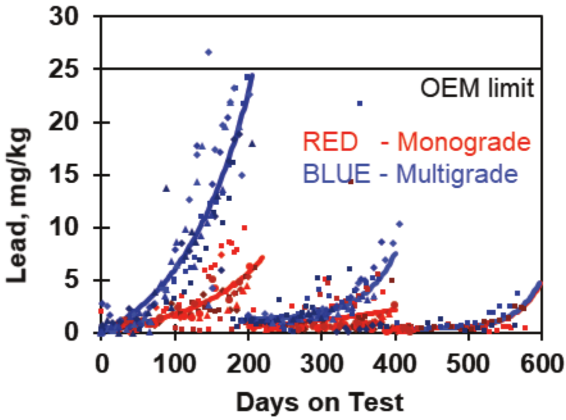

Figure 13. Lead vs. days on test

Both oils have significantly lower lead in the second oil drain, although the lower viscosity oil is still higher. By the third oil drain, both oils are equal and low.

5.6 Bearing condition

Representative photographs of bearings from each oil are shown in Figures 14 and 15. The bearing conditions are comparable and mild, considering they each have only one year's service.

6 CONCLUSIONS

A field trial was conducted to determine the fuel economy benefits of a lower viscosity, SAE 20W-40 multi-grade oil compared to an SAE 40 mono-grade oil in railroad service.

The lower viscosity, SAE 20W-40, oil gave (1.42 ± 0.35) % lower brake specific fuel consumption and (37 ± 20) % lower brake specific oil consumption, compared to the higher viscosity, SAE 40, oil.

Figure 14. Bearing from mono-grade engine

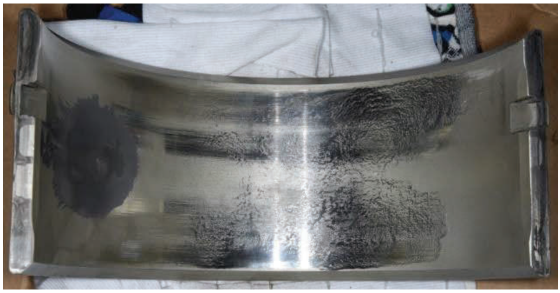

Figure 15. Bearing from multi-grade engine

The lower viscosity oil protected the engine – especially the journal bearings – as well as the higher viscosity oil, and was better for oxidation and soot-handling.

This demonstrates that lower viscosity, multi-grade oils, may have significant performance benefits in railroad service, compared to higher viscosity mono-grade oils.

This also demonstrates that fuel efficiency can be measured in "real-life" service, by careful recordkeeping and reasonable attention to detail.

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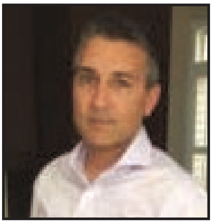
Report on the Committee on Electrical Maintenance

Monday, September 23, 2019 at 2:45 PM



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PERSONAL HISTORY

Amarjit Soora, P. Eng

Senior Engineering Manager, R&D and Project Management
ZTR, London Ontario

Amarjit (Am) was born in London England but has spent most of his life in London Ontario, where he went the University of Western Ontario. After obtaining a Bachelor of Science degree in Electrical Engineering in 1996, Am went to work with the Electromotive Division (EMD) in London. While there he had roles within the Engineering team, including Manufacturing Engineering and the Controls Group.

After three years Am joined ZTR, with whom he has been with for the past 20 years. While at ZTR Am has had several roles within engineering including R&D, Applications Engineering and Product Management. For the past ten years Am has managed various teams for domestic and export development projects, and has also led several long term control system programs.

Am currently lives in London with his wife Kulvinder of 22 years, and his daughter Parveen and son Amit. His passions outside of family and engineering include fitness, photography, soccer and the Indian Classical Instrument the Tabla.

The Electrical Maintenance Committee would like to thank Siemens Mobility and GO Brightline for hosting our February winter meeting in West Palm Beach Florida. Special thanks to Steve Mueting for the arranging the meeting and hospitality.

We would also like to thank Derya Ferendeci for arranging and hosting our July summer meeting at ABB Rail and Traction Converter in Richmond, VA. We also thank them for providing a tour of their facility.

Lost In Transition
The Collaborative Effort to Develop a Solution for Generator Transition Circuit Failures

Prepared by:
Jason Smith, Progress Rail

Contents

Introduction & Background

Transition fuses and diodes are a common root cause component of locomotive road failures. A Class I railroad identified transition fuses and diodes as one of the top root cause failures on their fleet of transition generator equipped locomotives. Due to the large size of this locomotive fleet, these fuses and diodes became a focus of reliability improvement efforts. Preliminary failure data analysis uncovered failure patterns and specific modes of operation that seemed to contribute to failures.

Based on the findings of this analysis, the railroad and manufacturer jointly decided to further investigate the failures of AR20 transition fuses and diodes through a collaborative "Tiger Team" of subject matter experts from each organization.

The purpose of this technical paper is to describe the challenges posed, the team assembled to determine the root cause of the failures, and finally, the steps taken to develop viable solutions to eliminate the failures.

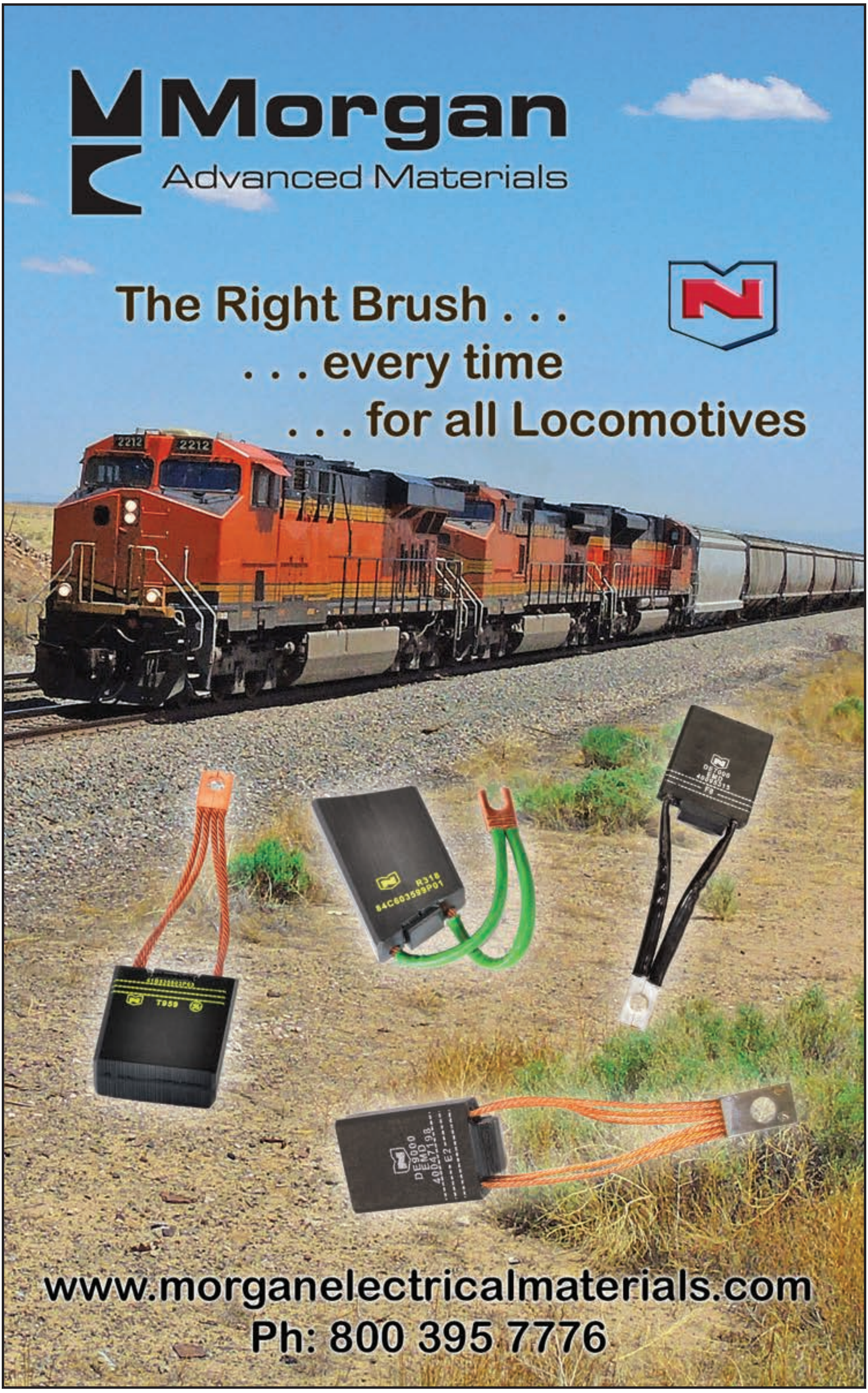
Transition Generators

Transition type generators such as AR8, AR11, and AR20 contain two separate alternator stators excited by a common rotor. The stator windings are intermixed in the frame, and the output of each stator is applied to its own rectifier bank. This system can be considered as two power sources in a single casing.

Configuring two stator outputs in parallel generates a high current necessary for startup and slow speed operation. By reconfiguring to connect the stator outputs in series, the high voltage required for high-speed operation can be generated.

Transition Circuit/Rectifier Design

Several important circuits of the transition generator, which are explained further in this section, include the Transition Paralleling Links, the Rectifier Bridge, the Series Generator Contactor circuit and the Ground Relay circuit. A diagram of a typical transition type generator is provided in Figure 1 for reference.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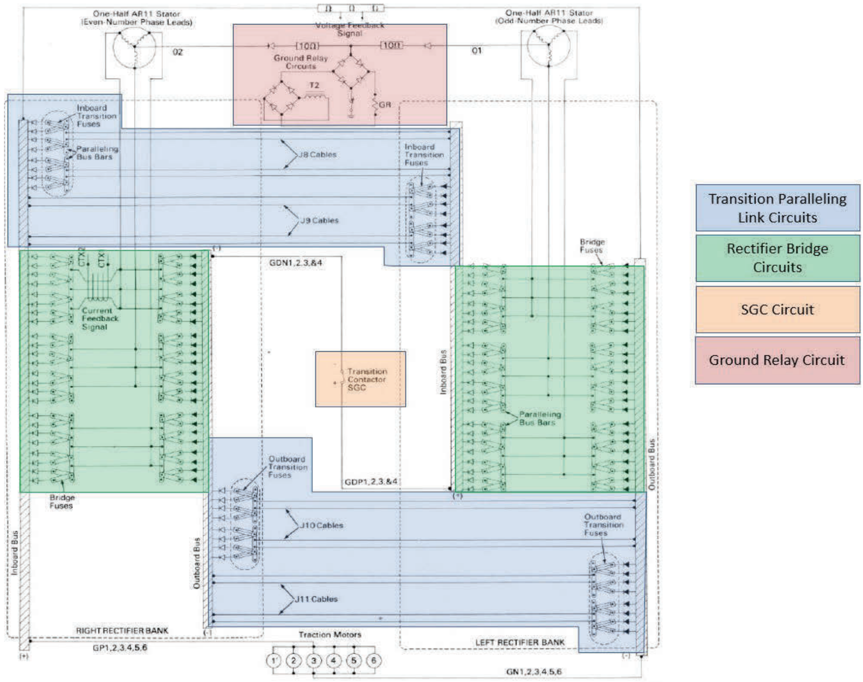


Figure 1. Diagram of a Typical Transition Generator

Transition Paralleling Link Circuit

The transition circuit consists of a set of jumpers, known as paralleling links, from the rectified DC output of one generator half to the same polarity rectified DC output of the other rectifier half. This effectively shorts the positive terminal of one generator half to the positive terminal of the other generator half, and the negative terminal of one generator half to the negative terminal of the other generator half. This creates the parallel connection. The paralleling links include a set of fuses and diodes, (i.e., the transition fuses and diodes discussed in this paper) that when transition to series configuration occurs, work to block current flow across the paralleling links.

Series Generator Contactor

The Series Generator Contactor (SGC) is a large, heavy-duty contactor, which is connected from the positive terminal of one half of the generator to the negative terminal of the other. When this contactor closes, it causes the transition diodes in the paralleling links to bias and block current flow across the paralleling links. This results in a series connection where the current flow of one half of the generator flows through the SGC contactor to the other half of the generator.

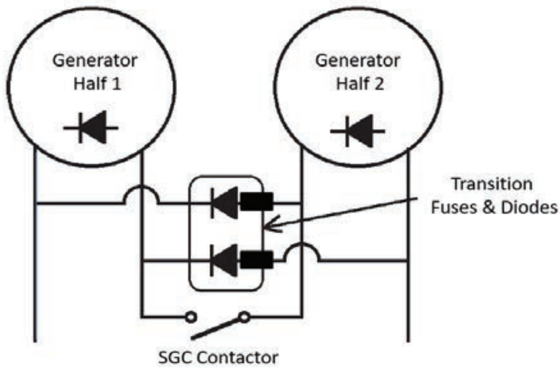


Figure 2. Simplified Diagram of Generator Transition Circuit

How Transition Works

When the locomotive starts to pull a train and operates at slow speed, the locomotive is configured in parallel to allow the high current needed to launch the train. As train speed increases, current drops and more voltage is needed to overcome counter electromagnetic force and speed up the motors. As the train reaches approximately 25 mph, a forward transition occurs and the SGC is picked up.

During this transition, a power reduction is made to control inrush currents through the SGC. After the SGC contactor has closed, the power is ramped back up so that the voltage is similar to where it was when the transition began. The locomotive is now operating in series mode. The entire transition process, including power reduction and SGC operation, happens over 1-2 seconds.

The locomotive will continue to operate in series until the speed reduces (while still in power) to below approximately 23 mph, when a backwards transition will occur. Similar to the previous transition, the power will be reduced so that the SGC contacts can open and so that the inrush current on the paralleling links is controlled. After the SGC opens, the power is ramped back up so that the transition diodes no longer block current flow on the paralleling links and the generator is now in parallel configuration.

Current Dividing Circuits

Transition type generators by design utilize current dividing circuits, which consist of multiple parallel paths that divide the full current coming from the generator into smaller circuits. The intent of this design is to control the maximum amount of current that will flow through the components, and to provide a robust and redundant circuit where an individual failed component will be isolated from the remainder of the circuit. These current dividing circuits are utilized for both the transition paralleling links and for the rectifier bridge circuit.

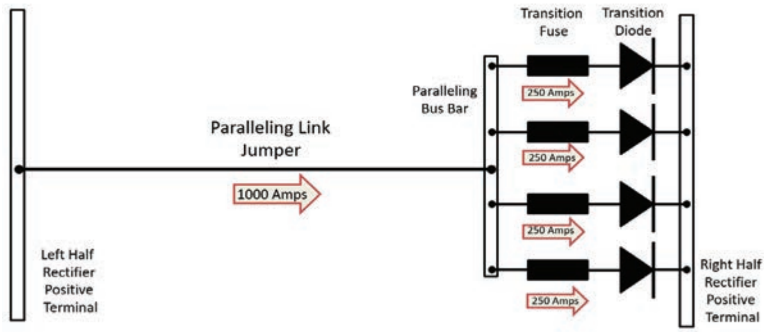


Figure 3. Current Dividing in Transition Paralleling Link Circuit (AR20)

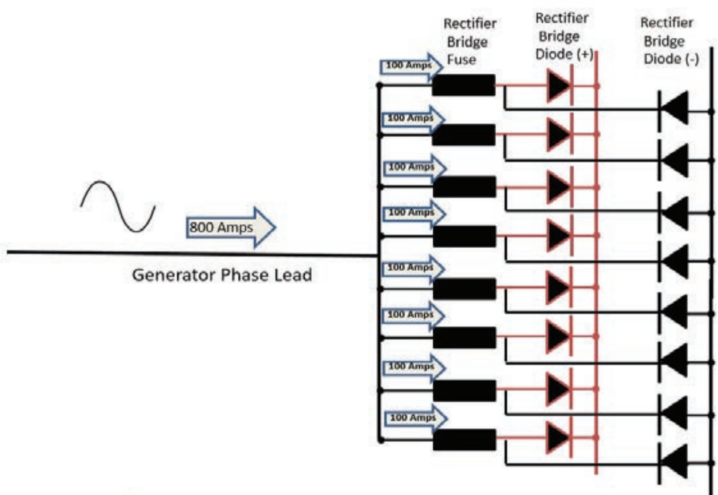


Figure 4. Current Dividing Circuits in the Rectifier (AR20)

Equal current balancing across the parallel paths is critical for these current dividing circuits to work. If a single leg of the circuit is overloaded due to an imbalance, it could fail and stress the remainder of the circuit. This presents challenges, particularly in aged generators where component age begins to change the resistive properties of fuses and diodes and cause imbalance. It is this imbalance in the parallel current dividing paths that became a focus of this project.

Ground Relay Circuit

The Ground Relay circuit provides the ability to detect high voltage AC and DC grounds in the traction system so that power output can be shutoff to protect traction system components. For locomotives equipped with transition generators, the Ground Relay circuit is also used to detect a failure of the transition circuit. When a transition circuit fails, usually due to blown open fuses, the ground relay circuit is activated which results in shutting off the power output of the generator. The activation of the ground relay circuit is what actually causes the no load condition when the transition circuit has failed.

Preliminary Failure Analysis

Faced with trying to implement a solution to improve the reliability of the generator fuses and diodes, the railroad began with a preliminary analysis of failure data. Data for all generator fuses and diode failures over an 18-month period was utilized for analysis. The approach of the analysis was to try to identify in a fault archive the actual initial failure event, and to analyze the datapacks from those faults for patterns or signatures of the failures. In addition to the fault data packs, the event recorder data for the time of failure was used to investigate the actual operating conditions at the time of each failure.

The data from the various sources was compiled into a dataset that provided a profile of the failures that was used for breaking down the problem. This data analysis supplied a few interesting patterns. Transition fuses and diodes were found to consistently fail a few years after the generator overhaul, indicating a possibility of extreme wear from age or duty cycle. In addition, two unique operating conditions were observed where the failure of the transition fuses were likely to occur.

The first and most likely failure scenario was a full power, slow speed heavy pull or stall condition, in which the generator amps were near current level limits. This is a somewhat expected failure condition due to the high currents that would stress the fuses. However, the circuit design should allow maximum operating current and still be well within the rated limits of the fuses and diodes.

The second failure scenario was at or around the time of backwards generator transition, which occurs near 25mph. The second scenario was typically observed when the locomotive was operating in Notch 8 full power and slowed to backwards transition speed range due to a slow down in speed that would typically be associated with operating on a grade, or loss of power elsewhere in a locomotive consist. An event recorder display showing this type of failure is shown in Figure 5.

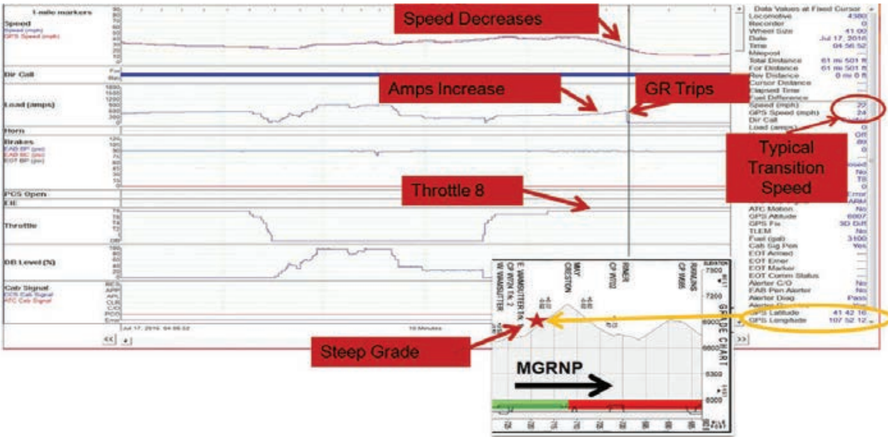


Figure 5. Event recorder example of generator fuse failure around reverse transition point.

Project Inception

Because of the observations made in the preliminary analysis, the railroad hypothesized that the control of the backwards transition could possibly be contributing to failures of the transition fuses and diode. At this point, the railroad reached out to the OEM for help further investigating these failures. A mutual agreement was made by the railroad and the OEM to establish a "Tiger Team" to attempt to determine the root cause of the failures, and to develop a solution to eliminate the failures.

Tiger Team

"Tiger Team" is a business term used to describe a team of specialists who work together to achieve a specific goal. The "Tiger Team" described in this paper was conceived by the railroad to be a team of engineers and subject matter experts from both the railroad and the OEM, who would work in collaboration to solve a locomotive reliability issue utilizing a systematic problem solving method. This team was tasked with working through the problem solving method to determine the root cause and develop a solution for the failing transition fuses and diodes.

Structured Problem Solving

The team utilized a structured problem solving method known as A3. A3 is a common eight-step problem solving approach used in lean production. The steps of A3 problem solving are shown in Figure 6.

Figure 6. A3 Structured Problem Solving Process

The team utilized the railroad's analysis, set a target to reduce road failures and moved onto the root cause analysis phase, which is the content focus of much of this paper.

Root Cause Analysis

Root cause analysis of the problem was completed through four approaches.

- **Data Analysis**: Data from both the railroad and the OEM's work order systems, defect reporting systems and material usage systems were collected and used for statistical analysis and pattern recognition.
- **Component Teardown**: Failed and aged components were analyzed in conjunction with the component manufacturers.
- **Static Testing**: Locomotives were instrumented and tested in a shop environment to observe characteristics of both the transitions circuit and ground relay circuit at the singular component level.
- **Dynamic Testing**: A test train with instrumented locomotives was utilized to recreate the specific operating conditions in which the failures have typically been observed.

Data Analysis

The team initially attempted to build a comprehensive dataset for Weibull analysis by joining historical warranty records from the OEM with more recent defect data from the railroad. Several inconsistencies and gaps with the available data left the team with inconclusive results. The analysis suggested an increasing failure rate, but did not show a distinct wear-out.

Later in the root cause analysis phase, the team made another attempt at data analysis with a focus on comparing the reliability performance of three distinct populations within the SD70M fleet: (a) Original generators that had not yet been rebuilt; (b) generators overhauled with qualified and re-used transition fuses and diodes; and (c) generators overhauled with new fuses and diodes. The railroad had initially rebuilt their AR20 generators with fuses and diodes that were qualified and re-used. In 2015, the railroad made the decision to start replacing all fuses and diodes with new components at rebuild. The results of this analysis are shown in Figure 7.

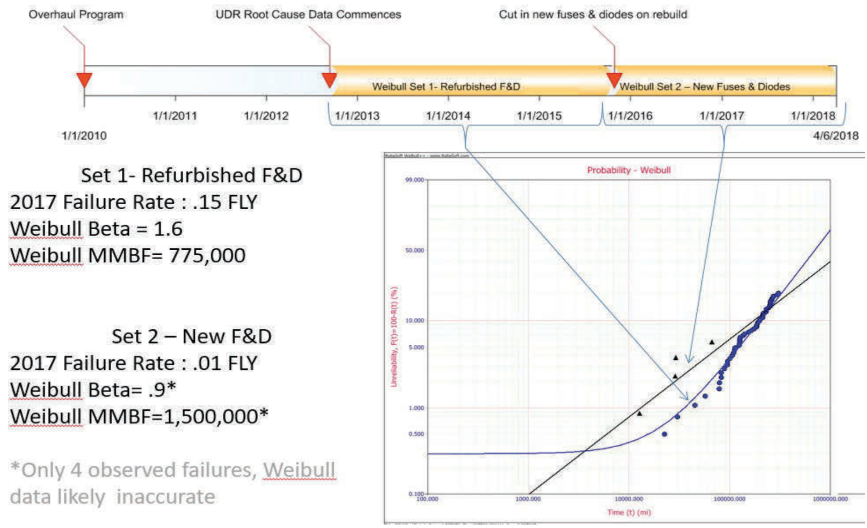


Figure 7. Weibull Comparison of Generators with Rebuilt vs. New Fuses & Diodes

It was this comparison of the distinct populations that confirmed a wear-out was occurring on generators which were rebuilt with re-used fuses and diodes. The reliability performance of the fuses and diodes on the generators rebuilt with new components was an order of magnitude better than those which were rebuilt with re-used fuses and diodes. The data supported a wear-out phase for fuses and diodes beginning around 800,000 miles[1].

Component Teardown

Failed and non-failed fuses and diodes from several locomotives with transition circuit failure were removed and collected for analysis. The failed components were analyzed in the lab by taking resistance readings with a Digital Low Resistance Ohmmeter (DLRO).

The testing showed that many of the non-failed fuses had large differences in resistance readings when it would be expected that the resistance would not have much variance. Diodes also showed varying resistance properties, but there were no actual failed diodes discovered in any of the teardowns. This was consistent with field reports of failed transition fuses that were found to be paired with diodes that were not failed. This suggested that the transition circuit failures were more likely due to the failure of the transition fuses and not the transition diodes.

1. This wear-out is a function of age and duty cycle, and is specific to this customer

Transition Fuse Analysis

The fuses from the teardowns were sent for X-ray analysis, which showed that the fuses were varying in resistance because they had broken internal fusible elements. The fusible elements are designed to melt when exposed to current beyond their rated limit, but the X-ray showed the elements were physically broken and not melted.

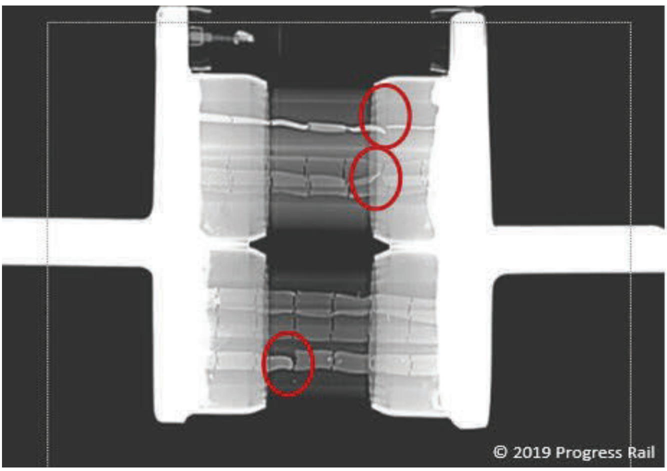


Figure 8 – X-ray photo of transition fuse with broken fusible elements

The X-ray photos were reviewed by the fuse manufacturer, who confirmed that the elements were broken, and showed signatures of thermal cycle fatigue. As the fusible elements are subjected to cycles of heating up and cooling off, the thermal expansion and contraction results in microscopic cracks that start to form in the weakest areas of the element. Over time the cracks grow until the fusible element eventually breaks. Typical railroad environmental shock and vibration likely also act to accelerate breakage of weakened fusible elements.

The manufacturer was aware that this wear/duty-cycle related failure mode exists in other applications, including in other locomotive generators that use similar fuses for the rectifier bridge circuit. The effects of this wear are not seen until one of the internal parallel fusible elements physically breaks. Once an element is broken, the resistance of the fuse is increased and the fuse capacity is reduced – such that the fuse will fail at lower than rated current level. This wear-out failure mode is a key factor in the expected usable lifetime of the component.

Transition Diode Analysis

The diode manufacturer performed additional testing and analysis on aged rectifiers at its facility. The diodes were tested and measured, and then disassembled for internal inspection. The testing found varying resistive and forward voltage drop properties on aged diodes that would contribute to imbalances in the current dividing circuit. The teardown found that the diodes were experiencing signs of thermal wear including visible surface damage to internal diode layers from years of thermal expansion and contraction cycles.

The internal layers of the diode are comprised of several different metallic materials that expand and contract at different rates during the thermal cycle. The layers rub against each other and cause microscopic damage to the surface that builds up over time. The diodes include design features that are intended to mitigate this thermal cycle related wear, however, over time the wear is inevitable. The effect of the observed thermal cycle related wear is increased resistance and higher forward voltage drop.

Also observed in the diode teardown was surface oxidation and discoloration that was attributed to a possible age related failure of the diode's hermetic seal.

Figure 9. Disassembled aged diode showing wear.

Static Testing

After reviewing the results of the data analysis and the results of the component teardowns, the team decided to perform stationary testing onboard several locomotives. Testing of instrumented generators occurred on multiple occasions at the railroad shop facility. The goal of the static testing was to:

- Observe the current balancing in the parallel paths of the current dividing circuit;
- Observe the results of intentionally placing fuses with partially failed internal elements;
- Observe the effects on the detection circuit as a cascading failure was simulated.

The team instrumented individual paths of the transition circuits with current meters and logged the results with a data acquisition system. The key findings of the testing were:

- Significant imbalances of the individual parallel paths of the transition circuit were consistently observed. Every generator tested showed extensive imbalance, with individual current sharing paths often observed conducting 50 percent more than the expected balanced current. An example of the distribution of current sharing in a single generator transition circuit is shown in Figure 10.

	Left								Right							
	Lead #1	Lead #2	Lead #3	Lead #4	Lead #5	Lead #6	Lead #7	Lead #8	Lead #9	Lead #10	Lead #11	Lead #12	Lead #13	Lead #14	Lead #15	
Static – Inner	32	59	74	74	67	53	17	42	62	71	49	18	25	58	59	Δ 57 amps
Static – Outer	32	40	34	34	69	95	16	42	80	88	70	75	67	-	73	Δ 79 amps

Figure 10. Observed Current Imbalances in Parallel Circuits

- The team observed "diode selectivity" where individual paths conducted no current despite a functional fuse and diode due to the electrical properties of the path.
- The intentionally installed "partially failed" fuses with broken internal links conducted less current due the increased resistance caused by the broken links. This means that the impact from the broken links is impacted more on the rest of the circuit than on the "partially failed" fuses themselves.

The team decided that it was important to understand how the current imbalances seen while performing static testing, in which full power is greatly limited, would be affected in full power operation. If the imbalances were magnified linearly, or even more severely, then imbalances would be causing individual paths to operate close to or beyond the maximum rated limit for the fuses.

Dynamic Testing

In order to verify the proper operation of the transition circuit, and to investigate if the key findings of the static testing were consistent in full power operation, the decision was made to do a dynamic test on instrumented locomotives. The goals of the dynamic testing were to:

- Analyze and confirm transition control sequence;
- Characterize what happens electrically at time of forward and backwards transition;
- Quantify any voltage or current spikes;

- Understand effect of imbalance at full power;
- Try to simulate a failure by stressing a weakened circuit.

The team designed a test plan that would include making repeated intentional forward and backwards transitions, and would recreate some of the operating conditions that had shown in data analysis to be the likely failure conditions. Figure 11 shows an example of the testing that was planned.

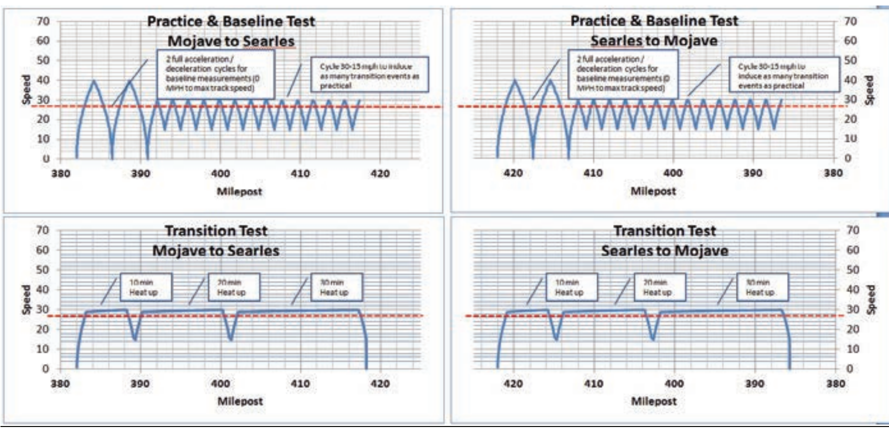


Figure 11. Test Plan for Dynamic Transition Testing

Because of the complexity of the operating conditions that the team wanted to test, it was decided that a conventional train would be impractical. The team decided instead to utilize a special test train with multiple braking units that would be used to simulate a full train. No actual cars were necessary to recreate the train forces on the locomotives.

Operating the test train with the braking units simulating a full train required the train to be simultaneously controlled by two crews. One crew would control the lead power consist that included the instrumented generator, and another crew would operate the braking consist to mimic specific operating conditions. The basic concept of the operation during testing was to control the lead locomotive to the desired power level, and use the dynamic brakes of the braking consist to control the speed to match the desired operating conditions.

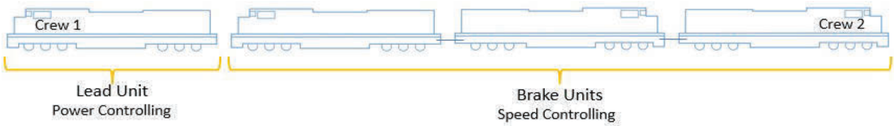


Figure 12. Test Train Configuration

Operating the test train to meet the desired conditions required an exceptional level of coordination and communication. The railroad provided two dedicated, highly experienced crews to drive the trains, as well as operational experts to coordinate and ensure safe operations. Because of their efforts, the team was able to collect all of the desired data on more than 10 test trips over a period of 4 days. An event recorder file from the testing is shown in Figure 13 to demonstrate how the team was able to recreate the desired operating conditions for testing.

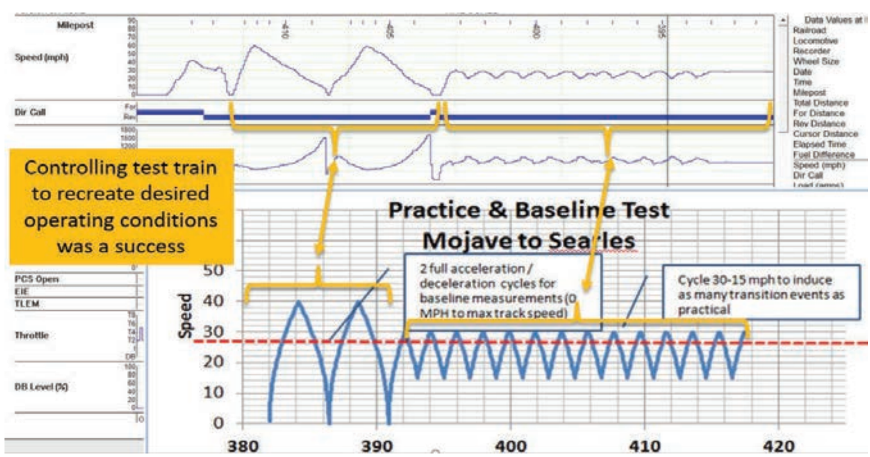


Figure 13. Event Recorder File from Dynamic Test Confirms the Test Train was able to Recreate Desired Operating Conditions.

The key findings of the dynamic tests included:

- Current imbalances are linear at all power levels. An imbalanced leg of the current dividing circuit that is drawing 30 percent higher than expected current at the reduced power levels of static load and stall testing will also draw 30 percent higher than expected current at full power levels.

- Transient voltage and current spikes do occur on the transition circuit during the backwards transition. The magnitude of the spikes are in direct relation to the individual diode current levels and affected by the current divider imbalance. Legs of the current divider circuit that draws more current due to imbalance would experience larger current spikes. However the magnitude of the observed spikes are in relation to a reduced "safe" controlled voltage/current level during the backward transition, and while significant, the spikes are well within manufacturers specifications. An example of an observed voltage/current spike is shown in Figure 14.

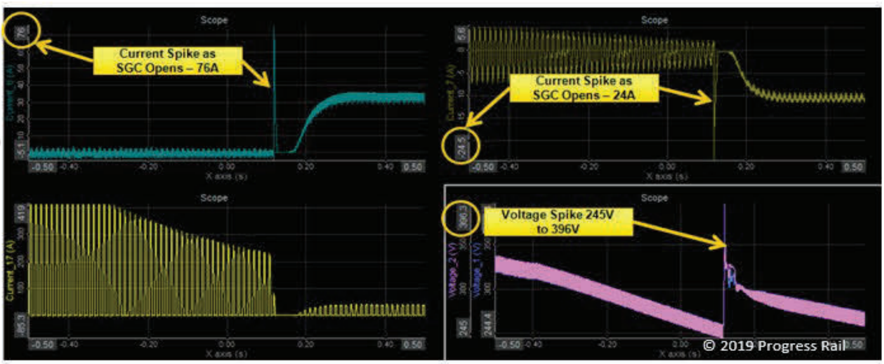


Figure 14. Test Results from Dynamic Testing Capturing Current and Voltage Spike During Transition

- Weakened system testing performed with the dynamic test train confirmed that fuses with broken internal links will fail due to reduced fuse capacity and start the "cascading failure" process. It is also confirmed that the diodes seeing the highest imbalance currents will fail once the imbalance current exceeds the fuse capability.

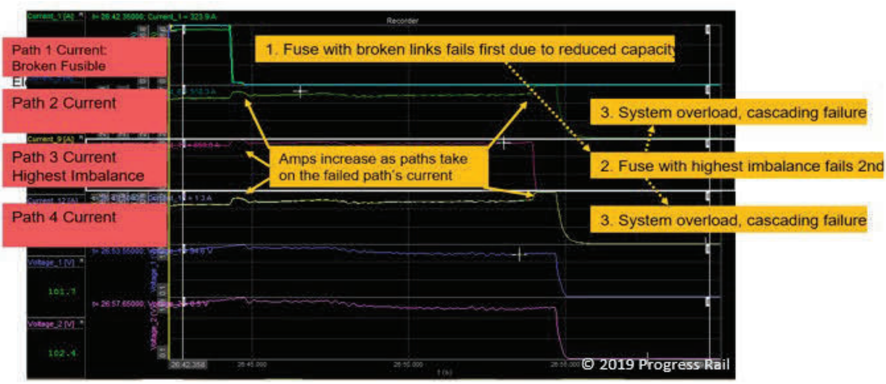


Figure 15. A "Cascading Failure" that was captured during dynamic testing.

Results & Findings

The team compiled the key findings of the various testing and analysis activities and made the following determinations:

- Transition control works as expected, with the transition occurring at adequate reduced power levels.
- Current and voltage spikes occur during transition, but they are in relation to the reduced "safe" power levels and are well within component ratings.
- It is unlikely that the actual transition event causes the components to fail.
- Fuses are subjected to wear-out due to thermal cycle fatigue. The effect of this wear-out is breakage of the internal fusible elements. This causes an increase in the effective resistance of the broken fuse's parallel path, which causes an imbalance across all parallel paths.
- Diodes are subjected to wear due to thermal cycle fatigue. The effect of this wear is to increase the resistance and forward drop voltage of the diode, which cause further imbalance in the parallel paths.
- As a result of the imbalances, the fuses and diodes of certain paths are stressed with currents that approach their rated limit, and subject them to greater thermal cycle wear which accelerates wear.
- This process creates a breakdown cycle in the circuits in which they are continuously stressed until a point of system failure. The team named this process the "Thermal Cycle Fatigue Breakdown Cycle". Figure 16 demonstrates this cycle.

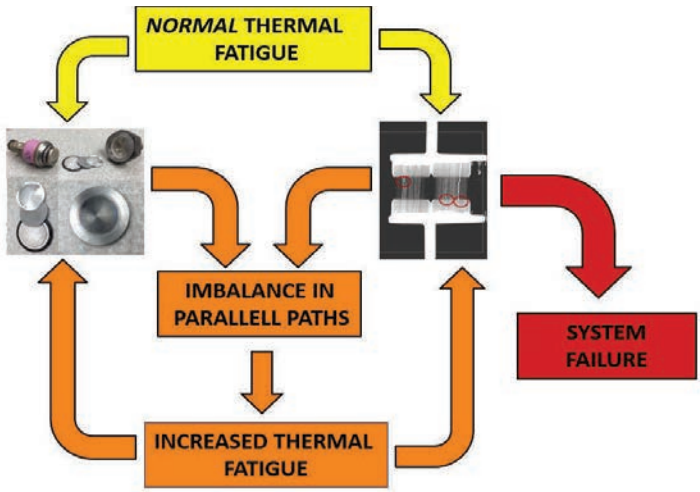


Figure 16. The Thermal Cycle Fatigue Breakdown Cycle

The team focused on this breakdown cycle as the root cause of fuse and diode failures in transitions generators. The railroad took the analysis a bit further and focused on missed opportunities to prevent the age related wear-out as the root cause of their failures on AR20 generators.

With the root cause determined, the team moved on to developing solutions to address the root cause.

Solution Development

The Tiger Team developed several possible solutions to address the root cause. The solutions were evaluated and scored in a decision matrix, and three solutions that were chosen to be implemented: 1) Component design upgrade for the transition fuse; 2) Control System development of a ride-through strategy; and lastly, 3) Generator rebuild scope change to include new OEM components.

Fuse Upgrade

The OEM worked with the fuse manufacturer to design an upgraded fuse. The internal fusible elements were re-designed to mitigate the effects of thermal cycle fatigue. The upgraded fuse has reduced resistance, which allows it to operate at a lower temperature and reduces the effects of thermal fatigue. The design change also provides increased strength and rigidity to the elements to better withstand shock and vibration. The upgraded fuse is being tested in the field on multiple railroads and will be available from the OEM in the near future.

Ride-Through Strategy

The concept for a ride-through strategy for the failed transition circuit was developed based upon the idea that although the transition circuit had failed, the generator itself was still functional. Closing the SGC and forcing the generator into a series configuration will effectively deactivate the transition failure detection. In series configuration, a level of performance can be maintained for most operating conditions that will allow the locomotive to continue working until it can be repaired. In fact, at speeds near or greater than the forward transition point of 25 mph, no difference would result in performance from a fully functional locomotive.

However, some control considerations were made for operation in series at slower speeds. As locomotive speed drops below 25 mph, the generator would be current limited and have reduced power output. The power would effectively be reduced linearly as speed reduced all the way to 0 mph. In addition, an extra 20 percent buffer was designed into the current limit in order to avoid stressing the bridge fuses and diodes by running long periods near the current limit, which would decrease expected life.

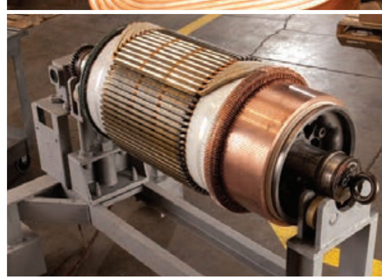
This ride-through strategy is currently in development.

Generator Rebuild Scope Change

As a result of the findings, the team determined that the recommended maintenance for fuses and diodes should be to complete a change out of aged fuses and diodes with new components at a specific age. Because the thermal cycle fatigue wear experienced by the fuses and diodes is duty-cycle related, the individual railroad should evaluate the proper change out interval for the fuses and diodes based upon failure data. In the case of the railroad involved in this project, it was determined that the scheduled generator rebuild, which occurs around 1 million miles, would be the appropriate time to change these components. In addition to the recommendation for replacement with new components, it is recommended that railroads consider implementing the upgraded fuse at the time of scheduled change out.

Conclusion

This project demonstrated a successful collaboration between an OEM, suppliers and customers to better understand and develop solutions for a difficult locomotive reliability challenge. Through the Tiger Team's efforts, several promising solutions were developed that address the discovered failure modes and are expected to improve locomotive reliability performance. Without the merging of the team's experience, knowledge, tools and data, it is unlikely these solutions could have been developed. This collaborative approach to problem solving has the potential to be utilized for other difficult locomotive reliability problems, and to continue to bring innovative solutions to the industry.



What Can the Load Regulator Tell Me?

Prepared by:
Dean Becker, Progress Rail

A maintenance issue that comes up quite often is that a particular locomotive is not making enough power. This situation could be described as 'The locomotive is low in horsepower' or 'The locomotive isn't loading properly'. To substantiate these reports, maintenance personnel would likely perform a load test on the locomotive and measure how much horsepower it could make.

If low horsepower is encountered during this test, the first question that should be asked is "What can the load regulator tell me?" Or more specifically, "What is the position of the load regulator?" The answer will determine if low power is a mechanical issue (engine-related) or an electrical issue (control system related).

Note: Load regulators are used when the locomotive engine is controlled by a mechanical governor. Newer engines may not use governors. Rather, they could use electronic unit injection. In these cases, the locomotive does not have a load regulator and the information in this paper would not apply.

The first step in checking the load regulator is to find it. Load regulators can be located inside the governor (Figure 1) or be provided as a stand-alone device (Figures 2 and 3). Stand-alone load regulators are often located on the equipment rack or nearby the engine. In older locomotives, some load regulators can be quite large (Figure 4).

Essentially, the load regulator is a variable resistor (or rheostat). This type of device has been used as the volume control for older radios and televisions. As the knob of the volume control was turned, the audio volume would increase or decrease. Similarly, when the load regulator is connected to the locomotive control system, rotational changes in its position can increase or decrease the amount of electrical load provided by the main generator.

Some very old load regulators created a variable resistance through the use of a commutator and a bank of large, fixed resistors (Figure 5). These devices could handle large levels of electrical current and often had direct control of the main generators field current. In Figure 6, the varying resistance of the load regulator would raise or lower the current through the battery field winding of the main generator.

So what causes the load regulator to rotate? The simple answer is that a vane motor is connected to the load regulator and responds to the flow of oil coming from the governor. The governor initiates pressurized oil to flow through a vane motor, which is a device that converts oil flow into rotational movement. (The vane motor is similar in concept to that of a waterwheel, which turns as river water flows over the wheel.) The vane motor is attached to the variable resistor as shown in Figure 7. Hence, the rotation of the vane motor is used to turn the variable resistor. With this background, attention is now turned inside the governor in order to see ***why*** and ***how*** it creates the flowing oil.

The primary purpose of the governor is to regulate the speed of the diesel engine. Based upon the throttle request, an engine speed reference is created. This value is compared to the value of the engine's actual speed and is used to increase or decrease the amount of fuel to the engine in order to achieve the requested speed value.

A secondary feature of the governor is to provide a form of load control. This is accomplished by adjusting the dominant load on the engine so that a prescribed amount of fuel is used. Within the governor, fuel usage is indicated by the rack indicator (see Figure 8) – where the engine rack corresponds to the position of power-piston tail rod. Furthermore, a target fuel usage value is created based upon the engine speed reference, which corresponds to the position of the speed setting piston rod. Through a system of linkages (see Figure 9), these two values are compared: If the fuel usage is too high for the present engine speed setting, the linkages raise a small plunger called the load control pilot valve. If the fuel usage is too low for the present engine speed setting, the linkages lower the load control pilot valve plunger. And if the fuel usage is "just right" for the present engine speed setting, the position of the load control pilot valve plunger will be in its neutral position.

The changing position of the load control pilot valve causes oil to flow to the vane motor. When the load control pilot valve is raised, the direction of oil flow is to move the vane motor – and the load regulator – in the direction that will reduce the amount of main generator power. (See Figure 10.) When the load control pilot valve is lowered, the direction of oil flow is to move the vane motor – and the load regulator – in the opposite direction, which may increase the amount of main generator power. And when the load control pilot valve is in its neutral position, no oil will flow to the vane motor and the position of the load regulator does not change. (See Figure 11.)

The remainder of this article explains "What can the load regulator tell me?"

If the load regulator is in the ***Maximum Field*** position, which is its furthest counterclockwise position (see Figure 12), it is an indication that the engine is capable of providing more power. This is because the engine is using less fuel than permitted based upon the throttle setting. If the load regulator is in maximum field and the power level is too low, the problem is likely due to an electrical (or control system) issue. Examples of this are using the wrong module, applying the wrong software, or having a defective feedback device.

If the load regulator is in the ***Minimum Field*** position, which is its furthest clockwise position (see Figure 13), it is an indication that the engine is overloaded. The engine is using more fuel than permitted based upon the throttle setting. If this situation is encountered, there may be other symptoms such as engine bogging or excessive exhaust smoke.

If the load regulator is in a ***Balanced position,*** *which is any intermediate and* steady-state position, it is an indication that the engine is operating at the intended fuel level. If the load regulator is balanced and the power level is too low, the problem is likely due to a mechanical issue. Examples of this are a bad injector or dirty air filters.

So if a locomotive is reported to be operating with low power, take a look at the position of the load regulator while the locomotive is loading. If the load regulator position is in a ***Balanced*** position, check the engine / mechanical system. If the load regulator position is in the ***Maximum Field*** position, check the electrical / control system. Hopefully, this advice will allow you to take the first step when troubleshooting reports of low horsepower.

Figure 1 Governor with an Integral Load Regulator

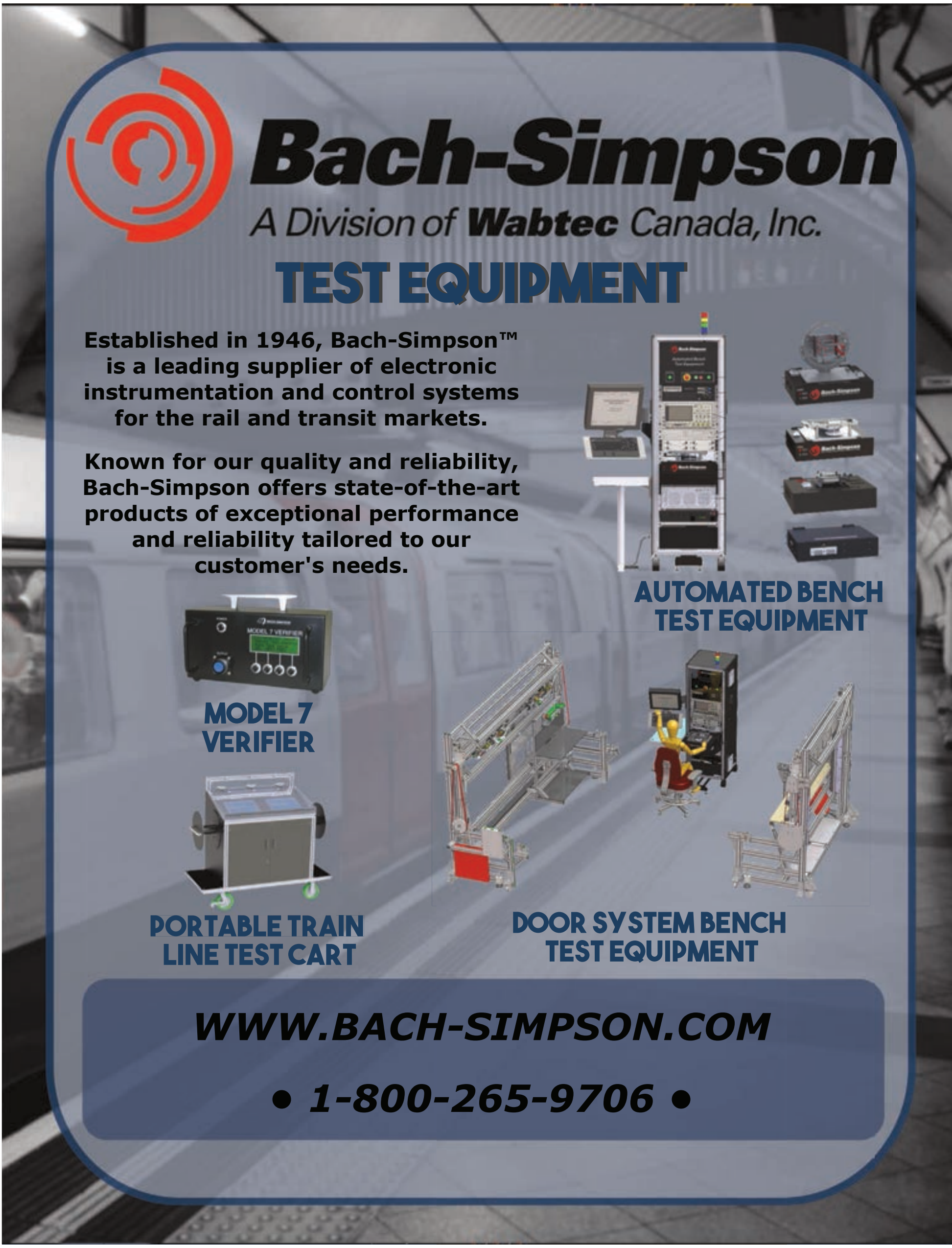

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Figure 2 Load Regulator

Figure 3 Load Regulator

Figure 4 Various Views of a Large Load Regulator

Figure 5 Commutator Load Regulator

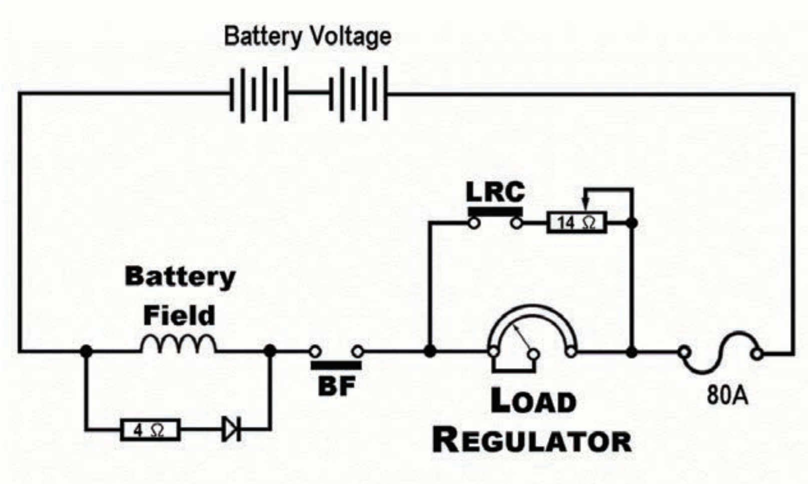

Figure 6 Application of Commutator Load Regulator

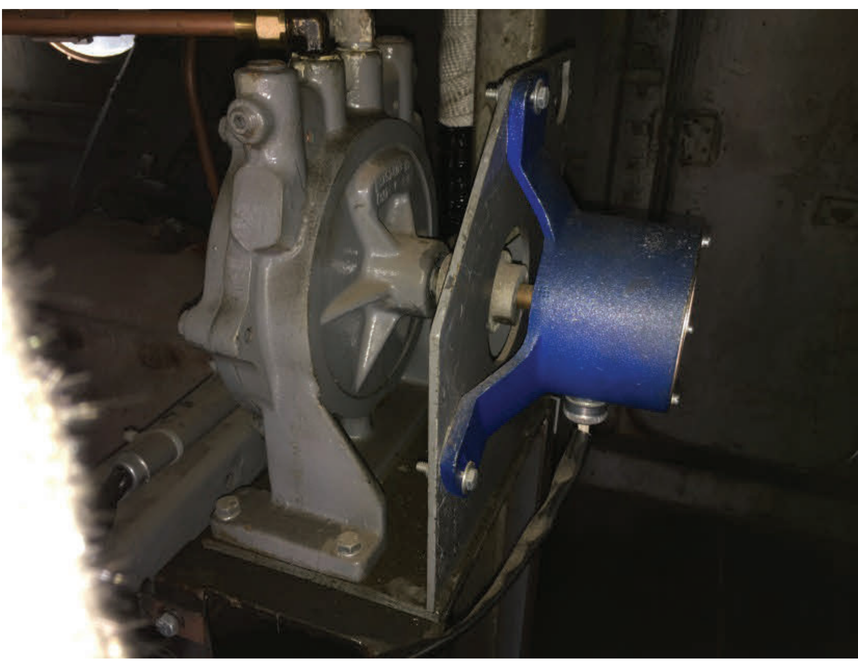

Figure 7 Vane Motor Connected to a Variable Resistor

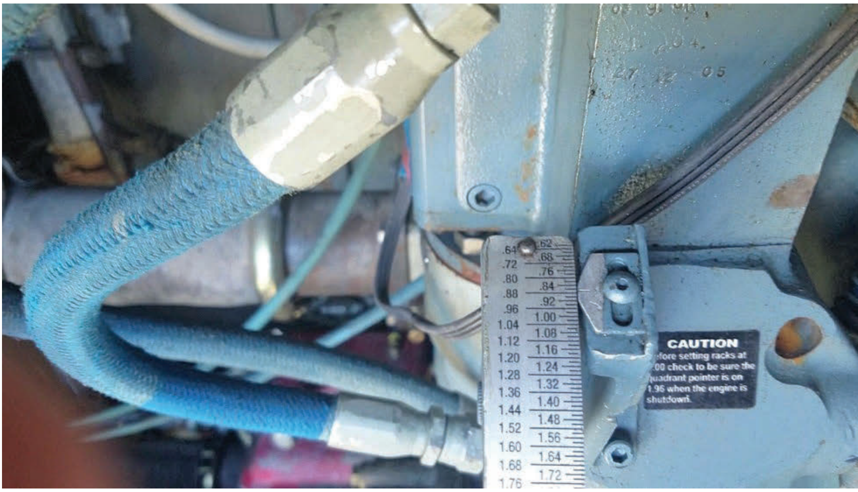

Figure 8 Rack Indicator

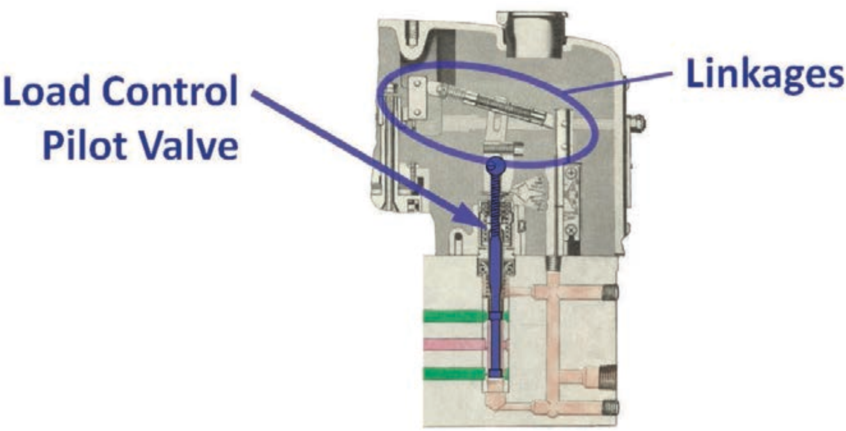

Figure 9 Cutaway View of Governor

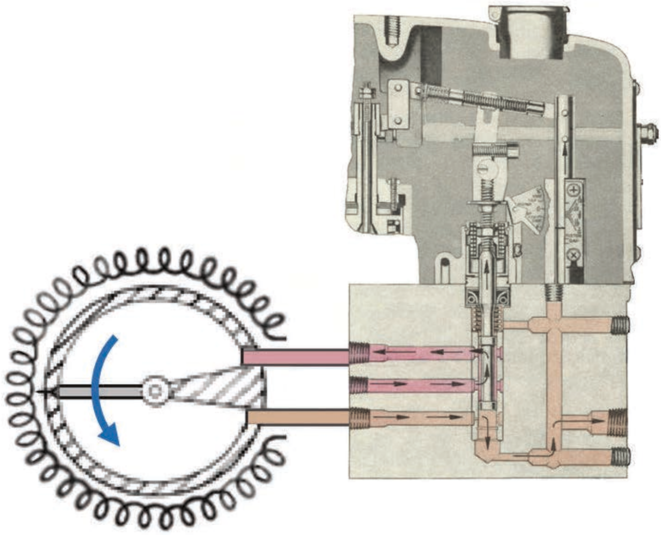

Figure 10 Cutaway of Governor (Fuel Usage is High)

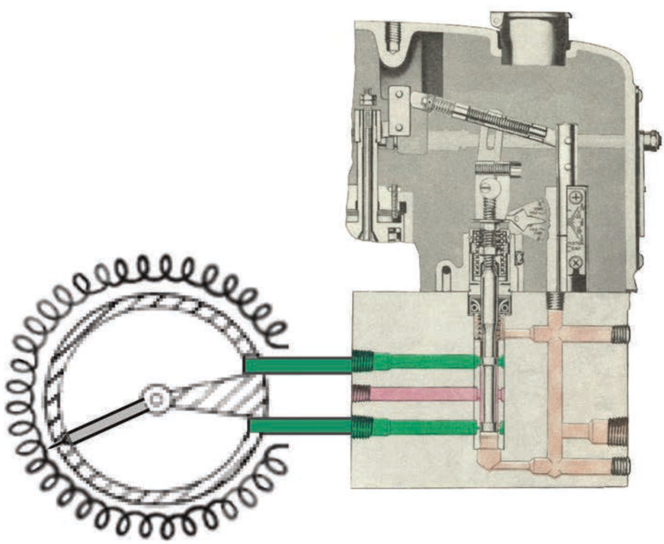

Figure 11 Cutaway of Governor (Fuel Usage is "Just Right")

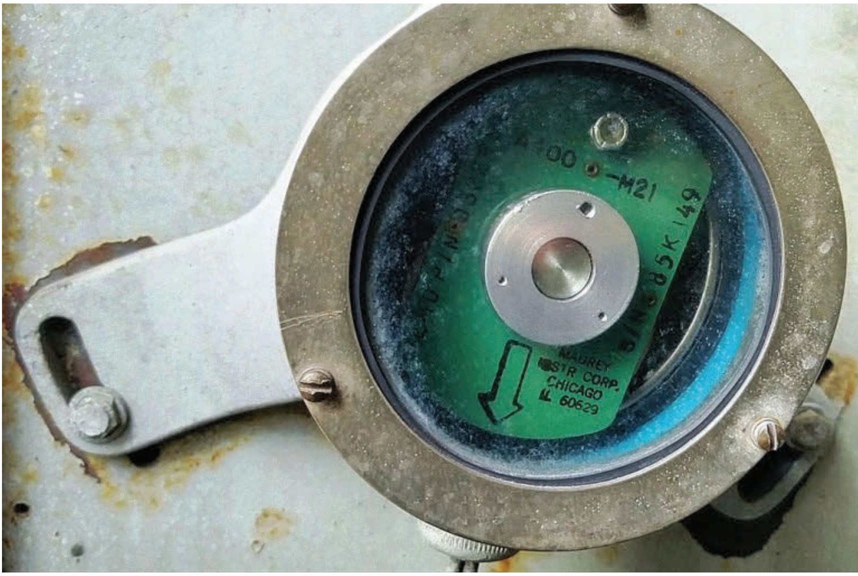

Figure 12 Load Regulator in the Maximum Field Position

Figure 13 Load Regulator in the Minimum Field Position

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Getting off to a Good Start

Prepared by:
Amarjit Soora, ZTR LLC
Shane Sledge, Norfolk Southern Corporation
Chad Muir, East Penn Manufacturing Co.

Introduction

"The engine won't start"

"The headlights were left on and the batteries are drained"

"The acid in the batteries have boiled out"

"Dead won't start"

Railroad operators hear the above and many more dreadful comments attempting to explain why locomotive engines won't start.

Starting methodologies on North American diesel-electric locomotives have evolved over the decades. Throughout this evolution lead acid batteries have been, and continue to be, widely used as the primary source of energy to turn the diesel engine. Lead acid batteries designs also evolved (flooded, valve regulated etc.).

Despite these advancements, unsuccessful engine starts due to battery related issues continue to be a problem for many railroads.

A paper written in 2018[1] spoke of a happy life batteries once lived in:

- The engine would run for long periods of time allowing the batteries to be fully charged
- Engine is shutdown with minimal hotel loads (low drain)
- Engine started and batteries once again obtain full charge
- Wash, rinse, repeat…

Over the decades, legislatively driven initiatives to reduce operational costs (fuel consumption) and improve safety (PTC) have created situations where the lead acid batteries live a good portion of their life in a state of partial charge.

This paper will cover many of the common starting technologies over time, engine starting issues they may encounter due to poor battery health, and remedies for several of these scenarios. This paper also utilizes recent papers and updates related to batteries, Automatic Engine Start Stop (AESS) and battery charging schemes.

Electric (DC) Start

Older yard or switcher locomotives are typically equipped with DC electric start. On several classes of switcher locomotives engine starting is accomplished in two common ways:

- If equipped with a DC Main Generator it has a dedicated start winding, so that during crank the starting contactor will connect the batteries directly to the start winding, thus using the generator as the engine starting motor.
- Locomotives equipped with Traction Alternators (e.g. AR10) have dedicated starter motors.

In either case, the demand on batteries during engine cranking is high. To generate the torque for the initial engine movement the batteries have to deliver a quick burst of current upwards of 1500-2000 ADC.

Some common issues with these configurations were:

- Starter abutment
- Wear on the engine flywheel and (starter) ring gears
- If not equipped with a start time limit, the motors may suffer from thermal damage and batteries can drain.
- Batteries with a relatively low State of Charge (SoC) cannot provide sufficient power to turn the engine

Most of these locomotives were originally equipped with single stage battery charging – meaning they are designed to maintain a constant charge voltage without any sort of charge current or temperature regulation.

Traction Alternator Start

Later generations of locomotives are equipped with traction alternator start (GE Dash 8 and 9 are examples). That is, the traction alternator is used as a synchronous motor for diesel engine starting purposes. During starting operation a high voltage (~700 V) is applied to a capacitor using the traction alternator stator windings and electrical resonance. The capacitor voltage is then used for forced commutation of the Silicon Controlled Rectifiers (SCR) in the cranking thyristor panels allowing for the generation of a rotating magnetic field using a DC power source (batteries).

With this configuration, the engine may crank with a battery in a lower state of charge compared to the DC start configuration. However, given these are often road locomotives they are typically equipped with more hotel loads such as cab electronics and, later, Positive Train Control (PTC). Improper shutdown (manual or due to a fault) often leads to the batteries being in a poor state of charge when it comes time to crank the engine.

Air Start

This technology was introduced on the EMD SD80MAC.

All the energy for engine cranking and rotation comes from compressed air. The compressed air is typically supplied from a dedicated air reservoir.

The battery's only role during the crank process is to operate the actuation circuits.

One of the obvious advantages here is the battery's state of charge is not a major concern for engine cranking.

A consideration must be taken for a backup mechanism. Some locomotives are equipped with a backup starter motor – if the system detects low air in the reservoir it will actuate the starter motors. Although the redundancy improves the reliability of overall cranking, the drawback comes in the form of additional components and the reliance on battery SoC.

Another consideration is leaking air systems - excessive air leaks that drain compressed air from the dedicated start reservoir may reduce cranking reliability.

Hybrid Start

Railway operators such as Norfolk Southern have some fleets equipped with hybrid start systems (e.g. SD70ACU/ACC locomotives).

Both electric and air starters are engaged for each start attempt. Each starter is applied to the engine ring gear on opposite sides of the locomotive. If the locomotive detects a fault with one of the starting mechanisms, it will automatically switch over to the functional one.

In addition to improved starting reliability, other benefits include faster starts and less wear on the ring gear and starter motors.

Super Capacitor Start

Several industries have turned to super capacitors as a source of energy to assist with engine cranking. In some cases the capacitors are used as the primary source of energy for the cranking process, while the battery is used to power onboard systems when the engine is shutdown. In both cases much, if not all, of the initial torque is provided by the super capacitor.

Super capacitors offer several advantages over lead acid batteries:

- Faster charge and discharge rates, where thousands of cycles can be performed without degradation
- Ability to maintain charge for long durations (months)
- Tolerant of temperature extremes
- Able to handle high current discharge without degradation

Solutions are available where the super capacitors are enclosed with isolation circuits and charge/discharge procedures for safe handling.

<u>How to Deal with Dead Won't Start</u>

The first thing is to understand the root cause(s). The section below offers thoughts on root causes and recommended remedies. Various methods may be utilized to acquire relevant data (i.e. remote monitoring) and to determine the root cause (i.e. fishbone diagram), however those specifics are not covered in this paper. Also note that some items below are being reviewed with the AAR AESS and Battery Task Force Update[2].

- Battery state of charge low due to hotel loads:
  - Remedy - Battery Saver technology. This technology typically disconnects "non-essential" loads on the cold side of the battery knife switch after certain conditions are satisfied when the engine is shutdown. For example, a specific time period has expired after the engine is manually shutdown. There are other conditions available as well, such as lower battery SoC. When the system detects crew action it will disable the saver and engage all loads. Examples of crew action are an attempt to crank the engine, or pushing a by-pass button often equipped with this technology.
  - Modernized locomotives and control systems often have this feature integrated, however stand-alone solutions are available in the market.
- AESS settings not optimal
  - Not all AESS systems monitor the battery SoC before initiating an engine shutdown sequence. To remedy this, the AESS system should be equipped with a battery charge current sensor, and only allow engine shutdown after the charge current drops below a specific point recommended by the battery manufacturer.
  - Additionally, some AESS systems may wait until the battery voltage is too low before initiating the engine crank sequence.
  - The AESS setpoints should be adjustable to allow for use with different battery types.
  - For further recommendations and studies in this area please refer to the AAR AESS and Battery Task Force Update[2]
- Battery SoC low due to inadequate battery charging schemes
  - Some common issues associated with existing battery charging systems:
    - Single stage charging. The system targets a specific voltage without monitoring other parameters such as temperature and charge current.
    - Allows for excessive current beyond the battery manufacturer's ratings, which damages batteries and reduces overall lifespan.
  - For lead acid batteries a 3-stage charging profile is recommended for optimal battery charge and performance.
  - Remedy - Locomotives not equipped with microprocessor control

have the option of stand-alone Voltage Regulator and Battery Charging modules, which are available and can be integrated with the locomotive and provide the recommended charging profile. These should be microprocessor based and configured such that charging parameters can be configured to meet the battery manufacturer's guidelines.

    - Most modernized locomotives are equipped with multi-stage charging. As long as they are equipped with sensors to monitor critical battery performance parameters (battery voltage, charge current and temperature), it is recommended to review the system settings to ensure they match the battery manufactures guidelines.
    - If the settings cannot be altered, aftermarket solutions are becoming available that can integrate with the existing OEM system.
    - Again, specifics of some of the above will be covered by the AAR AESS and Battery Task Force Update[2].
- Other additional remedies include providing an alterative energy source for the engine crank.
    - Air start was mentioned earlier. Although this is a proven design and equipped on many modern main line locomotives, integration with older locomotives is not practical. In addition to adding air starters, they would need a dedicated air reservoir with compressed air.
    - Super Capacitors are a solution that can be easily integrated in a safe manner. As mentioned earlier, some configurations provide an assist to the batteries by providing the initial torque while others provide all the energy for the full engine crank cycle. A major benefit of super capacitor systems is that, if integrated correctly, they are maintenance free. Also, during a typical engine crank, the battery voltage may initially drop down to 50% of it's nominal voltage, well below some of the minimum voltage requirements for on-board computer power supplies. This may cause certain computers to reboot, causing operational delays. On a Super Capacitor equipped locomotive, the initial demand does not come from the battery, therefore the battery voltage may not dip as much, leading to reduced or no impact on the computer systems.
- Alternative battery technologies:
    - Nickel Cadmium (NiCd) batteries[3]:
        - Performance doesn't degrade like Lead Acid variants in cold weather extremes, however, the ability to provide high currents in short time frames for engine cranking is lower compared to equivalent Lead Acid batteries. This then requires higher capacity batteries, which may add considerable cost[3].

    - Charging profile – most OEM battery charging systems do not offer the specific charging scheme required by NiCd batteries
    - End of life disposal of NiCd batteries often present challenges. At the end of life batteries are often disposed of or recycled at a cost to the end user. In some areas finding a viable source of disposing industrial NiCad cells can be a challenge which often leads to increased freight / transportation cost
  - Lithium Ion[3]
    - Used extensively in hybrid and electric vehicles, locomotive applications need large capacity variants. Higher energy storage introduces concerns related to volatility of the battery, and safety risks must be strongly considered and mitigated
    - As with NiCd batteries disposal of lithium variants is a challenge. Today's infrastructure for disposal of lithium chemistries does not exist on a large scale. Disposal of lithium is offered at a cost.
    - Lithium battery technology has presented some fundamental safety challenges that must be considered in the integration of the battery system.
  - Increase battery size – if this is being done to deal with the battery drain due to improper engine shutdown, then a battery saver solution is recommended. Increasing battery size adds recurring cost and more engine run time to ensure full charge.
- Starter abutment – schemes to detect abutment and stop the engine rank cycle are available and easily implemented.

Closing Comments

In attempting to deal with battery issues that result in failed engine crank attempts, there are several root causes and potential remedies. Depending on the age and class of locomotive, some may be easier to solve than others. Ideally the locomotive is equipped with technology to monitor and act on critical parameters, with software updates the only required actions.

Stand alone aftermarket solutions are available that can be integrated with the locomotive whether equipped with a microprocessor system or not.

Some further considerations:

- Throughout this paper, "crank attempt" has been referred to – what is the definition of a crank attempt:
  - Duration?
  - Desired engine RPM via cranking solution before engine takes over rotation?
  - How many crank attempts must the system be capable of?


KickStart

- Alternatives to lead acid batteries
  - NiCad
  - Super Capacitor Start
  - Airstart/Hybrid – dedicated air reservoir
  - Note: given trade offs in performance of the different battery types, perhaps a dual battery system designed to specifically support “hotel / parasitic” loads vs. starting loads warrants further consideration
- If equipped with a Super Capacitor solution, depending on the configuration some may need to be charged in between cranks. What are acceptable charge times?
- What is the capacity for a back up mechanism?
- Last but not least, cost. What is the operational impact of failed cranks vs cost of implementing the solutions discussed in this paper?

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2. “AAR AESS and Battery Task Force Update”, AAR, Chairman Mark Duve – in progress
3. “Battery Technology within the Diesel Starting Industry”, LMOA, Chad Muir, 2016

Report on the Committee on Facilities, Material & Support

Tuesday, September 24, 2019 at 9:45 AM

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(LMOA Past President)

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PowerRail Incorporated
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PERSONAL HISTORY

Bob Harvilla

Bob Harvilla started his career with General Electric in 1973, and had a total of 22 years with GE in various Management and Sales capacities. He is currently the Vice President of Sales for PowerRail Inc., responsible for Account Management and Sales at select Class 1 and Shortline Railroads.

Bob and his wife Barb have been married for 42 years and have two sons, Rob and Ryan, and two grandsons Max 8 and Griffin 5.

The Facilities, Material and Support Committee would like to express their sincere appreciation to the Genesee & Wyoming for hosting the committee's winter meeting in Jacksonville, Florida in January 2019. Special thanks to Kristine Storm and Rich Lutz for making the necessary arrangements.

The committee would also like to thank Norfolk Southern Corporation for hosting their summer meeting in Altoona, Pennsylvania in June 2019.

Wheel Truing Technology Development and Innovation

Prepared by:
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Wheel reprofiling machines have been in service since early in the history of railroading. During the steam era, the machines were initially configured in an above-floor installation, which required worn wheel sets be removed from a vehicle. Steam locomotives contained substantial moving parts that required a higher frequency of repair and maintenance while the wheel sets required less frequent service. As diesel locomotives became the primary source of motive power, a significant jump in productivity occurred in 1949, when the first pit-mounted, or underfloor, wheel truing machine was installed. Eliminating the time needed to remove the wheel set from a vehicle and then return it to the locomotive after reprofiling decreased the time required for the maintenance process. Since then, wheel truing machines have been installed in freight and transit maintenance facilities throughout North America. However, cycle times have remained largely the same since that first underfloor installation: approximately 40 minutes under normal wheel wear conditions.

An underfloor wheel truing machine installation

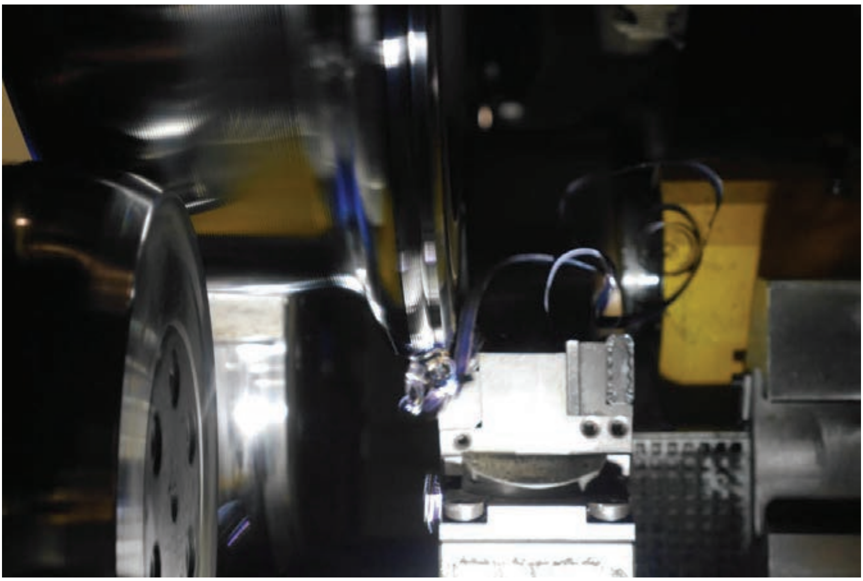
The railway industry has seen a revolution in the last decade in terms of leveraging new technologies to move products and people more efficiently, faster, and safer. Technologies such as positive train control, autonomous train operation, and digital wheel profile and defect detection are all recent examples illustrating positive industry advances. One area that has languished for many decades, though, is wheel reprofiling. Despite the introduction of computer control, automated cycles, and other updates, production time has remained largely the same. To keep pace with the rest of the industry, innovation is critically needed.

Wheel reprofiling is a machining process where metal is removed from the wheel to return the wheel profile to its optimal shape. The process is part of the wheel set maintenance process not only to conserve the wheel set's useful life, but also to keep vehicles running safely and efficiently. Current available technologies for wheel reprofiling utilize one of two machining processes: milling or turning.

Milling, known historically throughout the railway industry as wheel truing, is a metal removal process whereby the cutting tool rotates rapidly while the workpiece (in this case, the wheel) rotates slowly. The cutting tool, which is referred to as the cutter, consists of a cutter body holding multiple removable blades that themselves contain multiple carbide inserts. The milling cutter machines the full profile of the wheel.

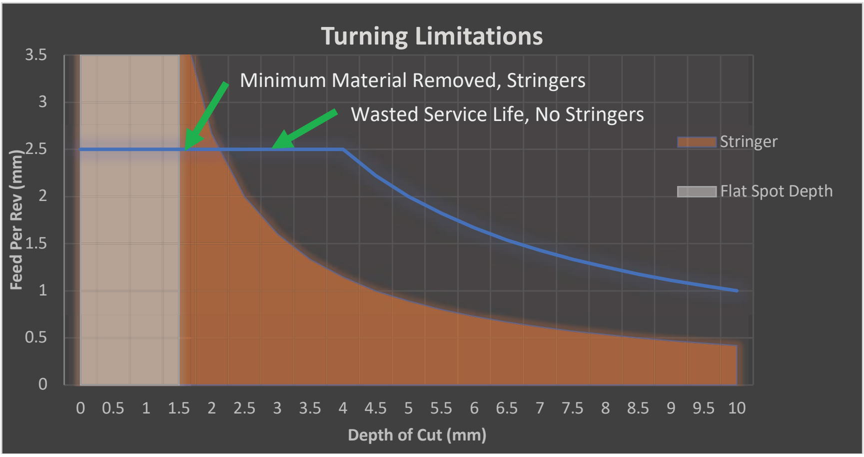
The milling process

In the turning process, the cutting tool is stationary while the wheel rotates rapidly. The cutting tool consists of a single carbide insert that feeds across the wheel tread and flange. Turning machines are also referred to as lathes.



The turning process

This paper will focus on the development and innovations related to the milling process, and will demonstrate that milling offers more opportunities for productivity growth and other advantages. The paper will further discuss how the turning process has reached its maximum production capability. The only way to radically increase productivity is to rotate the wheel faster. Doing so amplifies the issues inherent in the turning process: the single point cutting tool cannot withstand machining wheel wear without risk of damage. Decreasing the feed rate allows for a safer process and a deeper depth of cut, but it produces longer "stringers" (which are difficult to control and process). It also increases cycle time, negating any productivity gains. The current proven way to increase productivity is to install more lathes running in tandem or larger groups, which requires a larger footprint for the system and substantially higher capital investment.



Turning limitations: feed rate versus depth of cut

Through extensive research and experience with both reprofiling processes, we propose that milling is the technology that has additional opportunity for cost effective innovations. The process is ideally suited for railway wheel set maintenance operations. The full-profile milling process manages wheel wear conditions with limited operator intervention. Milling permits machining through wheel defects such as flat spots and shelling without decreasing workpiece rotational speed or changing cutter feed rates. There's also no need to undercut these wheel defects as required in the turning process, which means less service metal is removed. The slower rotational speed of the workpiece produces a more stable machining process by not inducing into the machining process dynamic forces caused by the large rotating mass of the wheel set. The milling process does not require substantive operator set-up and lends itself to considerable process automation. The chips created by the milling material removal process are small, facilitating simple containment and collection.

The milling cutter was designed several decades ago and has not kept pace with innovations in the larger non-railway/general purpose machining industry. In the last eight years, advanced digital manufacturing techniques such as CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) and 5-axis machining have been deployed to improve quality, performance, and cost.

The wheel truing machine has historically relied on manual, external measurement tools to identify how much metal must be removed from the wheel. Measurement data from these tools can vary between operators based on simple human error. And while there have been some digital measurement tools introduced, they are still external to the machine.

The current method by which the wheel set is held captive during the machining process, which is called clamping, is achieved by accessing the axle centers and applying significant pressure (6600 pounds / 3000 kg). This operation requires a large steel machine structure to withstand the forces generated between the machine's centers (horizontal) and the machine's cutters (vertical).

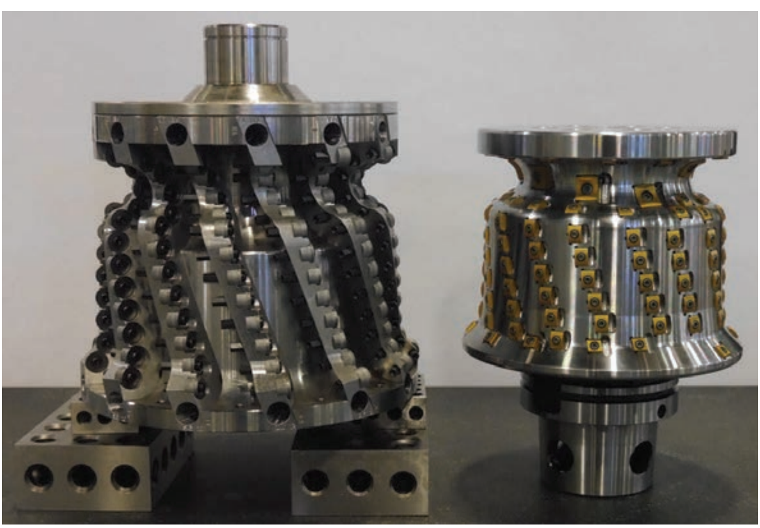
Wheel truing machine clamping process

Currently, milling technology has only been applied to an underfloor machine configuration. While it is possible to process a range of vehicles or even loose wheel sets in this configuration, the most prevalent use is for reprofiling wheel sets of locomotives while on the vehicle.

By deploying digital manufacturing techniques, a new milling cutter design has been developed with two effective flutes or double helix. The double helix design permits twice as much material removal per revolution, which allows for an increased feed rate. The outer diameter of the cutter has also decreased from 12 inches (305 mm) to 8 inches (203 mm). This change allows for an increased cutter RPM. When both of these design changes are implemented, the projected cycle time reduction is expected to be 40% (see attached table). A productivity increase of this amount would substantially reduce dwell or out of service time for locomotives with little additional capital investment.

	Current Cutter Design	Smaller Diameter and Two Effective Flute Design
Diameter (inches)	12	8
Number of Effective Flutes	1	2
Cutter RPM	239	358
Feed Rate (in/min)	4.8	14.3
Machining Cycle Time (min)	23.7	14.22
Projected Machining Cycle Time Reduction	0%	40%

The new cutter design has additional benefits to the wheel truing process. The current cutter assembly weighs almost 300 pounds (137 kg) and can take 30 minutes to an hour or more to exchange. As a cutter is designed to only reprofile one wheel profile type, this presents a challenge for fleets with multiple wheel profiles. The new cutter is 60% lighter and utilizes a quick change coupling, facilitating a less time-consuming exchange of cutters and thus wheel profiles.



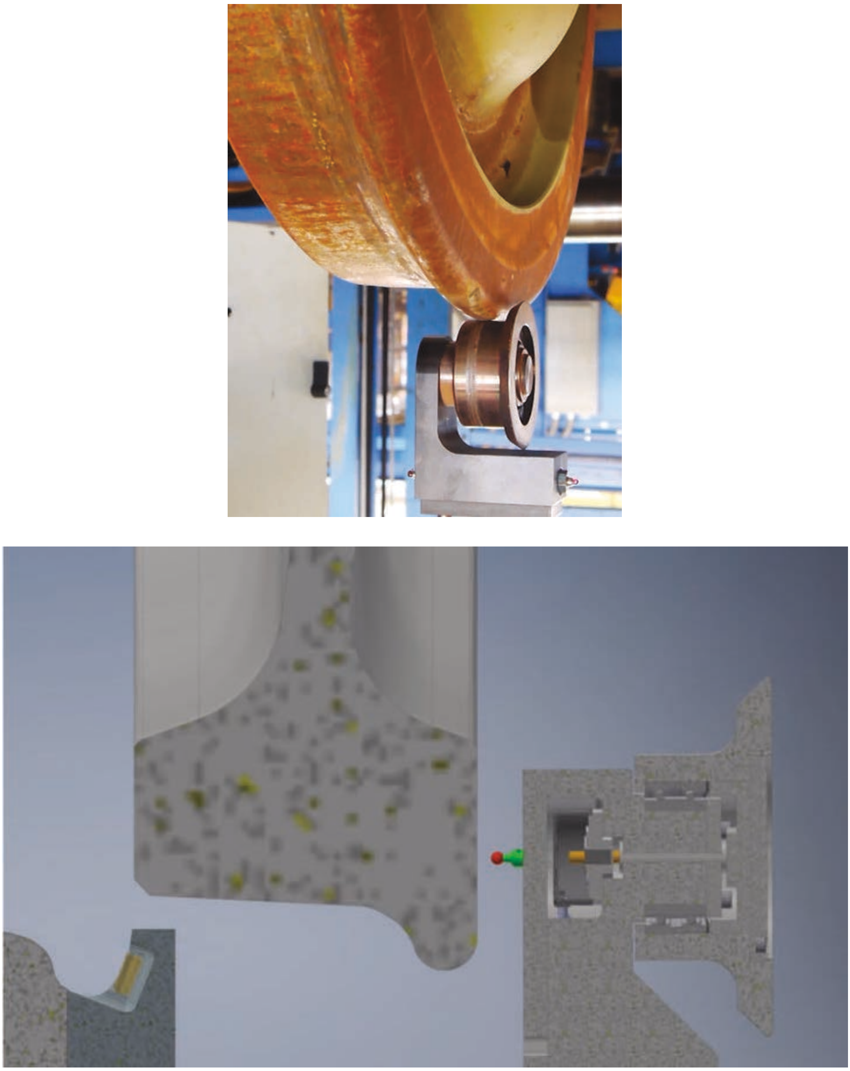
Older milling cutter next to new smaller cutter

The new cutter design is further updated by placing the indexable carbide cutting inserts directly onto the cutter body as opposed to on removable blades. This change means less vibration is created throughout the tool during the machining process, creating a stiffer, stronger interface that extends the useable life of the inserts. The enhanced insert geometry as well as modern computer solid modeling lay-out tools also produce a more optimal wheel surface finish.

While the modifications to the milling cutter design appear to be the most transformative, there are other developments taking place in the wheel truing machine's design. One would be the wheel set clamping method. The current underfloor wheel lathe design offers the ability to reprofile a wheel set without accessing the axle centers. This operation requires the lathe to force the wheel set's center line to be held at exactly the same place in space during the reprofiling process. This requires an immense amount of force, generally involving complex hydraulics and CNC systems, as well as a large machine structure to facilitate the operation.

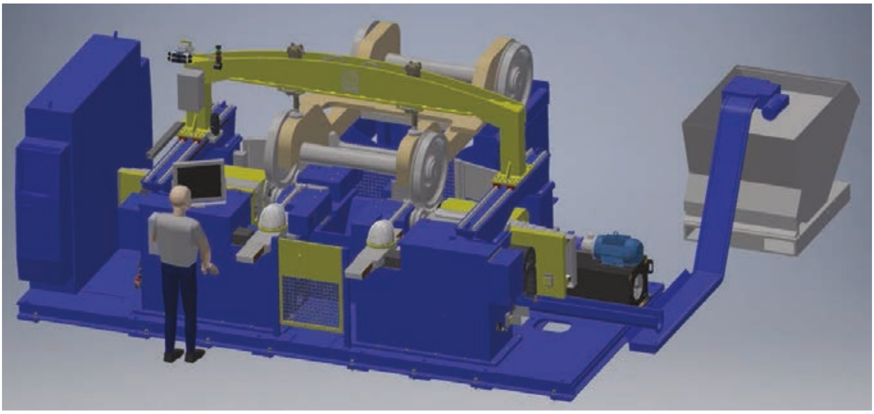
The new wheel truing milling machine design allows the wheel set center line to move while reprofiling. Instead of using heavy machine centers to clamp and hold the wheel set, a following probe monitors movement of the wheel set center line, and a closed loop servo system to keep the cutter at the correct radius. The axle centerline moves primarily vertically, but somewhat horizontally, as the wheel set rotates due to initial out-of-round condition, surface defects, a freshly cut surface contacting only one roller, etc. Our analysis shows that the horizontal movement has a negligible impact on the overall process. The newly integrated measurement system is used to find the initial location of axle center line with respect to cutter position. The cutter is then moved to the desired distance from axle centerline. If that centerline moves, the cutter moves with it, maintaining a constant distance. The process is therefore centerless (not requiring machine to physically reference the axle centers) and completely independent of the condition (roundness) of the incoming wheels. Furthermore, this process will take an out of round wheel and ensure that it is trued round.

Integrated measurement has also been introduced to the updated wheel truing machine design. As found throughout the railway industry, access to consistent and accurate measurement data has numerous benefits. The measurement data is collected pre-machining to influence a more precise reprofiling process. Parameters measured include wheel location (for cutter alignment), wheel diameter and width, the condition of the profile, flange height and width, wheel set back-to-back, and radial and axial runout. These parameters are also measured post-machining to confirm the wheel set has been trued to its target diameter. All of this data can be stored and evaluated later to better assess not just the state of the wheel truing machine, but also the state of the fleet's wheel sets. This data would prove invaluable when looking to implement a preventive maintenance program.



Wheel measurement system

As mentioned earlier, wheel truing machines have historically been limited to underfloor installations. While the new wheel truing machine will continue to be available in that configuration, the milling technology is being applied to above-floor installations as well. Currently being tested is an above-floor wheel truing machine to maintain loose wheel sets, bogies, and locomotive combo units. The centerless design means a smaller and lighter machine which requires no pit.



Animation of new above-floor wheel truing machine

The wheel truing milling machine development process is ongoing, and rigorous testing continues to confirm whether we are on the right track. The objectives of improved automation providing enhanced safety and productivity offers substantial benefit to the railway industry. We will report our continued findings to the committee as more data is collected.

Reducing Locomotives Held for Material

Prepared by:
Mike Zerafa, PowerRail, Inc

How Can Railroads and Suppliers Work Together?

Railroads and Suppliers can work together to reduce material and service supply delays and improve locomotive availability. With the advent of Precision Scheduled Railroading, it has made locomotive availability even more important. Parts and materials are critical to successful planning and scheduling. Not having the material or not planning the material within the required delivery results in a maintenance task that cannot be performed. The maintenance is then deferred or the locomotive is held or sometimes rework is required to be performed at a later date. All of this equates to locomotive downtime.

Meanwhile, Railroads are being asked to do more with less while Suppliers are trying to reduce inventory to reduce costs and improve their financial performance. Both the Railroad and Supplier face pressures on improving operating efficiencies and when working independently the end result can lead to disrupted service to the end customer.

When planning and forecasting materials and services we first examine the different types of maintenance:

- **Scheduled/Preventative Maintenance** – On a Regular Interval while equipment still functioning
- **Predictive Maintenance -** Time Based Maintenance (TBM) Form of CBM with the emergence of more remote diagnostics.
- **Failure Finding Maintenance (FFM**) –aimed at detecting hidden failures while something else has failed.
- **Risk Based Maintenance (RBM)** – preventative where the frequency and scope of maintenance activity is continuously optimized from the findings or inspection and a risk assessment made.
- **Condition Based Maintenance (CBM)** – not age related but there are some warning signs that failure may be about to occur. (intervening before it occurs)
- **Corrective Maintenance** – failure has now occurred or run to failure or as a result of unplanned failures.

The approach to planning material or services may vary based on the type of maintenance planned. Accurate forecasting is one of the top priorities for companies today. There are many advantages that can come from forecasting in planning and maintenance. Planners and Managers wish they had a crystal ball to glimpse into the future in order to cut the complexity and uncertainty of planning materials and labor to maximize their efficiencies and make educated predictions about material sourcing, inventory levels, job allocation, transport logistics and more. With more effective production scheduling, the Railroad is able to do more with less, quicker and more cost effectually. History is often like looking in a rearview mirror and often can help determine where you are going and doesn't necessarily help you avoid a multiple car accident up ahead. Forecasting gives companies the ability to be more effective in their production scheduling to meet customer demands and align the availability of raw materials and component parts. Forecasting also helps to better understand demand for certain parts and work more effectively with suppliers to achieve optimal inventory levels, minimize costly losses in either too much unused inventory or lengthy availability delays.

Forecasting helps companies reduce cost by providing the correct amount of material associated with job allocation reducing dwell times, improving cycle times, and reduces sourcing or ordering administrative costs. Forecasting assists in optimizing transportation costs – certain volumes to specific locations, combining shipments and selecting the best mode of transportation or negotiating the best rates. Forecasting helps to create a transportation strategy to better effectively manage these costs and get the parts the fastest and cost-effective way from point to point making sure the right products are at the right location at the right time. Forecasting contributes to the operational, logistics and production cycle platform all aimed at increasing customer satisfaction.

The traditional approach of the Railroad and supplier working together was the longer the lead time the more inventory was required in order to minimize the risk of material shortages. Delays can be caused by the ordering processing time, the supplier not ordering raw materials until they receive the Purchase Order – which means the supplier's lead time is added to their own lead time. Sometimes supplier's batch up orders to run them together in a large run. Delays in arranging shipping or consolidation creates delays while goods wait to be consolidated with other goods into a single shipment. Delays can be created at Cross-docks or Ports. The traditional approach does not stress communication and can frequently result in short term or long-term capacity issues at the supplier.

Communication between Railroad and Supplier has never been more critical. There are steps that the Railroad and Supplier can take to reduce lead times. Initially, you can apply lean manufacturing thinking by value stream mapping supply chain to understand the drivers of lead time. Then design a future state map to reduce factors that contribute to lead time.

It is important to have a good Service Agreement that outlines the way to do business together. It does not need to be a legal document but more of a procedure that includes agreed on performance metrics and targets, based on mutual accountabilities and key supply chain metrics including lead time and material availability.

Another strategy in reducing lead time is leveling demand and level orders onto supplier to be more predictable. This can make it easier to supply, plan manpower, and the supplier can respond quicker as they are more prepared. Allowing Suppliers to order materials against forecast does require the setting of some business rules to monitor order levels, with a two -way responsibility on the material ownership. The Supplier, by creating a dedicated line focused on that one product for that customer, minimizes the allocation of capacity for conflicting requirements.

Basic Strategies in place today to improve material and service availability have some advantages but also some limitations. Vendor Managed Inventory or Consignment requires some sort of collaboration between the railroad and the supplier. Basic strategies focus on the availability of key components and overall collaboration is limited. It is usually focused on specific warehouses or sites and the replenishment at the item level and not focused on end goal of equipment. In some cases, it results in reserving material at one warehouse but may cause a shortage for another customer or available at one Railroad site but not the other. This working together arrangement is however a Stepping-Stone to More collaborative approach in planning material and services to minimize equipment delays.

With the current state of planning there are typically multiple, independent demand forecasts, for various purposes such as the maintenance plan or the operating budget. It is usually done at a high level of detail and focuses on the annual budget by locomotive type or region or for a Period. The forecast accuracy is rarely measured or shared with the Supplier and not time phased across the value chain. It pushes the inventory to the stocking centers based on inventory parameters, is transactional based and driven by traditional or historical information.

Traditional Planning and Forecasting uses information from historical usage (EAU), programs and rebuilds, contracts or commitments to Suppliers. Information sharing is unofficial or done by verbal updates. The material is planned based off of standard lead times. Many are of the belief that maintenance can't be forecasted.

Collaborative Planning, Forecasting and Replenishment (CPFR) is Supply Chain Collaboration (SCC) and has become vitally important for companies seeking to achieve a competitive advantage. SCC is a process where both the Customer and Supplier work together to improve performance over working alone. It is a process that promotes inter-organizational cooperation, knowledge sharing and customer-supplier intimacy. Collaborative Planning, Forecasting and Replenishment (CPFR) is a process of jointly forecasting demand and scheduling production. It is aimed at creating a competitive advantage by improving the Customer and Supplier relationship through sharing of information, risks, benefits, costs and synchronized forecasts. It eliminates supply/demand uncertainty through improved communications and collaboration. Exchanging Maintenance/ Production Plan and order forecasts are continuously corrected and adjusted to develop an ongoing unique forecast. It allows the supplier to allocate production capacity against demand. The efficient flow of material and product is based on this adjusted demand. Ultimately the result is an improved service level and reduction in locomotive dwell times.

The key elements in CPFR is a greater integration and cooperation among Supplier and Customer. It is a collaborative performance system with performance metrics and information sharing. There is an alignment of Supplier and Customer sharing in risks and benefits. It encourages an environment based on trust and technology. Information sharing quality is the most critical factor in achieving success. Support of top management is paramount and generally requires a commitment and investment in technology to facilitate the exchange of information sharing.

In surveying some of the Railroads today we look at what information is shared with Suppliers currently and how does the Railroad approach their material and service requirements to minimize locomotive dwell time and improve locomotive availability. Locomotives out of Service drew a high level of visibility and Waiting on Material delays was the highest priority, other than safety. The number one railroad indicator is Locomotive Availability and Reliability. When a locomotive is held due to material, the Issue (locomotive, part/service and Supplier) gets the attention of the CMO.

Materials and services required for Capital Programs (Rebuild Programs) are forecasted and budgeted for internally at the Railroad, but there is no formal process to share the information with the Supplier. Material for unscheduled failures are held in inventory based on stocking parameters, Min/Max, lead Time, and historical failure rates. CBM and Run to Failure Maintenance type was handled similarly and this info was not systematically shared with the supplier. Few Railroads had any technology in place to share the data. There is little two-way communication in sharing information or flagging when forecasts are modified. One Railroad has invested in the technology that provides a Supplier Portal and provides performance measurements on delivery as well as item forecast in the system. Quantity on hand, lead time and forecast information is shared electronically. The Railroad is able to work with their value-added Supplier to drive down the safety stock required to be held on hand by the Railroad. The demand by Type of Maintenance is visible to the Supplier.

Capital Overhaul Program (Rebuild Program) material is forecasted and budgeted internally and shared with the Supplier 3 to 4 months before the year begins. Orders and Service Agreements are placed for these major items and scheduled. Weekly conference calls with service shops on Locomotives are held and schedules and status are revised from there. This information is not transferred via a System Technology.

One Railroad's approach is to smoothen out the production of the service shops and major material by balancing the load for the year. The goal is to allow Suppliers to hire, plan capacity, train and retain capacity levels while improving cycle times on services and materials.

Railroads have consolidated their supply base. They have entered into agreements and have established performance metrics in place for monitoring and driving performance. Risk and benefit sharing are evident. Changes to the schedule are communicated informally. The intent is for the information from the Railroad to be seamless. There are plans for investment in technology to facilitate the sharing of information but are not yet in place. The program is in its early adoption phase. Management of the Railroad has bought into and supports this Collaborative Planning and Replenishment strategy as an important part of their strategy going forward.

Final Words …

There is pressure on both the Railroads and the Supplier to improve their business metrics. Railroads and Suppliers are focused on increasing customer satisfaction. Currently, planning is done at a high level and is budget focused. We are beginning to see a more collaborative approach to planning and forecasting between the Railroad and Supplier. The performance is improved by inter-organizational cooperation, sharing of information and this new customer/supplier intimacy. Top Management is beginning to support these concepts and new processes where risk/reward and required investment in technology is critical to facilitate the information sharing and adjusting of the time phased demand over time. Supplier performance measurements and Service Agreements are in place and suppliers are being driven to perform. Inter-functional collaboration at the Railroad is vital for this process to succeed and Railroad leaders are being held accountable to deliver results. It's a start. Look to see more of these Best Practices (CPFR) hit the Rail Industry in the near future.

New Coating Technology for Graffiti Prevention

Prepared by:
Steven M. Johnson, NanoSlic Smart Coatings

Introduction

Without a doubt railroads have a lot of moving pieces. In the US alone, there are about 39,500 locomotives, 1,600,000 freight cars and 20,000 passenger cars. While many of us are enthralled to watch these marvels of transportation roll by, graffiti artists see the miles of metal as a never-ending canvas. Rolling stock has become a target of choice due to relatively easy access, large surface areas and the concept of a canvas-on-wheels. For years, much of the "tagging" was done on freight and tanker cars that sat unattended in the railroad yard or at a siding. But graffiti artists are becoming more aggressive in their tactics, painting the outside and even cabs of locomotives. Reporting marks that are painted over can result in identification issues and even fines.

Graffiti removal or re-painting is expensive and time consuming. While many types of anti-graffiti coatings have been employed in the past, an opportunity exists for new technology that can better address the issue of graffiti in the railroad industry. An advanced ceramic coating has been developed that combines three functions in one. 1) It is highly hydrophobic and oleophobic, meaning that oil-based or water-based paints will not stick 2) The ceramic coating acts as a hard topcoat with 9H hardness, protecting the underlying paint from scratches and marring and 3) Provides UV protection to underlying coatings and other surfaces.

*Although graffiti can be applied by spraying, rolling, brushing or other means, for the purpose of this presentation we will refer to spraying only.

Graffiti Removal

The processes currently used to remove graffiti are complex, expensive and time consuming:

1. **Pressure Washing:** Either hot water or solvent solutions added to water can be effective, but performance often depends on the type of graffiti paint that had been used. Pressure washing can also wear down or damage the underlying coating. When large amounts of solvents are used safety and environmental issues must be addressed.
2. **Chemical Removers:** This type of removal type will often etch, mar or otherwise damage the underlying surface, often leaving a haze or outline of the cleaning process.
3. **Spray Painting:** Graffiti can be covered over by re-painting or spot painting. Methyl Ethyl Ketone (MEK) or other paint thinners may be used

to first remove the graffiti, but this process carries inherent safety and environmental risks. Sandblasting can be used for removal but requires a large investment in time and resources.

Unfortunately, all re-painting methods can be viewed as a short-term solution since it leaves a fresh canvas for new graffiti.

Current Anti-Graffiti Coating Technology

1. **Sacrificial coatings:** These coatings form a clear coat "barrier" over the surface being protected. If graffiti is sprayed on, the coating can be removed or "sacrificed," using a high-pressure washer. The graffiti goes away with the coating.

Materials used to make sacrificial coatings are usually inexpensive, optically clear polymers such as acrylates, biopolymers, and waxes. These polymers form weak bonds with the substrate in order to facilitate easy removal. They also often help protect against corrosion and certain types of environmental damage. Since sacrificial coatings must be reapplied right after removal to provide ongoing protection, long term cost can be substantial. Reapplication can be frequent.

2. **Semi-sacrificial coatings:** These act as a sealer to protect the pores of the underlying paint coating. If graffiti is sprayed over the coating, it can be removed using a combination of a solvent and pressure washer. Typically, these coatings need to be reapplied every other time graffiti is removed.
3. **Permanent clear coatings:** These provide a barrier so graffiti cannot permanently adhere to the underlying paint. This type of coating has been made from acrylics, polyurethanes, fluorinated hydrocarbons, or siloxanes and each one works a little differently. Since most of these coatings are made from "conventional" polymers they carry over drawbacks inherent in those polymers. For example, coatings break down from UV, they can degrade from temperature exposure and they can be affected by chemicals in the air. Typically, solvents or other solutions are used to remove the graffiti, often with a pressure washer. Over time, these can damage the clear coating.

New Technology

New anti-graffiti coating technology has been developed that could offer many benefits to the railroad industry. It is based on a unique ceramic polymer technology that was developed for use in the electronics industry. At that time, there was a need for a coating that was 1) Extremely abrasion resistant 2) Resistant to practically all chemicals 3) Easy to apply and 4) Cost effective. Ceramic polymers are by definition, not carbon based. In this case, the polymer is primarily silica and so has many of the performance benefits of silicon-based materials, such as inertness, temperature resistance and UV stability. Functional groups are added to the polymer to develop application specific properties. These coatings are engineered to be very hydrophobic and oleophobic, quantitively more than Polytetrafluoroethylene (PTFE), yet they can be conveniently spray applied to form very thin clear coatings, that dry quickly and adhere to practically any surface.

From this platform chemistry a permanent anti-graffiti coating (hereafter referred to as slick technology,) was developed for use on unpainted or previously painted surfaces. General properties of this coating compared to other coating types are shown in Table 1.

	Slick Technology	**Acrylic Paint (Typ*)**	**Epoxy Paint (Typ*)**
Contact Angle (water) ASTM D7490	107	70	75
Contact Angle (n-hexadecane) ASTM D7490	63	-	-
Hardness ASTM D3363	9H	3H	4H
Adhesion D3359 (CRS)	5B (no loss)	4	5B (no loss)
UV Resistance QUV, ASTM G154	3000 hrs.	-	-
Yellowing/Cracking from UV	No	Yes	Yes
Salt Fog Resistance, ASTM B117, steel	Excellent	Good	Good
Number of Parts (1-part, 2-part)	1	1	2
Viscosity	Very Low	Mod	Mod-High
% Solids	23	40	75
Thickness	3-4 micron	100 micron	225 micron
Tack-Free Time	20 min	1 hour	7 hours
Cure Time (@73oF)	12 hrs.	2 hours	7 days
Coverage, ft2/gal	2200	400	400
VOC g/L	VOC Free	92	240

Table 1

*Typical Formulation

Preparation, Application and Equipment

The new coating requires no special surface preparation methods required beyond what would be needed for a clear topcoat. Bare metal surfaces should be thoroughly cleaned with a typical water-based alkaline cleaner, rinsed and dried. Previously painted surfaces should be prepared according to standard methods for any repainting operation. Any previously applied anti-graffiti coating may need to be removed of scuffed. Ventilation, PPE and other safety precautions typical for solvent-based paints should be used. The coating uses environmentally-friendly Volatile Organic Compounds (VOC) compliant solvents i.e. solvents that are considered non-VOCs by the EPA and do not contribute to global warming. No coalescents, additives or amine neutralizers common to waterborne coatings are used.

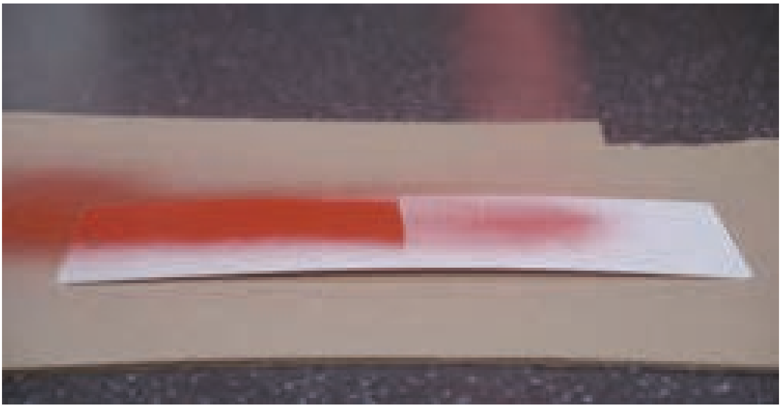
The coating can be applied by conventional High Volume Low Pressure (HVLP) equipment set for fine atomization. It can be applied relatively quickly since only 3-4 microns dry film are required for full performance. Typically, other coatings require 50-200 microns or more (2-8 mils.) Coatings are tack-free in 20-30 minutes and begin to cure right away at room temperature. 7H hardness is achieved after 18 hours and 9H hardness after 72 hours. Coatings are rainproof in 12 hours or less.

How the Coating Works

The coating can be considered a hybrid coating because it integrates three functional layers that begin to structure upon application. At the substrate interface, there is a nanometer thick layer that chemically binds to the substrate through -OH groups. Above that is a ceramic layer that imparts hardness, chemical resistance, corrosion, and scratch resistance. The top surface imparts hydrophobicity, oleophobicity, and chemical resistance.

The ceramic backbone is unaffected by UV and thus resistant to degradation. No adverse effects are observed in over 3000 hours of ASTM G154 QUV testing. The coating can also be viewed as a UV protective barrier to the underlying paint. The coating is very hard at 9H and resists scratching, marring and scuffing that is seen with conventional coatings. It withstands pH of 2-14 for long periods of time as shown in immersion tests and is resistant to most solvents. This means greater efficiency, reduced maintenance, longer life and ultimately significant cost savings.

This technology offers a form of graffiti protection that is different from other approaches. Most anti-graffiti coatings permit graffiti to be painted on but allow for easier removal. In this new approach, the low surface energy and ceramic structure make the coating totally resistant to both water-based and oil-based materials, such as paints, markers and crayons. These materials cannot wet out on the surface and will simply bead up and fall off.



Spray Paint Will Not Wet Out

When dry, any residue can simply be wiped off or removed with low pressure water spray. Since the coating prevents paint and inks from adhering, a tagger will quickly find his efforts useless and give up.

Another potential application is the selective protection of reporting marks. The coating can be easily applied using a small format HVLP gun or an aerosol can so that a car or locomotive's important marking can be rendered graffiti-proof in a few seconds. Locomotive cabs can also be coated, quickly rendering it graffiti-proof from markers, crayons and paint.

Finally, an important point is always cost. In considering this technology, both short and long-term costs should be evaluated. Although ceramic chemistry is inherently more expensive, coverage per gallon is typically 5-6 times higher. Because the coating is UV, chemical and scratch resistant it offers an overall paint upgrade and will offer graffiti repellency for many years.

Conclusion

Graffiti continues to be a major challenge for the railroad industry with significant dollars being spent on graffiti prevention and removal strategies. A new type of coating has been developed that prevents the graffiti artist from forming graffiti in the first place. If the tagger cannot form an image he will quickly move on. Important reporting marks as well as locomotive interiors can easily be protected. Because the coating is applied one time and is ultra-thin, it offers a cost-effective alternative for graffiti protection and deterrence. A high level of UV resistance offers additional protection to underlying coatings. We hope to report results from additional field testing in a future article.

Report on the Committee on Locomotive Software and Systems

Tuesday, September 24, 2019 at 12:45 PM

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N. Watters	Product Manager-Traction Transit	Morgan Advanced Materials	Greenville, SC
C. Wyka	Senior Reliability Specialist	Canadian National Rail	Edmonton, Alberta Canada

Note: Tom Mack is an Honorary Member

PERSONAL HISTORY

Viktor Gvelesiani

Director - Strategic Business Development, ZTR
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Viktor Gvelesiani is a Director of Strategic Business Development at ZTR. He has been working in the railroad industry for 25 years. His extensive work experience has been primarily focused on locomotive modernization, such as diesel-electric and electric locomotive overhauls, modernization of electrical and control systems on locomotives, manufacturing and field service.

Viktor has worked with major railroads all over the world and has in-depth understanding of challenges railroads are facing in today's world. He is actively involved with the AAR Locomotive Committee and Railway Electronics Standards Committee and various task force groups.

Born in Georgia, Viktor obtained Bachelor's Degree in Engineering at Kiev Polytechical Institute (Ukraine) and Master's Degree in Business Administration at Laurier University (Canada). He is a registered Professional Engineer currently residing in London Ontario, Canada with his wife Gillian and daughter Anna. His son Dennis works as a marketing team lead in Toronto, Ontario. Viktor enjoys being outdoors, especially camping, hiking, biking and golfing.

IoT – Big Data and Real Time Processing

Prepared by:
Connie Nordhues, Strategic Sales Manager at Wi-Tronix, and
Peter Scholtens, Customer Relations Manager at Integrity Rail Products

Modern locomotives can feature more than 200 onboard sensors that monitor performance and health. In addition, there are onboard computers that process more than 1 billion instructions per second. Even prior to implementation of Positive Train Control (PTC), locomotives, DMUs and cab cars held hundreds to thousands of potential data signal points. There can be 10-20 or more disparate sensors or systems onboard ranging from the locomotive control system, traction control system, engine control system, auxiliary power units, automatic engine stop start, GPS, air brake system, FRA mandated event recorder signals, HVAC, door controls, and even Digital Video Recorders. When you're talking about this massive amount of data, there's only so much you can house onboard a locomotive.

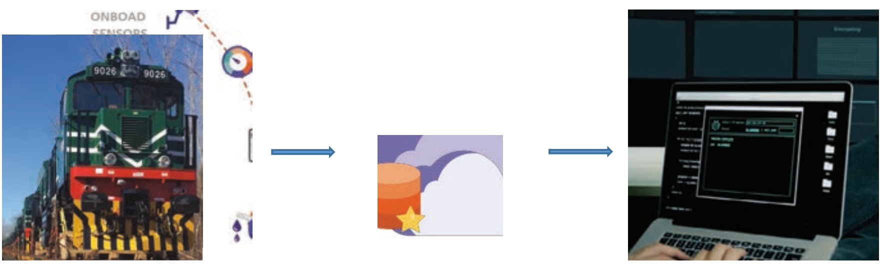
To determine the best ways to manage and process all the information generated by these on board systems, railroads are looking to their IT departments and their vendors to collect, analyze, merge and leverage this 'Big Data'. Railroads are trying to determine the value they can receive from 'Big Data', and who among all their stakeholders should have access to the data and receive value from it.

North American railroads weren't exactly early adopters when the Internet entered the mainstream between 20 and 25 years ago. Consequently, as the rail industry became "more instrumented, interconnected and intelligent," business model innovation became more attainable. Essentially, locomotives have become mobile data centers that represent 'Big Data.' The Internet of Things (IoT) is a phrase that characterizes the advanced connectivity of devices, systems and services that goes beyond your basic machine-to-machine (M2M) communications. It covers a variety of protocols, domains and applications. IoT enables freight and passenger roads to use sensors, "Big Data" analytics, cloud computing, and other technology to gather and analyze information from various sources and data streams.

The value of capturing all this data is high, but the value of processing the data, understanding it, and making decisions based on it, is often immeasurable. All this information, if obtained in near or real-time fashion can help railroads increase efficiencies, increase safety, boost productivity and improve processes in a number of departments.

The question is 'What is the outcome you want? What Value are you seeking?' These questions can come from Mechanical, IT, Transportation, Engineering, Claims and Safety, or Signaling and Communication. Absolutely every Department in the railroad can, and will, benefit from tapping into and engaging with the utilization of 'Big Data' streaming from your locomotives.

All the major roads, including short lines and regionals, have been investing in remote and real-time monitoring technology. In addition, they have been leveraging video for incident investigations and to measure locomotive health, track condition and component conditions. This is also true for passenger railroads and transit agencies. One of the big challenges is how and whether to integrate all the disparate systems on board. Many vendors are now offering remote monitoring on their particular product. There are other technology providers more than happy to help on the integration front.



IoT enables us to see patterns and leverage information to help make better business decisions. In addition, it can be used to automate processes. Ultimately, IoT accumulates a lot of past and current data that needs to be manipulated and analyzed to help predict future events.

Pulling together data from a growing number of sources and finding that stream of events (perhaps an engineer's stretch braking or throttle modulation) can provide value to many different departments. With the introduction of 5G cellular technology, more data will be available, and faster. It becomes closer and closer to real-time access, and with real-time access comes real-time decision making.

But there are significant challenges. There are more and more disparate data from different vendors, different parts of the locomotive, and from different pieces of equipment. There is no standardization. In addition, the data needs to be normalized and 'married' together in order to become a useful stream that provides the information needed to make timely decisions in improving processes and productivity. Because of these issues, it is helpful to consider the following key issues when implementing IoT.

1. Figure out the problem that you're trying to solve

When considering IoT, ask yourself if it will provide value for you and your colleagues. Once you've determined IoT will help you reach your goal, it's important to have a plan that is scalable. While it's exciting to pull out your phone and be able to automate something, it's crucial to ask if there is true value in employing IoT. Is there value in knowing exactly where your locomotive is at all times, real-time? Is there value in knowing water, oil, fuel levels? Does knowing this information provide value to Supply Chain, Safety/Claims, Mechanical, or Transportation Departments? Find out what value it provides, to whom and develop champions throughout the organization to implement IoT successfully.

2. Make sure that your project generates useful data, not noise

The real benefit is gathering all of this raw data in one location, and being able to view and analyze it. Consequently, sometimes the 'raw' data needs to be normalized. One model of locomotive might express fuel, air or oil pressure in a different format than another model. Thus the data will have to be cleaned up or 'normalized' to make sure that it's helpful. The more sensors or different models of locomotive you have, the more chance of noise. Clean it up, sanitize it, and ensure that it's truly useful to your customer, both internal and external. False positives can become a problem in which we become attuned to ignoring them. They then become a nuisance rather than a value and you risk the alerts being turned off. The last thing you want is false alerts that cause the customer to shut the alert off only to have a catastrophic failure or incident happen shortly thereafter.

3. Reliability – the more sensors, more potential spots for failure

Everyone should be aware of the concept of mean time between failure (MTBF). If you have 4 boxes or sensors with a MTBF of 100,000 hours each, you now have 4 points of failure within that 100,000 hours. A failure in any of these sensors will cause a failure in the system. With this in mind, it's imperative to consider consolidation of devices or have one device that can obtain more of the data with a much higher MTBF. Combining devices or sensors in one box or more signals using one path, is also a great idea considering available real estate on today's locomotives.

We can look to the aviation industry for good examples. They continue to increase their MTBF on all devices because it is critical to the entire system. In addition, all commercial planes include redundancy in their systems. Redundancy can be as important as reliability when gathering data used to make critical decisions in the organization.

4. Make sure that your IoT solution can scale

Ensure that you make wise decisions early so that when you scale up, you have the infrastructure in place that will carry the load for the larger scale.

An example of this is what happened to Facebook. They used a lot of scripting languages in the beginning. As a result, the company had to completely rework their backend when they began to grow. Because they didn't choose wisely initially, they were forced to do a lot of extra work to deal with the growth.

5. Cloud computing vs Edge computing

Cloud computing enables storing and accessing data via the internet. It's a great tool to use, but then there's the time spent sending it to the cloud, doing the analysis in the cloud, and then presenting through your portal or other device in which you get alerts, dashboards, etc. Ideally, extremely sensitive situations such as Engineer Initiated Emergencies or derailments, is information you would want instantly. In this type of situation, data analysis onboard or Edge Computing would be important.

6. Look for end-to-end solutions

For many people, IoT provides the tools of gathering big data. While it's excellent progress to have access to so many data points, what good is it if you don't have the ability to efficiently analyze this big data? While storing great amounts of data and information in the cloud is useful, it's important to think about how to best leverage this tool to increase efficiencies and improve solutions.

The true value chain lies in having an end-to-end solution. This includes the hardware, software, management tools and the analytics at the backend. The true winners are going to be those who figure out the customer's needs, anticipate changing business models, and create value for those opportunities. In traditional product companies, creating value meant identifying enduring customer needs and manufacturing well-engineered solutions. But in a connected world, products are no longer one-and-done. Thanks to over-the-air updates, new features and functionality can be pushed to the customer on a regular basis. The ability to track products in use makes it possible to respond to customer behavior. And of course, products can now be connected with other products, leading to new analytics and new services for more effective forecasting, process optimization, and customer service experiences. As you can imagine, value can be discovered and created during and after IoT implementation. As a result, vendors are more likely to become long-term partners.

7. Security issues.

When deploying IoT make sure your data is secure. After all, I don't know a road that wants to have a video of an incident posted on YouTube or Facebook. If utilizing Software as a Service, make sure your vendor is up to date with their

security certifications or SoC 2 compliant. Make sure there's sufficient security and 'chain of custody' is documented for all your data. And remember, in all dealings, it's YOUR data.

Conclusion

When utilizing IoT with all its advantages, detection and notification of relevant operating issues can be automated in real-time and will enable managers to identify and respond to incidents more proactively. IoT can also aid in documentation, communication and decision-making/preventative actions. The purpose is to be proactive rather than reactive. Look ahead and identify where problems are going to be and plan accordingly. This gets into things like predictive analytics and predictive maintenance, which will allow you to maximize capacity, reduce maintenance costs, and extend equipment life. Specifically in the rail environment, this should minimize equipment failure, derailments, and other significant causes of disruption.

The purpose is to use the 'Big Data' to automate human transactions and send electronic notifications directly, to the person that can affect immediate change to again increase safety, productivity and reliability.

That pretty much sums up why railroads are employing IoT principles. There already is a lot of data and insight at hand to help power business decisions. The question is: How do you best use and employ it securely?

Implementing Predictive Maintenance for Locomotives Using Big Data

Prepared by:
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Connie Nordhues, Strategic Sales Manager at Wi-Tronix LLC.

Predictive Analytics, Predictive Maintenance, the Industrial Internet of Things, (abbreviated as IIoT or simply IoT), and Big Data are not just the latest marketing ploy or corporate buzzwords. According to the *IoT Analytics Predictive Maintenance Market Report 2017 – 2022*, the Predictive Maintenance (PdM) market is fast growing with a thirty-nine percent compound annual growth rate and an eleven billion dollar technology spend thru 2022. Companies employing Predictive Maintenance solutions report real value and are seeing a return of twenty to thirty percent in maintenance efficiency gains. Predictive Maintenance (PdM) is the #1 use case in connected industry settings.

Most railroads primarily utilize a time-based 'Preventative Maintenance' program approach for locomotive maintenance. And although this is primarily due to it being mandated by the FRA, the rail industry still lags behind other industries in the adoption of the application of the 'Internet of Things' and 'Big Data' technologies to feed Predictive Maintenance that will enhance reliability and maintenance efficiency. In terms of using Predictive Maintenance for locomotive reliability, rail has not moved much beyond what limited Predictive Analytics the locomotive OEMs may provide, for free, during the initial warranty period.

Industry CEOs the world over are rapidly spending precious funds on IoT hardware and technology infrastructure. They are buying data acquisition systems, networks, sensors, and are hiring scores of IT personnel, analysts, and data scientists all in order to obtain their organizations 'Big Data.' They desire to unlock the nuggets of valuable Business Insights (BI) from their organizational data. Railroads are looking to attain their data and do the same. But, the question remains: what do you do with 'Big Data' once you have it?

There are many ways to implement a Predictive Maintenance program. This paper will discuss one way to augment FRA-mandated locomotive preventive maintenance, reduce practices that are reactive in nature, and provide example steps to establish a successful proactive locomotive Predictive Maintenance program.

For those of you not familiar with the different types of maintenance programs, here is a very brief summary:

Reactive Maintenance – A Reactive Maintenance program practices "break/fix" and has no proactive planning. This is also known as "run to failure." Not all Reactive Maintenance practices should be considered bad. There is a time and place for Reactive Maintenance at the piece-part or component level, but only after making an informed decision for that component based upon its Failure Mode and Effects Analysis (FMEA). Other reasons where Reactive Maintenance may have applicability would be due to low Mean Time Between Failures (MTBF), cost, and material availability. Unscheduled locomotive shopping's fall into the Reactive Maintenance category. Some railroads call them 'Road Failures,' others call them 'Failures with a Level of 1-9,' or 'Failures with a Severity of 1-7,' and still others call them 'Fallouts.' No matter what we call them Road Failures hurt our efficiency and our bottom line.

Preventive Maintenance (PM) – Preventive Maintenance programs are planned around usage and are based on actual operating statistics; or on a calendar/time/interval basis. Locomotive maintenance is typically time-based, meaning that equipment is serviced on calendar-based periods only (i.e. once every 92 days).

Condition-Based Maintenance (CBM) – A Condition-Based Maintenance program allows custom configuration as to when to service your assets (locomotives), which are based on run hours, seasonality, temperature, or some other factor. With a Condition-Based Maintenance program, specific conditions can be monitored. Equipment failure, as well as 'over servicing' can be averted. CBM is sometimes also referred to as "Diagnostics."

Predictive Maintenance (PdM) – A Predictive Maintenance program uses sophisticated analytics and actual operating characteristics to determine asset health. Predictive Maintenance treats each asset as unique and provides early warning and diagnosis of equipment failures. PdM is sometimes also referred to as "Prognostics" and "Predictive Analytics."

Reliability-Centered Maintenance (RCM) – A Reliability-Centered Maintenance program looks at all other maintenance programs that improve asset reliability. Reliability-Centered Maintenance targets the use of Reactive Maintenance, PM, PdM, and CBM in the most efficient manner. But in order to get to the RCM level, a Predictive Maintenance program must be established.

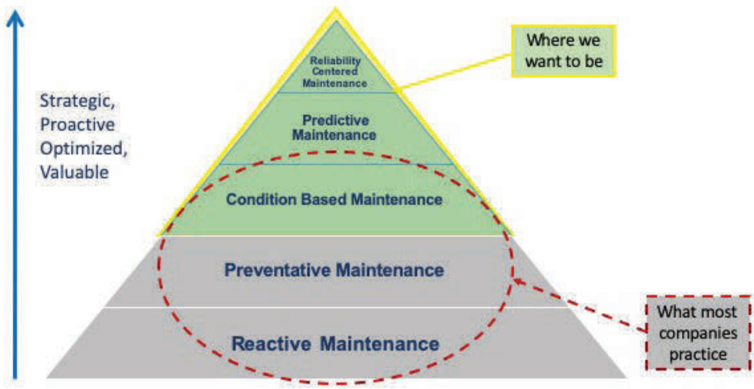


Figure 1. Maintenance Program Pyramid.

Figure 1 is one way to describe both the evolution of maintenance program practices and the technologies that support these programs, as well as the added value that each provides as one moves up the pyramid. The higher an organization moves up the maintenance program pyramid, the more early warning time is available, and the timelier that diagnostic information is available to make decisions. This means that maintenance teams are better equipped to plan their resources, order necessary parts, minimize unplanned maintenance events, prevent catastrophic locomotive engine failures and prevent the over servicing of equipment.

Concerning availability and reliability; the mission of every industry when it comes to their high value assets is 100% availability and reliability. And in our case, locomotives are the high value assets and they are mobile. Who here doesn't want to get to the utopian state of 100% availability and reliability? That's the maintenance mission. That's what we are all chasing. This is why we all attend events such as Railway Interchange.

So, how do we get there? What could make that possible? The only way to get there is by addressing the problems that cause locomotive failures, before they occur.

Predictive Maintenance is the "Killer App" for the Industrial IoT. As stated earlier, the Rail Industry is lagging in Predictive Analytics and in implementing full Predictive Maintenance. This is particularly true considering the "real" cost of locomotive failures.

The "real" cost of locomotive failures and how they affect Railroad operations is **why** Predictive Maintenance should be implemented:

Not only is there the initial primary part and labor costs, but also possible subsequent damage. Other real costs are:

- Asset downtime
- The possibility of an accident
- A blockage on a mainline can incur costs from:
    - Requiring emergency response personnel & equipment
    - Blocked crossings
    - The rerouting of trains
    - Redoubling (to go back and get the rest of the load)
    - Crew hours/the change out of crews
    - Late delivery penalties from customer agreements
    - Track violation fines for late occupation.

Road failures slow a railroad's average train velocity, which affect a railroad's efficiency, and that can have stock price implications.

Figure 2 below is data from a University of Illinois study from 2015 that estimates the "real" cost of a four hour delay on an intermodal train to be in the $14,000 dollar range.

Cost Category	805 km (500 miles)	2,012 km (1,250 mile)	3,219 km (2,000 mile)
Locomotive ownership	$105.00	$105.00	$105.00
Locomotive operating	$267.00	$267.00	$267.00
Locomotive fuel	$2,221.00	$2,221.00	$2,221.00
Railcar	$272.00	$272.00	$272.00
Crew	$318.00	$318.00	$318.00
Lading	$4,612.00	$4,612.00	$4,612.00
Mode shift (revenue loss)	$207.00	$574.00	$1,034.00
Emissions	$3,645.00	$3,645.00	$3,645.00
Level Crossing	$2,429.00	$2,290.00	$2,255.00
	$14,076.00	$14,304.00	$14,729.00

* Determining Freight Train Delay Costs on Railroad Lines in North America

Figure 2. Incremental delay cost for four hours of delay per intermodal train route.

In the Passenger market segment, what is the cost of damaging the reputation of a transit agency? It is not just freight railroads that need Predictive Maintenance, Transit and Passenger are also affected in terms of the real cost of a locomotive failure. What is a Passenger Railroads' reputation worth in terms of ridership and the associated revenue? Additionally, when a passenger or transit train fails it generally gets broadcast over social media sites such as Twitter, YouTube and Facebook as well as local television news outlets. Having transit system delays broadcast over social media and the morning news has a real cost to it as it diminishes the public perception and confidence.

Steps to establishing a successful Predictive Maintenance Program:

From working with customers, these are five steps that were utilized in regard to implementing a Predictive Maintenance program:

Step 1: Define the need
Step 2: Scope and define the objectives, address the customers' pain
Step 3: Establish success criteria
Step 4: Assemble and integrate the teams
Step 5: Prove the value

Step 1: Define the need

In order to define the need for Predictive Maintenance specific to your organization, utilize the three circles of feasibility. Begin by answering the following questions:

User Desirability:

"Do they (the Mechanical Department's internal customer, Transportation) want this?" – Improved reliability and availability of locomotives, yes please!

Business Viability:

"Why is this important?" "Why should we do this?" and more importantly, "Why shouldn't we do this?" – Efficiency and savings to the bottom line!

Technical Feasibility:

"Can we do this?" – Yes, of course you can!

Other items to consider:

"Where are the best opportunities for operational efficiency and effectiveness gains?"

"In general, how much does a road failure cost us?" - Quantify and define this question for your railroad as we will come back to this question in Step 3.

To quickly realize savings from implementing a Predictive Maintenance program, there are many complexities to consider, some examples are:

- The type of locomotive fleet
    - The fleet utilization percentage

- The age of the locomotive
    - The date of last overhaul
    - The asset utilization percentage

The specific railroad organization and the type of revenue service the locomotives are utilized in are also some of the parameters that will influence how quickly you can realize Predictive Maintenance savings. Additional factors include the digital maturity of the railroad, their willingness to adopt new technology and processes as well as their current 'data and connectivity infrastructure;' those systems that communicate with their locomotives.

Step 2: Scope and define the objectives

In order to scope and define the objectives of a Predictive Maintenance program implementation, you will need to engage and mobilize the organization:

Determine the organizational impact – Get 'buy-in' from the various teams within.

Identify champion(s) and stakeholders both executive and non-executive. These personnel will need to be promoters, and not detractors of a Predictive Maintenance implementation. Promoters can be either internal or external to the organization. Executive sponsorship is one of the single most important items to have in any initiative. Most improvement programs, and especially reliability improvement programs, even if successful, fail without proper executive sponsorship.

In terms of budget, remember to keep your Finance Department happy. Have a financial plan and stick to it.

Identify the 'Must Haves'

Map the existing highest value failure modes first. Complete what one might call a 'backwards Failure Modes and Effects Analysis' to see the high value failure modes and how they line up to your available data. If that is too difficult, simply rank the top locomotive failure modes (by fleet) into a list. Creating a Pareto chart(s) will help to focus on the most significant (most frequently occurring) failure modes.

From the top failure modes list, assess the failure modes vs. the available data. Then, review the top failure modes with your (internal) customer(s) to validate the high value failure modes and clearly identify the "customers' pain" for the fleet(s). Re-rank the top failure modes list with input from the customer in terms of operational impact. Be honest with the internal customers (stakeholders) about what can and cannot be caught with the available data. A burnt out locomotive stairwell light bulb may very well possibly be in the top failure modes list. Modern event recorders can provide data in terms of the position of the on/off switch for the headlights, but locomotives are currently not manufactured to provide data concerning an open light bulb circuit at the ascension stairwell.

Validate your ability to address a potential failure mode prior to the functional failure (Failure modes vs. PF-FF interval). Then ask the question, "Do the Predictive Maintenance alerts provide enough advance warning to schedule a fix and avoid a mission failure?" This helps to further refine the value and operational impact of the various locomotive failure modes in the failure list.

Identify the 'Would like to Haves' – the customers' desires.

So, which of the failure modes from the top failure modes list can you not currently predict with your current data? Have the customer prioritize those failure modes and later on develop solutions to attain the needed data in order to close the gaps. Sounds easy right? Well, that's actually the fun 'product development' stuff.

For the failure modes in the top failure modes list that cannot currently be addressed because of a lack of readily existing data output from the locomotive, generally, a decision and agreement should be made to put those failure modes aside for now to be worked at a later date. Certainly, in the light bulb example above, a current sensor or 'smart bulb' could be added and/or video intelligence (VI) could be used to provide this data, but these options may not currently be cost effective to address the low impact (low value) of a burnt out stairwell light bulb failure mode.

Define the communication format

When defining the objectives of the Predictive Maintenance program implementation, identify the communication format of program outputs, to make sure you are all speaking the same language.

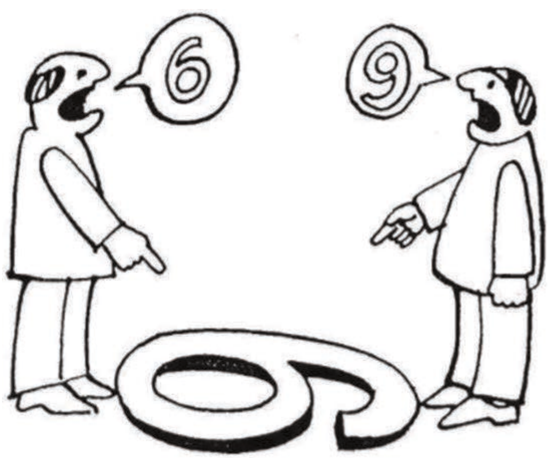


Figure 3. Ensure all stakeholders are speaking the same language.

Sample Objectives

Some sample Predictive Maintenance program objectives could be:

- Identification of abnormalities in advance of failure - Early detection, problem identification, and advanced notification of equipment health and performance problems.
- Problem tracking and trending analysis prior to scheduled maintenance events.

- Abnormalities identified with level of criticality.
- Validation that identified abnormal signature(s) have recovered after repair.
- Validation that additional abnormal signatures are not introduced during a maintenance event.
- Identification of additional signals for future development.

Step 3: Establish Success Criteria

Disclaimer: As mentioned previously, there are many ways to implement a Predictive Maintenance program, this paper will discuss and share examples for implementing a Preventive Maintenance program.

In order to establish the success criteria of a Predictive Maintenance program it is more customer centric to jointly define the format of a scorecard and the scorecard criteria together with your customer(s). Make sure to discuss and agree on the value of the Predictive Maintenance alerts.

Differentiation in value can be made based on the severity of the Predictive Maintenance alerts. For example a red, yellow, and white scale could be used where:

Severity Level: Red, Derating HP, Check at next service track.
Severity Level: Yellow, Possible reduction in HP, check at end of trip.
Severity Level: White, Check at scheduled maintenance.

Or if it is desired to "keep it simple," differentiation in value of Predictive Maintenance alerts can be made based on the operational results in terms of "catches" and "saves":

Define the savings value for a **"Catch":**

- Identify a problem with a locomotive and **"Catch"** an issue that would not have caused an immediate road failure, but requires future maintenance action.
- Apply specific dollars based on historical data.

Define the savings value for a **"Save"** of a locomotive failure:

- Identify a problem and **"Save"** the customer from an issue that would have caused a Road Failure with high probability.*
- Apply specific dollars based on historical data.

Justification: Removal of a locomotive from revenue service.

*Note: This is a judgement requiring customer acknowledgement.

Make sure research in this area is complete, as the financial values assigned to each, a "catch" and a "save," should be used to roll up to a total value "saved" by the Predictive Analytics program.

Based on past experiences, the figures associated with each of these two definitions; that of a "catch" and the definition of a "save" are likely to be different for each customer and generally, each customer already knows what their numbers are for a catch and a save. The challenge is to have the customer provide those numbers.

Agree to discuss, and also agree to the actual scorecard results with your customer on a monthly basis.

Utilizing a scorecard method similar to the "catches and saves" example will enable your Predictive Maintenance, "customer champion(s)" to shine by providing them with solid evidence of financial value when it is time for next years' budget discussions.

Step 4: Assemble and integrate the teams

General Stanley McChrystal was in charge of the US Forces in Afghanistan during the height of the Global War on Terrorism. McChrystal had a huge tactical operations center that would receive nonstop, massive amounts of intelligence from areas all over the theater of operations. This quote from General McChrystal about his time as the Commander of the Joint Special Operations Command really drives home the need for leaders to recognize the differences in skillsets between functional personnel such as data experts and locomotive subject matter experts.

"…gathering data points is not the same as gaining a situational understanding. 'Big Data' can show you what is happening, but it falls short of contextualizing ***why it is happening****. Sound decision-making demands more."*

'Big Data' teams alone won't get it done. There is a tendency to think that one only needs data scientists to enable Predictive Maintenance. This is a common mistake in implementing a Predictive Maintenance program. An assumption is that the only resources needed are purely IT resources that understand data. However, Subject Matter Experts (SME's) with actual asset knowledge, are a very critical part of this process, and this requirement should not be underestimated. The SME's can help the data scientists to answer the "Why" when they see an abnormal signal in the data.

The roadmap of our Predictive Maintenance journey has led us to integrating an Analytics Team and a Maintenance Team together, utilizing a 'Closed Loop' process, where the Analytics Team and the Maintenance Team are dependent upon one another for Predictive Maintenance program success.

The Data and Information organization, the "Analytics Team" should include the following:

- Predictive Maintenance Program owner
- **Data Scientists/Data Engineers** – Can be remote or third party
- IT specialists – as needed for data flow set up

The "Maintenance Team" organization can be made up of a combination of any of the following:

- CMO/ACMO (Chief Mechanical Officer, Assistant Chief Mechanical Officer)
- Manager Locomotive Assets (Railroad Fleet Manager)
- Senior Manager of Locomotive Reliability
- **Sr. Reliability Specialist/Reliability Specialists (Loco Technical SMEs) – aka. "Super-Techs"**
- Mechanics are also SMEs
- Materials Department personnel
- Central Control/Dispatch/Network Operation Center personnel
- Fleet Analytics personnel

The two positions in bold, the **Data Scientists/Data Engineers** and the **Reliability Specialists** are key players in the success of the day-to-day activities of a Predictive Maintenance program. The Data Scientists/Data Engineers are the "Data Experts," and the Reliability Specialists are the "Locomotive Experts." When these two groups are put together, this becomes a very powerful combination. The "Data Expert" can raise his/her hand and alert the program team to an abnormal signal occurring with a locomotive, and the "Locomotive Expert" can validate the issue and provide clear context of why and what is transpiring with the locomotive.

After being questioned directly by more than one Railroad Chief Mechanical Officer with a, "What makes you smarter than us?" mentality, we created the below process (**Figure 4**) as the overall "How we do it." The below 'Closed Loop' process illustrates the roles of each team, dependencies, and most importantly helps to answer that question back to any C-Level leader and showcase the differences between the 'data and information experts' and the 'Locomotive Experts.'

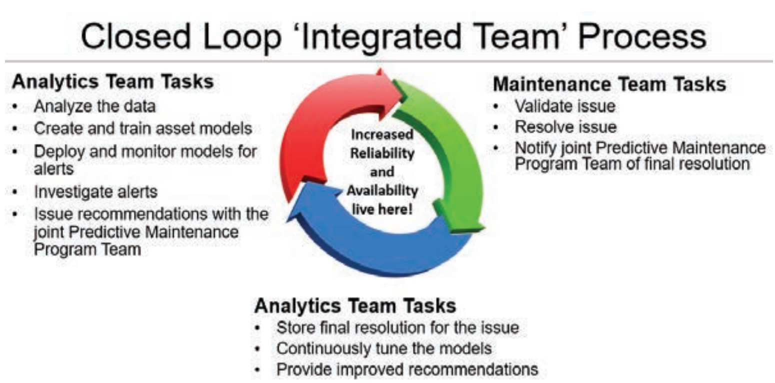


Figure 4. The Closed Loop Process, the overall "How it works"

Eventually thru the 'Closed Loop' process the teams will map out all of the common failure modes for the various fleets and less reliance upon the locomotive SMEs will be required as the Analytics team continuously tunes the predictive models and should also be populating/creating a 'case based reasoning tool.' One example that explains failure mode "mapping" would be a locomotive with a steady trend of increasing fuel pressure. A steady trend of increasing fuel pressure generally indicates the gradual clogging of fuel filters, depending on the location of the fuel sensor in relation to the fuel filters. Even though a Data Scientist may not be a locomotive SME, he or she would only need to see the increasing fuel pressure signal trend a few times with a few locomotive cases in order to formulate a solid conclusion. Then, a recommendation could be issued to the Predictive Maintenance program team without the need for locomotive SME review.

Predictive Maintenance Program Team administrative stuff:

The Predictive Maintenance Program Team leader should lay out an internal Predictive Maintenance Program Team "Roles, Responsibilities, and Expectations" document. Then, create and share a Predictive Maintenance Program Team roster and distribution list. This way, all team members will have a general understanding as well as everyone's contact information, and this will help to remove potential excuses.

Meeting cadences will need to be set up. In the beginning, a touchpoint using an online web meeting service should be held every week until the team is comfortable enough with the process to move to an every other week cadence. Provide training to the team on the processes to make it all work. Do not be afraid to try new things, and if those new things fail, regroup, adjust and iterate, iterate, iterate.

Step 5: Prove the Value

Demonstrate what you can do

Perform Proof of Concept (PoC) pilots first. One PoC utilizing one locomotive is not enough. Execute the pilots — results should look something like this:

Without Predictive Maintenance:

- Asset suffers a total or partial mission failure
    - Operators report in the rail environment often fails the entire consist
    - Sometimes, too general for specific action
- Unit(s) shopped
    - Load test to recreate problem
    - Problem may not be visible in load test
- Fix problem
- Validate with equipment test
- Final validation in-service from crew reports

With Predictive Maintenance:

- Asset specific alert to team prior to mission failure
- Joint Program Team makes a recommendation focusing attention to the source, using expert maintainers
- Opportunity to defer to scheduled maintenance or a service track fix - avoiding an unscheduled failure
- Shortened Inbound load test
- Problem is fixed with the least impact on service
- Closeout information back to the team
- Validate with equipment load test
- Quick in-service validation with the data

Utilize the scorecard discussed in Step 3

Discuss and brief the scorecard results monthly with the team as well as with the champions and executive sponsor(s).

- Maintain the running financial value tally for all "catches and saves" so that it can be used to justify project expansion.
- Create and provide specific case example sheets that demonstrate the value.

Provide exceptional "White Glove" service

Execute the pilots and provide such exceptional service that they turn into a permanent implementation opportunity.

Become ingrained in the customer's daily routine. Make them miss you when the pilot is over.

Summary

In summary, and in the spirit of continuous improvement, continue to find ways to show additional value by offering additional reporting and services such as fleet studies, fleet overhaul prioritization lists, and deep dives of data for warranty support.

There will be challenges. Implementing a Predictive Maintenance program is a culture change. Provide exceptional service. Close the gaps on the failure modes that cannot not yet be predicted.

Always thwart the challenges – and be ready to 'Prove it' with data in order to create raving fans.

Footnote

This white paper is the second paper in a series of three papers for 2019 from the Locomotive Software and Systems Committee of the Locomotive Maintenance Officers Association (LMOA). This year, the Locomotive Software and Systems Committee decided upon three papers centering on 'Big Data and analytics' for maintenance of locomotives.

In general terms, the first paper discusses, "How do I get the data from locomotives?" the second paper discusses, "What do I do once I have the data?" and the third paper discusses, "What do I do once I find a locomotive issue in the data and how do I integrate that back into my CMMS system?"

These papers are to be presented Tuesday, September 24th from 12:30 – 1:15 PM at The RSI Education & Technical Training Conference at Railway Interchange 2019:

1. *IoT – Big Data and Real Time Processing* – Connie Nordhues, Wi-Tronix LLC and Peter Scholtens, Integrity Rail Products.
2. *Implementing Predictive Maintenance for locomotives using Big Data* – Jason Mann and Connie Nordhues, Wi-Tronix LLC.
3. *Analytics Through Repairs Integration* – Casey Pytel, Progress Rail.

Railway Interchange is the largest railway exhibition and technical conference in North America. We look forward to seeing you on September 22-25, 2019 in Minneapolis, Minnesota, USA.

References

IoT Analytics Predictive Maintenance Market Report 2017 – 2022, IoT Analytics GmbH, March 2017.

Determining Freight Train Delay Costs on Railroad Lines in North America, Alexander H. Lovett, C. Tyler Dick, Christopher P. L. Barkan, Rail Transportation and Engineering Center (RailTEC), Department of Civil Engineering, University of Illinois at Urbana-Champaign, 2015.

Analytics through Repairs Integration

Prepared by:
Casey Pytel, Progress Rail

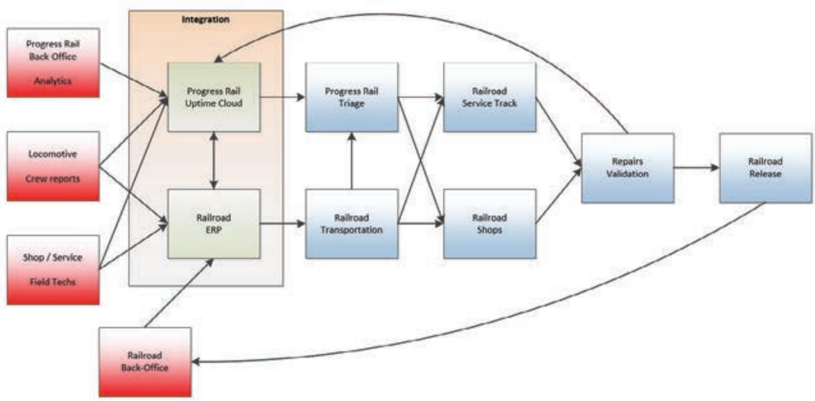
Introduction and Executive Summary

It is no secret that the rate at which we receive and process information is increasing at an alarming and exciting rate. This deluge of data impacts our day-to-day lives and multiple industries, including transportation. For railroads, it has become increasingly critical to manage data and use it to the industry's advantage to enhance, advance and optimize operations. For that purpose, this paper will present an overview of locomotive data, its integration into the locomotive repair and maintenance process, and related workflow – narrowing in on the changing landscape of predictive analytics and how it can be applied within global railroad operations. Integrating data within the correct shop process and workflow is key to maximize efficiencies and gain value.

Data analytics in rail has exploded over the past few years. To succeed in this space, there are a few key requirements: a combination of deep rail expertise; scalable systems for secure data management; and a mastery of various data modeling and machine learning processes.

Multiple sources of locomotive data exist today and are readily available; however, they are spread out in federated systems. Each of the various systems can feed data into Progress Rail's analytics application, PR Uptime®, into railroad back-office, into railroad ERP (Enterprise Resource Planning) system(s), and other programs. The collection and use of data is an ever-increasing cycle, as more data has the potential to generate better analytics and provide for better value.

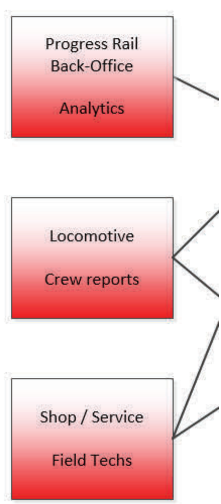
A theoretical example of processes and flows is provided below related to the deployment of data analytics at a railroad. This paper walks through the various phases, including identifying the problem with the locomotive, integrating and synchronizing between analytics and ERP systems, and taking action to repair the problem.



Identifying Pending or Active Locomotive Failures

The locomotive troubleshooting process starts with identification of a pending (prognostic) or currently active (diagnostic) failure. Three workflows typically identify problems:

- The first is based upon back-office data in combination with analytics models, rules, and human detection of a pending or an active failure;
- The second is based upon a crew report about the locomotive or train consist;
- And finally, the third is based upon inspections during service, scheduled maintenance, or other repairs.



In an ideal case, back-office analytics tools predict and identify all pending locomotive issues early enough to capture any concerns and ensure adequate shop planning. This bypasses the need for alternative workflows, and as such, serves as the optimal objective. However, reaching this level of coverage will likely not be cost effective. Locomotive analytics tools, like Progress Rail Uptime®, have grown in their ability to cover locomotive failure modes and gain prognostic power over time. New sensor deployments, better data access, advanced locomotive telematics, and a combination of OEM insight and improved modeling techniques have further strengthened predictive analytics.

The Progress Rail Uptime Cloud® (back-office) hosts the analytics data ingestion platform. Locomotive machine data is continuously ingested as the asset connects and communicates with the back-office. In addition to machine data, resources, such as field technicians, provide human entered insights related to shop activities and work-scope statuses. Once housed in the back office, data is automatically fed into the various analytics processes (such as alert generation, machine learning, data cleansing, and others) running in the analytics application. The ultimate output of the analytics application, in combination with human analysis, is a specific work-scope tailored to address a particular locomotive's issue or pending failure.

To create analytics models that maintain a low level of no defect found (or NDFs) and high precision OEM and subject matter experts (SMEs) are a necessity, which requires specific learning and real-world experience. This domain expertise extends the value of the analytics platform and available data, to not only provide descriptive information (e.g., the engine is hot), but also allow the analytics suite to provide prescriptive data (e.g. the engine is hot because fan #1 failed, and here are the 10 steps to troubleshoot the problem). With non-OEM analytics suppliers, these skills are not readily available, which reduces overall value of the information being provided at the onset, and any resources plugged in to crunch the data.

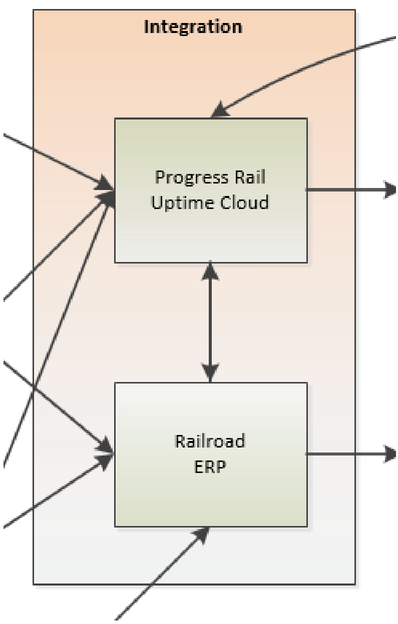
In the case of failure modes not being identified by the analytics application, crew observations can lead to identification of the problem. As the crew encounters operational issues and engages the railroad helpdesk and monitoring analysts, they can provide support to expedite resolution of the issue using the analytics application. If the issue cannot be resolved, the locomotive is then sent to the shop. Based upon crew troubleshooting, the analytics application receives and processes machine and human entered data simultaneously into the railroad's ERP system(s). This data creates context used by the analytics application and monitoring analysts to ultimately create a specific work scope tailored to address the particular locomotive's issue and present a plan to resolve any concerns.

Railroad service personnel or field technicians can also identify issues with the locomotive, not already identified by the processes mentioned above, during scheduled maintenance, servicing and other inspections. Those observations can be supplied to the analytics application, as well as entered into railroad ERP system(s). These human insights, working in combination with data already in the analytics application, enable field technicians to create specific work scopes to address issues found during locomotive inspection.

Various data sources feed into the analytics application to enable the prediction and identification of locomotive issues, along with the generation of alerts and work scopes fed back to the railroad. This integration of data, alerts, and work scopes puts the power of optimized rail operations within the railroads' hands, allowing them to take action.

Synchronizing Data and Taking Action

Working within the application's cloud environment, data becomes synchronized for further use. PR Uptime® Cloud allows the Progress Rail analytics platform to be constantly updated. Synchronization of these systems allows railroads to capture value from analytics, focused work scopes, service track repairs and other analytics application features.



To minimize missed opportunities, the synchronization of data between railroad ERP systems and PR Uptime® is critical. This ensures that railroad personnel and systems, field service technicians and locomotive analysts have access to all relevant data and react appropriately. This eliminates the risk that

Uptime identifies an issue and generates an alert, but the railroad is unable to take action because they are unaware. This can be caused by human error or excessive work load on key personnel related to getting the data into the right railroad system.

By collecting data from the locomotive, train crews, field and shop technicians to refine the models, update rules and thresholds, and generate work scopes, the application can create (or select) targeted work scopes to permit more efficient shopping or service track planning and operations. As accuracy of the alerts and work scopes improves, unscheduled shopping can decrease, while reliability can increase. In all cases, data quality must be considered and, in many cases, cleansed as part of the data ingestion process. Erroneous, duplicitous or non-relevant, human-entered data is married with machine data and scrubbed. This allows the application to provide appropriate reports, performance measurement (KPIs) and drive improvement in relevant metrics.

The cleansed data serves as a valuable tool in supporting existing systems to maximize resources and minimize costs. Since the data is already available within the application, there is less data scrubbing needed by the receiving system. Shop and service scheduling systems can be fed with task information, work scopes, asset location, and other data.

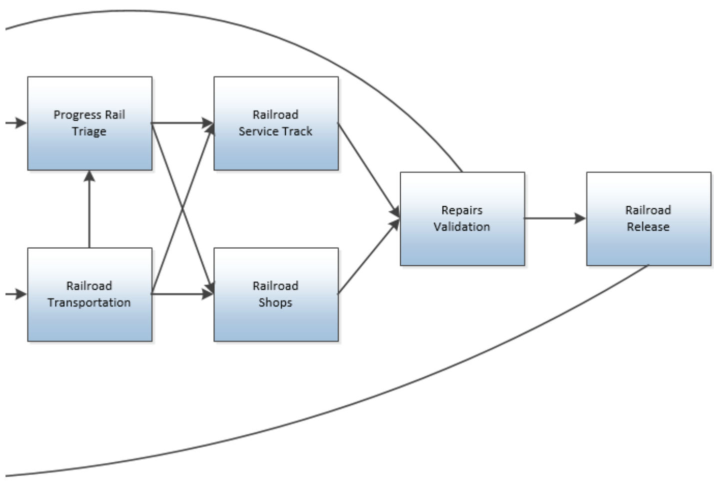
To facilitate the machine learning features of the analytics application and allow work scope refinement along with the creation of additional analytics models, shop feedback on repairs and general maintenance is required. This data is often partially captured in both railroad ERP systems and in the analytics application. Synchronizing this data allows for a clear view of the work scopes completed and the results of the shopping to continue to improve the quality of the analytics models and focused work scopes. By railroads providing the analytics application access to other datasets about the locomotives, such as fluids, wayside and fueling data, machine learning within the application can determine and create new or improve analytics models, thereby driving additional value to the railroads.

The cleansed shopping feedback and close out data validates the analytics application and recommendations. Additionally, the OEM can use this data within its research and design processes to improve and address common failure modes experienced at the railroads, or deploy new sensor packages to better capture and predict pending failures. This ultimately allows the OEM to provide the railroad with an optimized fleet through better maintainability.

Using PR Uptime Cloud to deliver and ingest data from the railroad ERP system allows railroads to take action on pending failures and issues and optimize their shop planning process (e.g. repair on service track or repair in shop).

Efficient Release to Service is The Goal

Railroad ERP systems feed synchronized data into the railroad transportation process to move the locomotives into yards, shops, and to setup trains. The analytics application feeds work scopes and recommendations to the railroad ERP systems and field technicians to support their inspections, triage, repair and release activities.



The analytics application allows the work scope to be created in advance of shopping events. Once the scope of the shopping is known, the ability to shift work from the shop (usually with long cycle times) to the service track (comparatively, quick focused repairs) can greatly improve locomotive fleet availability and reduce delays and costs. Pre-work can be performed to schedule correct resources, stage parts in the appropriate locations, and have railroad transportation teams provide yard access. If the repair can occur on the service track, dwell and the elapsed time can be shortened significantly. Even if a repair must go through the shop, analytics application features, such as virtual load test (VLT) and outbound load test analysis can reduce dwell spent at the shop.

Once the locomotive arrives at the yard, inspection and triage is performed by field technicians prior to shopping or service track repair, to ensure all failure modes have been identified. The recommendations and work scopes are then reviewed and other pre-work performed. After this review, railroad technicians can execute analytics application supplied focused work scopes, instead of standard generic troubleshooting guides, as the analytics application uses synchronized data to shorten troubleshooting steps.

Finally, an outbound load test validates completed repairs. The analytics application analyzes the results of the test, allowing locomotive monitoring analysts to make a recommendation to release or roll-back the locomotive (if the repair is not completed properly). Paperwork is reviewed by field technicians to ensure all necessary steps have been completed, and the locomotive is recommended for release by the railroad. However, should an issue be found, the locomotive may be returned to shop or service track to complete the needed repair, prior to delivery back into service. This reduces the number of repeater failures. If the railroad concurs with the release recommendation, then the locomotive is returned to transportation. Upon release, close out information is entered into the railroad's ERP system and the analytics application, to enable machine learning features of the analytics models.

The simple ability to collect the data pales in comparison to understanding the data and being able to interpret it, if the locomotive is performing as expected. By supplementing the analytics application with OEM knowledge in conjunction, railroads are able to ensure the locomotive is returned to service in the most efficient way.

Data Security

As the amount of data transmitted and shared has increased, higher measures of security requirements have also surfaced. Data security is critical, as railroads safeguard all operational information. Understanding operational, repair, and related information could provide financial and operational advantages to competitors – and it is also a matter of running safe and efficient operations, which is in the best interest of transportation providers.

Data integration requires an increased focus for security of all systems. Security must be considered upfront as integration and data end-points are defined. A number of security standards are relevant to data and data communications.

Conclusion

Locomotive analytics platforms, such as PR Uptime®, have grown in their ability to cover various locomotive failure modes and gain prognostic power over time. This has been driven by growth in new sensor deployments, better data access, advanced locomotive telematics, and a combination of OEM insights and improved modeling techniques.

The key to capturing value from data analytics is to properly integrate data into existing maintenance and operating systems and processes at the railroad. It may also be necessary to create new processes to leverage the output of the data analytics application and its coordinating resources. Integration can be done in an automatic or manual (human) way, but to get maximum value, automated railroad ERP system synchronization with data analytics platform is needed. This ensures that railroad personnel and systems, Progress Rail Field Service Technicians and locomotive analysts have access to all relevant data and are reacting appropriately.

Routine data scrubbing is a key factor in having successful deployments of data analytic tools. In many cases data is cleansed as part of the data ingestion process. Removing erroneous, duplicate, non-relevant human entered data by marrying it with machine data.

In many cases, data is partially captured in both railroad ERP systems and in the analytics application. Synchronizing this data allows for a clear view of the work-scopes completed and the results of the shopping to continue to improve the quality of the analytics models and focused work-scopes.

Using machine learning, new data analytics models or improvements can be generated when railroads provide the analytics application access to other datasets about the locomotives, such as fluids, wayside, fueling and more data. Additionally, the OEM can use this data to design out common failure modes experienced at the railroads or deploy new sensor packages to better capture and predict pending failures. This ultimately allows the OEM to provide the railroad with resources to better optimize their fleets.

Finally, data security needs to be considered upfront as integration and data end-points are defined.

For more information, and to find out how you can tap into data that will deliver results, contact info@progressrail.com.

Acknowledgement

Alex Shubs, Progress Rail

Locomotive Data Publication Standard S-XXXX.V1.0

Prepared by:
Cody Fischer, Canadian Pacific Railway

Table of Contents

1 Introduction

1.1 References

- Edge Message Protocol – S9354 V2.0
- Data Dictionary V1.0 – S-9353

1.2 Purpose

This document standardizes the message protocol for data elements found in Data Dictionary (S-9353). Any device, sensor, recorder, application, etc. that requires the exchange of these data elements should use this standard to either create a message or interpret a message containing these data elements. This protocol uses the envelope structure Edge Message Protocol as defined in S-9354. This standard does not define message transport requirements.

This standard is the second stage in the 3 stage process to facilitate data element exchange. See figure 1.

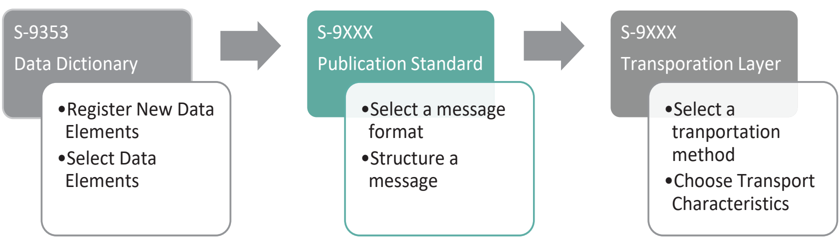


Figure 1: Data Exchange Process

Without this standard, any new AAR ICD's, 3rd party systems, etc. will come up with their own messaging protocols and make it very difficult for analytics tools and data acquisitions systems to integrate.

1.3 Background

With the creation of the LIG to PTC ICD (S-9353), there was born a data dictionary full of data elements. The LIG to PTC ICD describes methods to group those data elements into messages: PTC, DP1 and DP2. The message format is an adaptation from a format described in the EMP protocol S-9354. Other ICD's also use similar methods of sharing data elements, but none are consistent. This fragmentation of standards creates a few problems. First, the EMP standard no longer is the recognized method for organizing data tags into a message (It also should not be as it is an envelope protocol and should not concern itself with the payload). Second, a messaging standard residing in the LIG-PTC ICD, does not allow for use by 3rd party manufacturers and cannot be referenced by other

ICD's. The purpose of this document is to take that fragmentation and unify into one messaging standard that can be used by all. Figure 2 illustrates just a few examples of beneficiaries of this standard.

3rd Party Devices: 3rd party sensors such as Fuel Sensors, Battery Sensors, Compressors, Inertial, Location etc. could all utilize this standard to speak the same language on the locomotive network. Such a standard would incentivize them to design their hardware around a common interface.

Locomotive Control Systems: The control system either through the LIG or LCCM could use this 3rd party sensory data as a means to update its own internal information without the need of an ICD.

LDARS: LDARS devices could be setup to record this sensor data out of the box without any additional firmware developed.

Alerting Agents: Can be developed to work using a common industry standard, again without the exchange of ICD.

UI: User interface tools can be developed to automatically view all the sensory data and work with the LIG or any other 3rd party sensor.

The full scope of this initiate is still in flux as this development is ongoing, however these are a few of the benefits and reasons for this initiative.

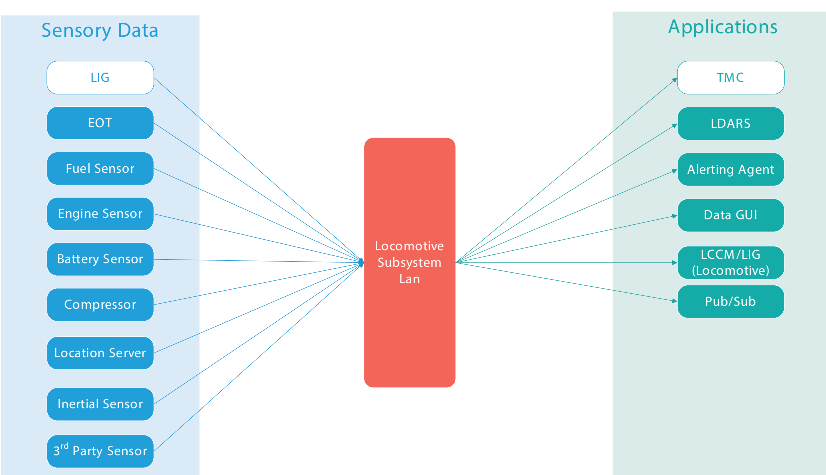


Figure 2: Publication Standard Beneficiaries

1.4 Acronyms and Definitions

EMP – Edge Message Protocol
ICD – Interface Control Gateway
LDARS - Locomotive Data Acquisition Reporting Systems

2 Protocol Format

2.1 Prerequisites

As the process shows in figure 1, the first step in creating a message is selecting the data elements required for that message. Data elements must be selected from the data dictionary found in S-9353. If a specific data element does not exists, a new element can be requested. The data dictionary will provide, among other things, the Data Elements ID, Size and format which will be required to create the message.

2.2 Edge Message Protocol

This standard uses Edge Message Protocol (EMP) as the envelope for the data publication message. The EMP standard found in S-9354 describes how to create the EMP header message as well the Cyclical Redundancy Check (CRC) that follows the EMP body. See Figure 3: EMP Structure. The Data Publication Standard will reside within the EMP body.

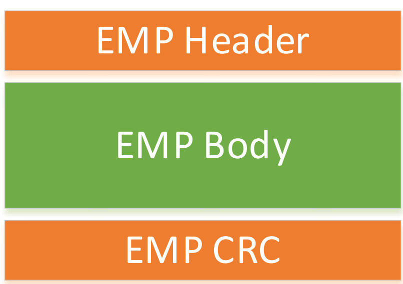


Figure 3: EMP Structure

The message creator shall use the EMP protocol requirements to create the header. All Common Fields (Protocol Version, Message Type, Message Version, Flags and Data Length) are required. Additionally, the Optional Field (Message Number and Message Time) are also required.

Note: The Message Time field can have Relative or Absolute time. If "Absolute Time" is used, the time applied to the tag must represent the time from the "Time Sync Source" in the fixed header found in section 2.3.1.

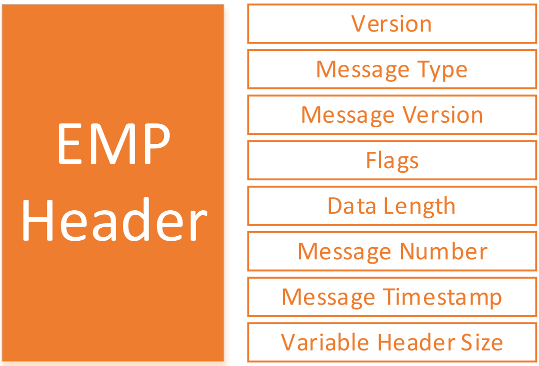


Figure 4: EMP Header

2.3 Data Publication Protocol

The data publication protocol will reside in the body of the EMP message and will be split into two parts: A Data Publication Fixed Header and a Data Element List Format.

2.3.1 Data Publication Fixed Header

The data publication message always requires the following Data Publication fixed header. The fixed header shall be created using the compound data element ID *0xFFFA (found in S-9353 and Appendix A). The compound Data Element is comprised of a tag, size and the values of the following data elements. The full description can be found in Appendix C and the data Dictionary S-9353.

1. Data Dictionary Version: The version of the Data Element Dictionary (S-9353) in which the data element were chosen.
2. Data Publication Fixed Header Version: Version of the 0xFFFA compound data element
3. Manufacturer ID: The identifier of the sending device to help distinguish messages
4. Time Sync Source: This data element will identify the source in which the sending device is using to keep its internal clock synchronized. NTP Time using S-9103 is always preferred. Note: At any point in the message, if a timestamp is applied, it must use the time from the specified time sync source.
5. Data Publication Protocol: This tag specifies the protocol in which the tags will be arranged. See Data Element List in section 2.3.2.
6. Data Publication Version: Version of this document
7. Count: The data elements to follow
8. Validity: The validity value to the fixed header
9. Epoch: The transmission time of the message. Note: this must use the time source specified in the Time Sync Source element.

The Data Publication Fixed Header is shown in green in figure 5.

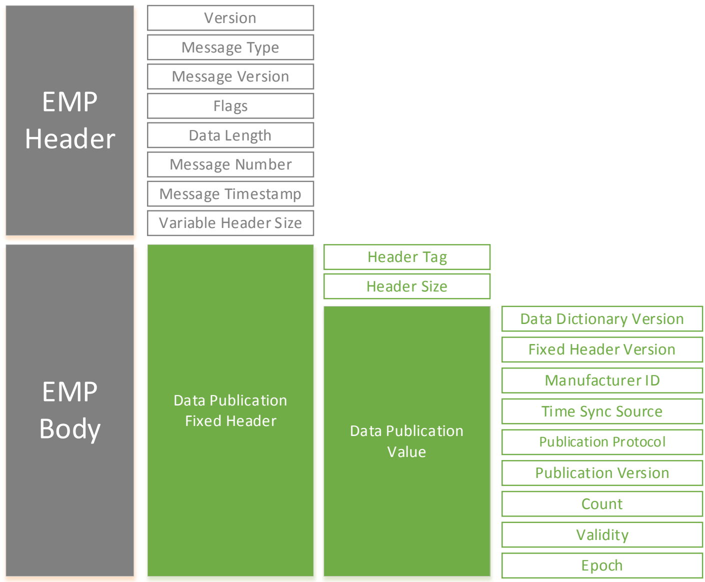


Figure 5: Data Publication Fixed Header

2.3.2 Data Element List Formats

Following the data publication fixed header are the data elements chosen from the data dictionary. Every data element has a tag, a value size and value. Depending on the protocol chosen, one or all of these fields may be required. To arrange the data elements, choose from one of the following arrangement options:

1. Self-Describing with Integrity
2. Fixed Format

The chosen message format shall then be communicated in the **Data Publication Fixed Header** using the **Data Publication Protocol** data element.

2.3.2.1 Self-Describing with Integrity

Self-describing format allows the message reader to traverse the message without knowing the message contents ahead of time. There are several benefits to a self-describing message:

1. Tag Variability: The number of tags within the message does not have to be fixed. The data sender for instance could use this feature to only send tags that have changed if desired.
2. Message Backward Compatibility: With tag variability, comes message backward compatibility. New version of messages or variations of

messages can be created without breaking the original application so long as the original tags still exist.

3. Universal Parser: The application for parsing these messages does not need to know anything about the message ahead of time and can therefore be created to handle any and all messages without modification.

To create a self-describing message, the data element(s) shall be laid out as follows using the ID, Size and Value found in S-9353:

Tag 1 ID (2 Bytes) – Tag 1 Size (4 Byte) – Tag 1 Value (X Bytes)
Tag 2 ID (2 Bytes) – Tag 2 Size (4 Byte) – Tag 2 Value (X Bytes)
Tag n ID (2 Bytes) – Tag n Size (4 Byte) – Tag n Value (X Bytes)

If self-describing format is used, it must be registered in the **Data Publication Fixed Header** using the Data Element Protocol tag.

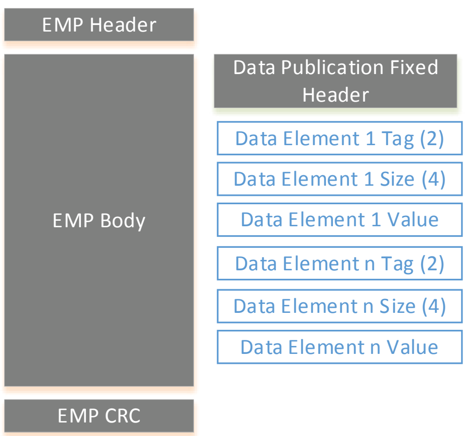


Figure 6: Self-Describing Format

2.3.2.2 Fixed Format

Fixed Format arranges only the values of the tags one after the other and does not have any descriptor about the tag itself. As such, an application reading the message must know its exact arrangement ahead of time. Some of the benefits for a fixed format message are:

1. Predictable Messages: With fixed format, the message size is fixed. This is beneficial for security purposes as any message that does not match the expected size can be discarded. It also helps with application design as there will be any variability reading time.
2. Shorter Message Length: With only the value fields, messages can be significantly shorter.

To create a fixed message, data element values are to be placed one after the other in a fixed order as follow:

Tag 1 Value (X Bytes)
Tag 2 Value (X Bytes)
Tag n Value (X Bytes)

If fixed format is used, it must be registered in the **Data Publication Fixed Header** using the Data Element Protocol tag.

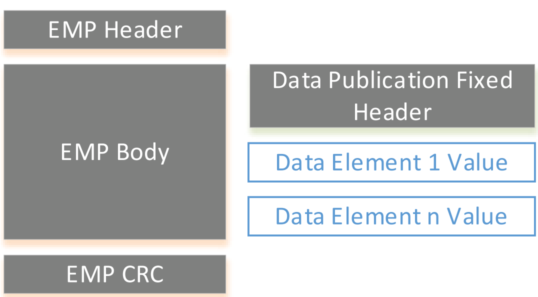


Figure 7: Fixed Format

2.3.3 Data Integrity

Data integrity information can be added to each data element value in cases where it is required. If a data integrity option is chosen, it must apply to all data elements in the message.

The data integrity option chosen must be registered in the **Data Publication Fixed Header** using the Data Integrity tag. The following data integrity options are available:

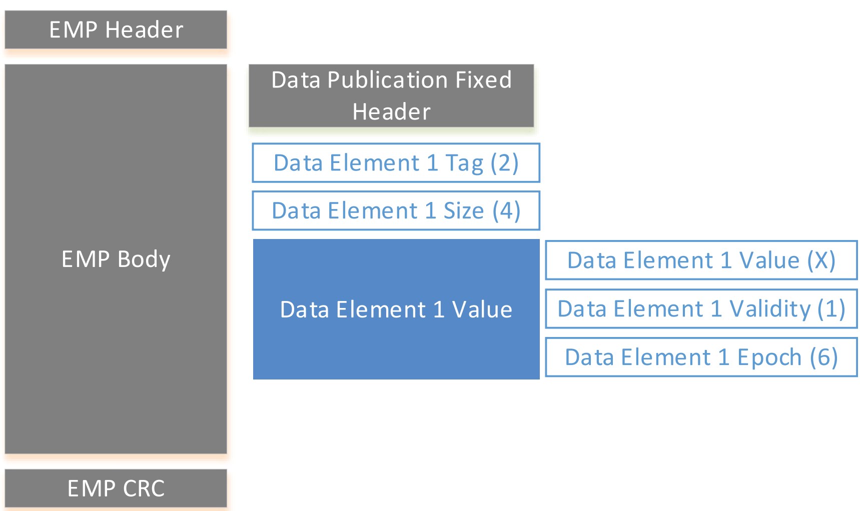
1. Value Only
2. Value + Validity + Epoch

2.3.3.1 Value Only

If this option is chosen, only the value of the data element is contained in the value field of each data element.

2.3.3.2 Value + Validity + Epoch

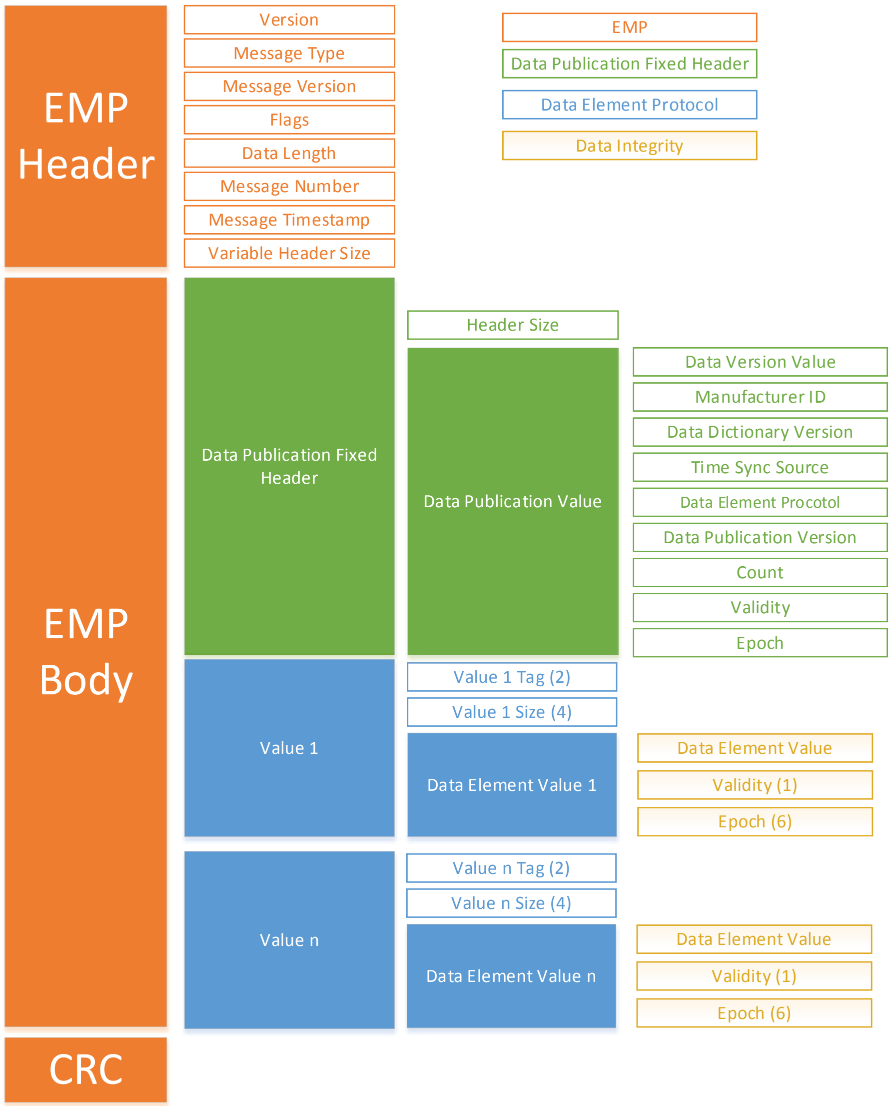
If this option is chosen, the value field for each data element will be split into 3 parts: Value, Validity and Epoch.



Note: Adding Validity (1 byte) and Epoch (6 bytes) will increase the size of the value by 7 bytes. When creating a self-describing message, the tag value size must therefore be increase by 7 bytes from its original size. It is also important to understand this when reading messages

2.4 Full Example

Full example using self-describing protocol with validity-epoch data integrity.



3 Recommendations

This standard aims to unify the industry for the sharing and collection of sensory data. It provides a small barrier for entry to devices looking to participate on the locomotive network. It allows cross platform systems integration out of the box and a standard to data acquisitions systems to build to.

This initiative has been approved in the AAR to proceed as task force to further develop this standard. The taskforce will shape the scope of this standard, as well as solidify the contents of this message. This standard will not make it to completion unless there is sufficient interest from railroads and vendors alike. For that reason, if you feel this initiative is worthwhile and would like to contribute or ask questions, please reach out to me at:

Cody_Fischer@cpr.ca

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Constitution and By-Laws Locomotive Maintenance Officers Association

Revised October 3, 2016

Article I – Title:

The name of this Association shall be the Locomotive Maintenance Officers Association (LMOA).

Article II – Purpose of the Association

The purpose of the Association, a non-profit organization, shall be:

- to improve the interests of its members through education,
- to supply locomotive maintenance and technical information to Association members and their employers,
- to exchange knowledge and information with members of the Association,
- to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad industry.

Article III – Membership

Section 1 – Railroad Membership shall be composed of persons currently or formerly employed by a railroad company and interested in locomotive maintenance. Membership may be subject to approval by the General Executive Committee.

Section 2 – Associate Membership shall be composed of persons currently or formerly employed by a manufacturer of equipment or devices used in connection with the maintenance and repair of motive power. Membership may be subject to approval by the General Executive Committee. Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at the Annual Meeting, serving on Association committees and shall have the privilege of voting and holding elective office.

Section 3 – Life membership shall be conferred on all Past Presidents. Life membership may also be conferred on others for meritorious service to the Association, subject to approval by the General Executive Committee.

Section 4 – Membership dues for individual railroad and associate membership shall be set by the General Executive Committee and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end September 30. Members' whose dues are not paid on or before the opening date of the annual convention are subject to being prohibited from attending the annual meeting, shall not be eligible to vote and may not be entitled to receive a copy of the published Pre-Convention

Report or the Annual Proceedings of the annual meeting. Failure to pay membership dues within a reasonable amount of time will result in loss of membership. Life members will not be required to pay dues, and will be entitled to receive a copy of the Pre-Convention Report and Annual Proceedings.

Article IV – Officers

Section 1 – Elective Officers of the Association shall be President, First Vice President, Second Vice President and Third Vice President. Each officer will hold office for one year or until a successor is elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, continue to serve as an elective officer and be allowed to elevate through the ranks as naturally occurs, to include the office of President.

Section 2 – There shall be one Regional Executive officer assigned to oversee each technical committee. Regional Executives shall be appointed from the membership by the General Executive Committee for an indefinite term, with preference given to those having served as a Technical Committee Chairperson. A Regional Executive who leaves active service may continue to serve as such, and shall be eligible for nomination and election to higher office.

Section 3 – There shall be a General Executive Committee composed of the President, Vice Presidents, Regional Executives, Technical Committee Chairpersons, and all Past Presidents remaining active in the Association.

Section 4 – There shall be a Secretary-Treasurer appointed by and holding office at the pleasure of the General Executive Committee, who will contract for his or her services with appropriate compensation.

Section 5 – All elective officers and Regional Executives must be LMOA members in good standing. (See Article III, Section 4.)

Article V – Officer, Nomination, and Election of

Section 1 – Elective officers shall be chosen from the active membership. A Nominating Committee, composed of the current elective officers and the active Past Presidents, shall submit a slate of candidates for each elective office at the annual convention.

Section 2 – Election of Officers shall be determined by a voice vote, or if challenged, it shall require a show of hands.

Section 3 – Vacancies in any elective office may be filled by presidential appointment, subject to approval by the General Executive Committee.

Section 4 – The immediate Past President shall serve as Chairman of the Nominating Committee. In his absence, this duty shall fall to the current President.

Article VI – Officers- Duties of

Section 1 – The President shall exercise general direction over all affairs of the Association and approve expenditures subject to availability of funds.

Section 2 – The First Vice President shall, in the absence of the President, assume the duties thereof. He shall additionally be responsible for arranging a mid-year joint meeting of the Association, preferably to be held in the early part of May.

Section 3 – The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers required to underwrite the cost of the Annual Proceedings.

Section 4 – The Third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly prepared and distributed, monitoring membership levels and reporting same at appropriate times to the General Executive Committee.

Section 5 – The Vice Presidents shall perform such other duties as are assigned them by the President.

Section 6 – The Secretary-Treasurer shall:

A. Keep all the records of the Association.
B. Be responsible for the finances and accounting thereof under the direction of the General Executive Committee.
C. Perform the duties of Secretary of the Nominating Committee and General Executive Committee, without vote.
D. Furnish surety bond in the amount of $50,000 on behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.
E. Arrange the schedule for presentation of technical reports at the annual convention and coordinate same with the other associations to minimize conflict.
F. Serve as liaison for the LMOA with other associations
G. Arrange for publications of the LMOA Annual Proceedings.

Section 7 – The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.
B. Monitor material to be presented by the technical committees to ensure reports are accurate and pertinent to the goals of the Association.
C. Attend and represent LMOA at meetings of their assigned technical committees.
D. Promote Association activities and monitor membership levels within their assigned areas of responsibility.
E. Promote and solicit support for LMOA by helping to obtain advertisers.
F. Train new Committee Chairpersons on LMOA procedures and bylaws. Mentor and support Chairpersons.

Section 8 – Duties of General Executive Committee:

A. Assist and advise the President in long-range Association planning.
B. Contract for the services

and compensation of a Secretary-Treasurer.

C. Serve as the Auditing and Finance Committee.

D. Determine the number and name of the Technical Committees.

E. Exercise general supervision over all Association activities.

F. Monitor technical reports for material considered unworthy for publication or inaccurate.

G. Approve the tentative schedule and list of topics to be presented at the annual convention and published in the Annual Proceedings.

H. Exercise authority to disapprove, for just cause, any new committee member or other item submitted for its approval. Such member or item will stand approved as submitted if the General Executive Committee declines to act.

I. Handle all matters of Association business not specifically herein assigned.

J. Handle all public relations decisions within LMOA and coordinated associations with confidentiality.

Article VII – Technical Committees

The technical committees will consist of:

Section 1 – A chairperson appointed by the President and approved by the General Executive Committee.

Section 2 – A vice chairperson selected by the chairperson and approved by the President.

Section 3 – Committee members, selected as follows:

A. Representatives of operating railroads and regional transit authorities submitted by their Senior Mechanical and Materials Officers and approved by the President of LMOA.

B. Representatives of locomotive builders designing and manufacturing locomotives in North America submitted by their perspective company and approved by the Committee Chairperson.

C. The Fuel, Lube and Environmental Committee will include members from major oil additive companies or their subsidiaries submitted by their perspective company and approved by the Committee Chairperson.

D. As needed, the Committee Chairperson may invite other non-railroad personnel to participate in committee activities on either a limited time or permanent basis

E. The Chairperson will submit the name of perspective new committee members to the Executive Committee which reserves the right to approve or disapprove membership.

F. Companies are allowed a primary and alternate member on committees at the Chairperson's discretion.

Section 4 – All individuals who are on technical committees must be LMOA members in good standing. (See Article III, Section 4.)

Section 5 – Each technical committee shall prepare one or more technical reports for presentation at the annual meeting and publication in the Annual Proceedings. Oral presentations should include the use of slides, videos, or other media as appropriate to the subject.

Section 6 – Subjects for technical papers will be selected and approved by the General Executive Committee.

Article VIII – Proceedings

Section 1 – The Locomotive Maintenance Officers Association encourages the free interchange of ideas and discussion by all attendees for mutual benefits to the railroad industry. It is understood that the expression of opinion, or statements by attendees in the meeting, and the recording of reports containing the same, shall not be construed as representations or statements ratified by the Association.

Section 2 – Those present at any meeting called on not less than thirty days advance written notice shall constitute a quorum.

Article IX – Rules of Order

The proceedings and business transactions of this Association shall be governed by Robert's Rules of Order, except as otherwise herein provided.

Article X – Amendments

The Constitution and By-Laws may be amended by a two-thirds vote of the active members present at the Annual Meeting.


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