COALITION for SUSTAINABLE RAIL

Steam Locomotive Rail Wheel Dynamics Part 1: Precedent Speed of Steam Locomotives

John T. Rhodes, David R. Stephenson

Edited Ing. W.A. Fengler and D.A. Ward

About the Coalition for Sustainable Rail

The Coalition for Sustainable Rail (CSR) is dedicated to the refinement of solid biofuel technologies for use in the world's first carbon-neutral higher speed locomotive. Our team is a combination of the University of Minnesota and Sustainable Rail International (SRI), a 501c(3) nonprofit dedicated to the research and development of modern steam locomotives. A scientific and educational organization, CSR's mission is to advance biofuel research and production; to research and develop sustainable railroad locomotives; to promulgate associated sustainable technologies; and to support and conduct non-partisan educational and informational activities to increase awareness of sustainable railroad locomotives.

About CSR's White Paper Program

Working in conjunction with the University of Minnesota (U of M), the Porta Family Foundation, and other not-for-profit rail and biomass research organizations, CSR's White Paper Program is bringing works pertinent to biofuel, modern steam locomotive and transportation research into the public discourse.

Acknowledgements

A portion of the text provided by David R. Stephenson for use in this paper was written originally for publication in the PRR Historical Society newsletter. He received all PRR correspondence and schedule data courtesy Hagley Museum and Library. CSR would like to acknowledge the assistance of the following people who were involved in the extensive background research for this paper: Marge McNinch & Chris Baer, both at Hagley Library; Abram Burnett, Harry Bundy, Gordon Hamilton, Bud Jeffries, Robert Johnson, Ed King, Ken Miller, Louis Newton and Frank Wrabel. Their help in locating sometimes obscure documents and small yet significant details made this analysis possible. CSR would also like to thank Bruce Fingerhood for use of his images of 611 from its operations in the 1980's in this report; his eye for photography helped bring this document "to life."

Cover Photo - *Sister locomotive to that tested in 1944, locomotive 611, pulls an excursion train in the late 1980's on the Norfolk and Southern Railway near Clifton, Virginia. - Bruce Fingerhood Photo*

Steam Locomotive Rail Wheel Dynamics Part 1: Precedent Speed of Steam Locomotives

John T. Rhodes and David R. Stephenson

Edited Ing. W.A. Fengler and D.A. Ward

Foreword

Dear Reader:

The Coalition for Sustainable Rail (CSR) has received a few pointed questions about the feasibility of a modern steam locomotive to operate efficiently and safely at higher speeds since announcing "Project 130" in May 2012. That in mind, it has decided to formulate a two-part white paper on steam locomotive speed and rail dynamics: 1.) Precedent Speed and 2.) Primer on the Mechanical Balancing of Steam Locomotives. This paper focuses on the anecodotal history of traditional steam locomotives at speed, while the next paper will provide an in-depth engineering investigation of locomotive wheel balancing and engineering.

The current interest in the Norfolk & Western Railway (N&W) J Class steam locomotive, due to the recent announcement of the Virginia Museum of Transportation's *Fire Up 611* committee to investigate the feasibility of restoring locomotive 611 to operation, provides an ideal segway into a solid precedent on steam locomotives at high speed. In this white paper, the high-speed performance of the N&W Class J will be explored. While the 3460-class of locomotives, of which CSR's 3463 is a member, were well suited to running at 100+ miles per hour, I thought it valuable to take lessons learned from the Class J, which has 14" smaller diameter driving wheels and could attain similar operational speeds.

It is also worth mentioning that the Norfolk and Western Class J was perhaps one of the most advanced steam locomotives of the traditional era, specifically with respect to ease of servicing, maintenance cost and reliability. To that point, CSR provides further information into steam vs. diesel tests undertaken by the Norfolk and Western Railway and Southern Railway in the late 1940's, as well as what impact that data has to-date.

Please enjoy this first of two white papers and, as always, consider supporting the mission of the Coalition for Sustainable Rail through a U.S. tax-deductable donation on our website or by mail.

Sincerest regards,

John T. Rhodes

Vice President & Treasurer

Summary:

ooOOOoo

1. **PRR's Interest in N&W Js**
2. **PRR Tests N&W Locomotive 610**
3. **Evaluation of 610's Performance**
4. **Norfolk & Western and Southern Railway's Steam vs. Diesel Maintenance Comparison**
5. **Modern Steam: What's Next?**
6. **Conclusion**

ooOOOoo

1. PRR's Interest in N&W Js

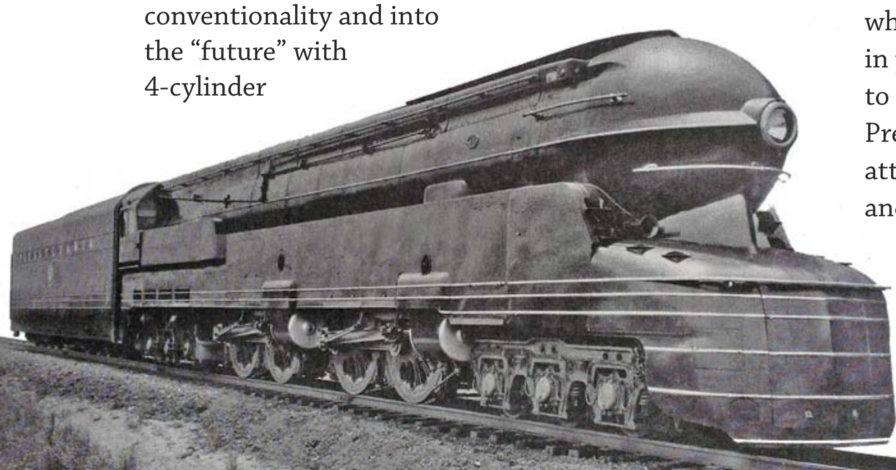
In the late 1930's, the Pennsylvania Railroad (PRR) was busy testing and engineering its S1-class 6-4-4-6, later of New York World's Fair fame [BELOW]. During over-the-road tests it demonstrated a turn of speed but, despite extensive engineering, its enormous size proved considerably impractical. The railroad was displeased with its overall performance and, in turn, PRR began to develop a pair of duplex-drive, 4-4-4-4's based on a Baldwin concept. These would become the T1 prototypes referenced in the CSR white paper: *The Case for the Modern Steam Locomotive*.

Around the time PRR turned its design attention to the T1, the first five Norfolk & Western (N&W) Class Js had been constructed, between October 1941 and January 1942. The first PRR T1 6110 was completed in April 1942, a few months later. Both of these locomotives had four driving axles and distinctive streamlining. But, the similarities ended there. Although totally modern and highly refined, the N&W J was a conventional locomotive. The PRR T1, however, was an attempt to jump past conventionality and into the "future" with 4-cylinder divided drive and poppet valve gear. Both the J and T1 were designed for their respective road's passenger service but, as it turned out, these requirements were at opposite ends of the operating spectrum.

PRR No. 6110 was tested on the Altoona, Pennsylvania test plant from late April through early July 1944, where it generated very impressive performance statistics. Translating this test performance into daily practicality, however, proved to be not so simple.

In September 1944, John F. Deasy, Vice President - Operations, commented: "The T1 locomotive is not performing well on the Railroad." That one-sentence memo to H. W. Jones, Chief of Motive Power, said it all. Over-the road tests indicated the locomotives could attain exceptional performance levels with thorough preparation and careful handling, but neither of these seemed to be available on a consistent basis.

PRR President, Martin Clement asked his staff whether the N&W's Class J would be suitable for use in passenger service on the PRR as a solid comparison to the new PRR design. James W. Symes, PRR Vice-President, Western Region, noted the locomotive's attributes – high boiler pressure, roller bearing axles and link motion and many more features. Deasy agreed to a future test.



Left - *PRR Promotional Photograph of its S1, from the 1941 Locomotive Cyclopedia.*

Locomotive 611 at Irondale, Alabama during its excursion service - Library of Congress

In early November 1944, N&W's Robert H. Smith, then Vice President - Operations, agreed to provide a Class J for testing by PRR. By mid-month, PRR accepted the offer and proposed testing a J on a 30 day cycle, operating between Harrisburg, Pennsylvania and Chicago/St. Louis. An in-house analysis of a J's dynamic augment at 95 mph indicated that its highest wheel load was less than PRR's restrictions. This cleared the way for testing at speeds of 90 to 100 mph.

Due to clearance limitations, however, all tests were run west of Crestline, Ohio, with certain locations near Chicago being off-limits (mainly due to bridge clearances). This would not seem to have been the best area for the J, a locomotive designed to operate at moderate speeds through the mountains, not at high speeds across the plains. The test proved otherwise.

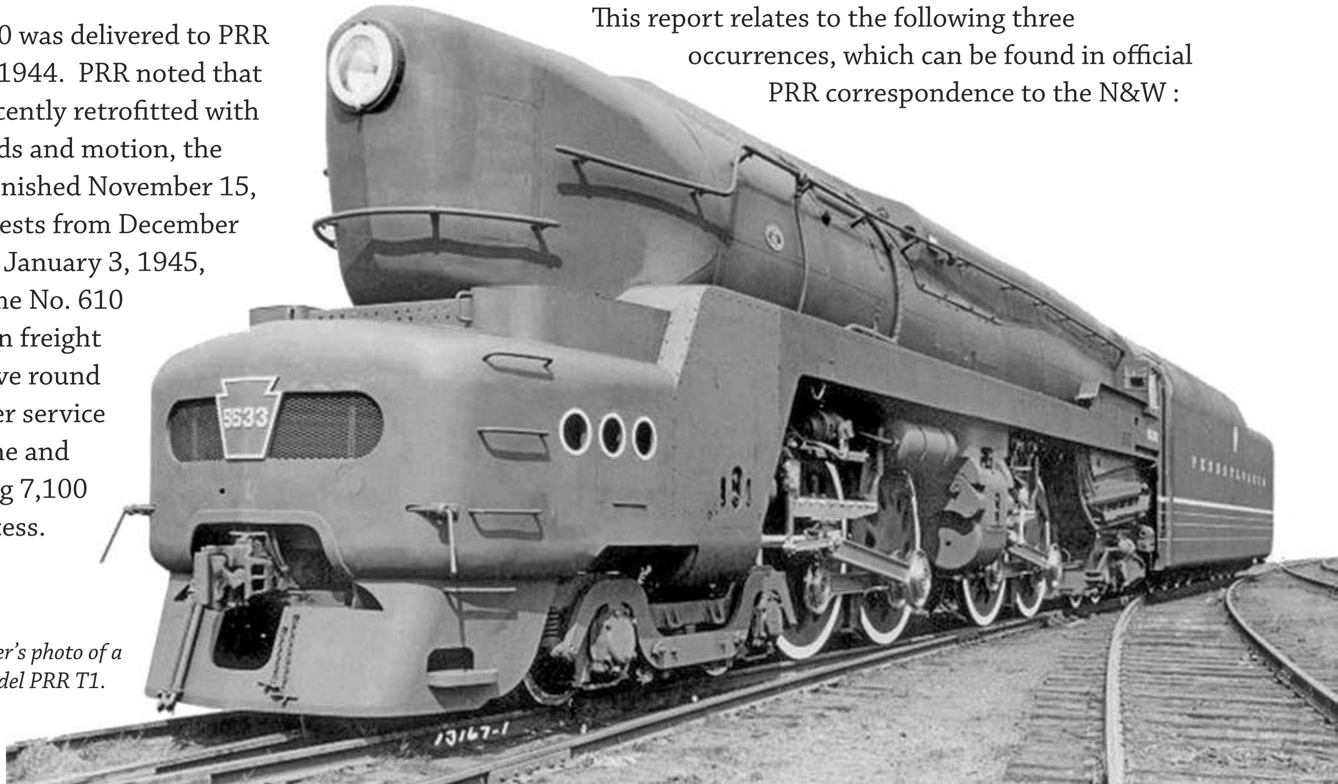
2. PRR Tests N&W Locomotive 610

N&W Class J 610 was delivered to PRR on December 4, 1944. PRR noted that 610 had been recently retrofitted with roller bearing rods and motion, the work had been finished November 15, 1944. PRR ran tests from December 5, 1944 through January 3, 1945, during which time No. 610 made two trips in freight service and twelve round trips in passenger service between Crestline and Chicago, covering 7,100 miles in the process.

The number of passenger cars hauled varied from 9 to 16. These tests were on regularly scheduled trains, not special test runs, and included PRR named trains such as the famous Broadway Limited, General, Admiral, and Liberty Limited. With the exception of one trip, 610 shuttled back and forth between Crestline and Chicago without mechanical difficulty.

All of the runs were made with regularly scheduled PRR passenger trains and there were several references to very high speeds. On one run, an average of 94 MPH was sustained over 45 miles and PRR test reports written by two of the Assistant Road Foremen involved in the tests outline that engineers on the N&W test locomotive "...we were able to operate with this low driver [diameter] at speeds up to 111 miles per hour, and had no trouble whatever operating this locomotive for distances of 45 to 50 miles and averaging 80 miles per hour or better."

This report relates to the following three occurrences, which can be found in official PRR correspondence to the N&W :



Right - *Baldwin builder's photo of a production-model PRR T1.*

12/7/44 – 110 mph, train 71, The Admiral, westbound Crestline-Chicago, 15 cars
12/8/44 – 111 mph, train 57, Liberty Limited, westbound Crestline-Chicago, 11 cars
12/8/44 – 109 mph, train 28, Broadway Limited, eastbound Chicago-Crestline, 13 cars

At 111 mph, 610's 70-inch drivers were turning at 533 rpm, or 8.9 revolutions every second. This is perhaps the highest operating speed actually documented on a 4-8-4 in regular passenger service.

How would this compare to locomotive 3463, which has 84-inch diameter driving wheels? Since the mechanical rotational speed of a traditional steam locomotive is limited to a set number, generally somewhere between 504 and 525 RPM, the maximum speed is therefore governed by the size of the driving wheels.

As built, Baldwin and Santa Fe designed the 3460-class locomotives to have the potential for great power at great speed. At the same rotational speed as the Class J at 111 miles per hour, the 3460-class locomotive would have a speed of 133 miles per hour, with a slower piston speed (due to its shorter stroke).

These numbers, the feasibility of this speed and details of its impact on track structure will be addressed in the following white paper in this series. It is important to note, however, that the locomotive class was advertised by Baldwin to have a top speed of 120 mph [BELOW], and was designed with 1930's engineering. With better balancing and computer simulation, that number will surely increase.

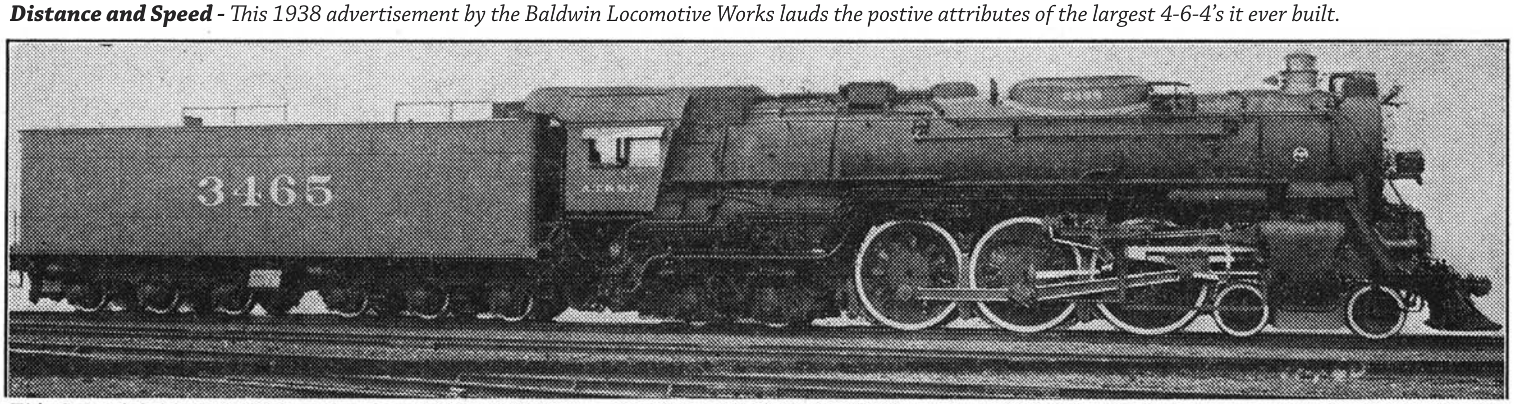
3. Evaluation of 610's Performance

PRR personnel wrote several evaluations about 610's performance during the month-long series of tests, and all were very positive. Because of the thorough nature of the test reports and the fact that they are original source documents from the men who were involved in the tests, they are presented here largely unedited. It's extremely unusual that such first-hand technical evaluations survive to the present.

The first was written by L. B. Jones, PRR Engineer of Tests, to his superior, H. W. Jones, Chief of Motive Power, January 6, 1945:

> *.....The best run made was with train No. 71 on December 7th when, hauling 15 cars, the time from Fort Wayne to Bart was 1 hr. and 34 min., compared with the scheduled time of 1hr. and 55 min. Very little time was made up on any of the few runs that were made with 16 cars. On two trips with train No. 28 and 13 cars, the time made up was 17 min. and 25 min. from Bart to Crestline.*
>
> *Riding Qualities:*
> *Our inspector reports that the locomotive rides very smoothly, and it is the consensus of the Fort Wayne Division that it rides better than any of our own locomotives except S1 locomotive No. 6100.*
>
> *Traction:*
> *At slow and medium speeds it is more powerful than any passenger locomotive used on the Fort Wayne Division. Its tractive power is somewhat higher and it is not a slippery locomotive, with the result that it accelerates the train at a higher rate.*

Distance and Speed *- This 1938 advertisement by the Baldwin Locomotive Works lauds the postive attributes of the largest 4-6-4's it ever built.*



This Great 4-6-4 Is One of Five (Nos. 3461-3465) Recently Completed by Baldwin for the Santa Fe. With 23½ x 29½-Inch Cylinders, 84-Inch Drivers, 300 Lbs. Pressure, Weight of 412,380 Lbs. (without Tender), and Exerting 49,300 Lbs. T. F., They Are the Largest and Heaviest of Their Type, Can Pull a Heavy Train at 120 Miles an Hour. Last December No. 3461 Hauled Mail Train No. 8 All the Way from Los Angeles to Chicago without Change, Making the Longest Continuous Run on Record for a Steam Engine. The Weight of the Train Varied from 757 to 939 Tons. No Speed Record Was Tried for, Since the Train Was on Regular Schedule (Running Time Was About 49 Hours for the 2228 Miles)

__Speed:__
The locomotive is equipped with a speedometer which we did not calibrate but speeds of over 100 m.p.h. were reported. On one trip an average speed of 94 mph was maintained for 45 miles. This locomotive has valves of large diameter and long travel, giving large port openings at short cutoff. It is this feature that made these high speeds possible in spite of the fact that the diameter of the driving wheels is only 70 in.

__Steaming Capacity:__
The locomotive steams very well, much better than the T1, and does so even with a rather poor grade of coal. This can be attributed largely to the grate, which is 18 percent larger than that of the T1.

__General Comment:__
The Norfolk & Western locomotive is a conventional locomotive of very good design, embodying such desirable features as a large boiler, large valves with long travel, and roller bearings on the rods and all journals. With 80 in. driving wheels, its dimensions would be quite similar to those of a Santa Fe 4-8-4 type passenger locomotive.

On January 15, A.B. Long and H.H. Neal, Assistant, Road Foremen of Engines wrote a second detailed commentary in a memo to J.A. Warren, Road Foreman of Engines, Fort Wayne Division:

We find that this locomotive has made the schedule or better on our fastest and heaviest passenger trains operated between Crestline and Chicago, and Chicago and Crestline that require two Class K4 locomotives to handle.

The large valves, long valve travel, big firebox and big boiler capacity is responsible for this high acceleration, making it possible to maintain a uniform steam pressure at high speed. We had no trouble getting sand on rails, and engine does not slip unless rail is in very bad condition. Also, all slides were removed from the tender of this locomotive, which we figure is very beneficial and fuel saving. No hot parts developed, which proves that proper lubrication and roller bearings are essential for successful operation. This locomotive rides exceptionally smooth at all speeds. This large firebox is evidence that an inferior grade of coal can be used successfully as we witnessed no steam trouble at any time, although we used stored and Indiana coal when a better grade was not available.

We are aware of the fact that this locomotive is equipped with a low driver of 70", nevertheless it is proven it can make better time and faster schedules. We are curious to know how a locomotive of this class would perform with 76" to 80"drivers.

J.W. Symes wrote the fourth evaluation Jan 22, 1945 in a memo to H.W. Jones. He added perspective regarding the benefits of roller bearings and accessibility for inspection and servicing:

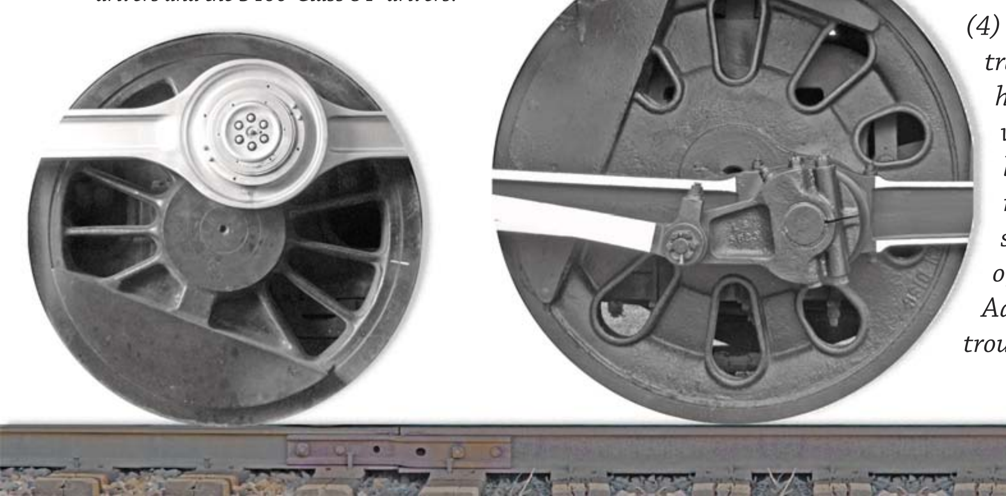
A summary of the opinions expressed by the people who either operated, rode or maintained this locomotive indicates that they were well pleased with its performance. The main points brought out are as follows:

(1) Quicker turning of locomotive in enginehouse territory due to roller bearing application speeding up lubrication work

(2) Ability to clean fire at the end of each trip, without having to examine locomotive, account reports of low steam. Sufficient leeway in grate area and heating surface in this locomotive to provide safe margin in production of steam

(3) Construction of the engine is such that there are few parts not accessible to ready inspection and repair of the engine in the enginehouse

(4) This locomotive successfully handled such trains as 57, 77, 56, 76, and 28 with ease, hauling 15 and 16 cars. Only one failure was experienced, and that was after the locomotive had run approximately 2100 miles, when the valve gear on the left side failed, which we attribute to loss of lubrication in the left valve chamber. Additional oil was provided and no further trouble experienced.



Big and small - *The Class J features 70" drivers and the 3460-Class 84" drivers.*

Home turf - *Class J locomotive 611 pulls an excursion train through Crum, West Virginia in this 1986 photograph on a mountainous line as it was designed to operate. - Bruce Fingerhood Photo*

(5) Locomotive was equipped with manual blowdown and enabled crews to successfully handle the carrying over of water.

During the test period, the J acquitted itself very well, earning high praise from all those involved in the tests. It made or bettered the schedule with PRR's heaviest and fastest trains, accelerated these trains quickly, rode smoothly at all speeds, steamed well with a clear stack at high demand rates, was easy to inspect and maintain, and operated at speeds up to 111 mph.

After the tests, N&W 610 went back to home rails and contributed to the J's well-deserved reputation for reliable and economical service for another 14 years.

4. Norfolk & Western and Southern Railway's Steam vs. Diesel Maintenance Comparison

The train handling performance of the Class J was not the only aspect of its characteristics that were put to the test by comparative studies with other railroads. Similar to the PRR example discussed above, the N&W and Southern Railway were interested in how the maintenance costs of new diesel-electric locomotives compared with those of contemporary steam locomotives.

On September 28, 1945, the N&W and the Southern Railway signed a memorandum of understanding to exchange maintenance cost information that would allow for a comparison between the 1941-built N&W Class J steam 4-8-4 and 1941-built EMD E6 diesel-electric passenger locomotives. The comparison was based on two 5,000 horsepower Class J steam locomotives (numbers 600 and 601) and two E6A-E6B pairs totaling 4,000 HP per pair (numbers 2900+2950 and 2901+2951).

The Class J's were assigned to round trip runs of 504 miles between Roanoke and Norfolk, Virginia and the E6's were assigned to one-way runs of 552 miles between Bristol and Memphis, Tennessee. In order to maintain accurate record keeping, the locomotives used in the cost comparison were restricted to specified services and terminals, all locations where cost accounting could be tightly controlled in support of maintaining accuracy of the cost comparison.

The maintenance comparison was carried out over a year-and-a-half, between November 1945 and March 1947, and focused on five primary areas:

1) Locomotive availability,
2) Locomotive utilization,
3) Cost of repair per 100 locomotive miles,
4) Cost of servicing per 100 locomotive miles and
5) Cost of lubrication per 100 locomotive miles.

In all categories and in total, except for lubrication cost, the N&W Class J outperformed the EMD E6. The Class J had two percent better availability and nine percent better utilization. The Class J's cost of repair per 100 locomotive miles was 32% less than the Southern EMD E6. The Class J's cost of servicing per 100 locomotive miles was 26% less than the EMD E6. The Class J's cost of lubrication per 100 locomotive miles, however, was 33% more than the EMD E6. Of note, the Class J's total cost per 100 locomotive miles was 29% less than the EMD E6.

When railway officials plotted accumulated total maintenance costs, it revealed an interesting pattern. The Southern E6 diesel-electric locomotive maintenance cost per 100 locomotive miles would rise steadily between heavy overhaul, but the accumulated costs would rise substantially. In contrast, the Class J exhibited a more substantial increase in cost due to heavy overhaul with costs falling after rebuild, exhibiting fewer ongoing repairs to be required between heavy overhauls compared to the diesel. This means over the lifespan of the locomotives, the Class J would be significantly less expensive to maintain than the diesel-electric.

Despite the results of this study, which clearly showed the Class J steam locomotive to be roughly 30% less expensive than a comparable set of two E6 diesel-electric locomotives to maintain, Southern dieselized its entire fleet of locomotives in 1951, the first major railroad to do so.

It should be noted, however, that the newest steam locomotive in Southern's fleet were of 1920's design and had little in common with the efficiency of the N&W Class J. In contrast, Norfolk and Western was the last major railroad to switch from steam power, relying upon its vast coal reserves and advanced steam locomotives to carry it to 1960.

5. Modern Steam: What's Next?

What has been described in the preceding text about the N&W Class J, leads to two questions:

1. Was the N&W Class J an uncommonly good design that was capable of incredible performance in many of its aspects?
2. Is more research and development in to passenger steam locomotives warranted? Yes!

To the first point - while it is true that the steam locomotive, as many understand them in the US, had short comings, the average US steam locomotive that was replaced with a diesel-electric locomotive at the end of the steam era had little in common with the N&W Class J, a locomotive replete with non-fabricated frames (one-piece cast), roller-bearings on all axles and motion and complete mechanical and pressure lubrication with modern servicing facilities that reduced labor expenditures. This fact in mind, it is reasonably safe to say that the majority of steam locomotives and infrastructure that were replaced by diesels were outmoded and needed to be replaced, but for a variety of reasons on post World War II US railroads, diesel-electrics were selected as the replacements and not more advanced steam locomotives.

The experiences of the Class J with respect to machinery speed are useful in both understanding what is reasonable with respect to testing a locomotive that was originally built in the same era, CSR's 3463, as well as being useful information in the design of a new-build locomotive. Comparing the N&W Class J, on the 111 mph run, the driver RPM, with new unworn tires, would be 533 RPM, though likely the tires were not new and the RPM was higher. This 533 RPM would have yielded a piston speed of 2,843 feet/minute. CSR plans to test its rebuilt testbed locomotive, former A.T. & S.F. 3463, at up-to 130 mph. This equates to an RPM of only 520 and a lower piston speed of 2,558 feet/minute. As can be seen the N&W Class J sets a precedent for the machinery speeds CSR means to obtain during its test regimen.

Also important to note is that research on the topic of the steam locomotive didn't end with the dieselization of the US railroads. Because of the continued developments on the topic of the steam locomotive over the past 70 years, CSR is confident the modern steam engine is worth investigating in the current time as a passenger locomotive as well as small scale, off-grid, power generation.

The main driving force behind the development of the steam locomotive after the end of US Class I steam operations is Livio Dante Porta, born in 1922, who was an Argentinean mechanical engineer. At the age of 27 (in 1949), he built his first steam locomotive, nicknamed "Argentina." Argentina was the most thermally efficient steam locomotive, more than double the thermal efficiency of a standard US steam locomotive. "The importance of Livio Dante Porta to the survival of the steam locomotive into the 21st century, and to any possible future large scale revival of its use, is difficult to exaggerate," stated George Carpenter, translator of Andre Chapelon's book La Locomotive A Vapeur.

Porta, who died in 2003, developed numerous advances in steam locomotive engineering, with three being crucially important parts of a truly modern steam locomotive:

- Clean high efficiency combustion – Gas Producer Combustion System (GPCS)
- High efficiency exhaust – Kylpor, Lempor & Lemprex
- Heavy-duty boiler water treatment, known as Porta Treatment (PT)

A close friend and following in his footsteps was David Wardale, who in 1981 transformed the South African Railway 4-8-4 #3450 into the SAR Class 26, nicknamed the Red Devil. He raised the drawbar horsepower (DBHP) from 2,500 to 4,000, a 60 percent increase, and increased the efficiency to close to double the thermal efficiency of US steam, utilizing GPCS, Lempor Exhaust and Porta Water Treatment, while decreasing fuel and maintenance costs substantially.

Following in Porta's footsteps and a colleague of David Wardale's, Shaun McMahon, CSR Director of Engineering, is an internationally-renowned modern steam locomotive mechanical engineer. Managing the intellectual estate of the Porta Family and working at the National Institute of Industrial Technology (INTI) in Buenos Aires, the same organization where Porta worked and developed many of his improvements, McMahon is the ideal leader of engineering modifications to CSR locomotive 3463.

6. Conclusion

CSR is confident that, based on the knowledge of the past that further research and development of the passenger steam locomotive is warranted. CSR seeks to improve upon the technologies briefly described and several others pertaining to the thermal efficiency, mechanical longevity, etc. of the steam locomotive. Combining the combustion and mechanical improvements with the use of a truly "carbon neutral" biocoal that CSR, and it's partner, the U of M, are developing will make an inexpensive, environmentally friendly, high performance steam locomotive suited for use as a higher speed passenger locomotive in the USA, and a universal use locomotive that is easy to maintain in developing countries throughout the world.

Coupling that simplicity with an easy-to-produce biofuel makes the economics of modern steam more and more favorable as the world's carbon bearing natural resources become more expensive and difficult to obtain.

While it is important to understand the past, the precedent speeds attainable by traditional locomotives, the comparison of those steam locomotives with diesel-electrics of the era, CSR understands that there is a cross applicability that needs to be defined between motive power of the 1950's and that of the present day. Certainly diesel-electric maintenance costs have improved in the past decades, but so too have those of the modern steam locomotive (to the tune of 90+% reduction in costs).

The next CSR White Paper will focus on the mechanics of steam locomotive valve gear at speed, while following papers will delve into maintenance cost considerations.

A first step towards a modern steam locomotive - *Modernized steam locomotive 3450 of the South African Railway, known as the "Red Devil" pulls a revenue passenger train in the early 1980's. This locomotive featured roughly twice the thermal efficiency of the Class J and roughly the same horsepower, despite being narrow-gauge and having a firebox 65% the size. - John Crosford Photo*

References

1) G. Hamilton. "N&W Steam vs. Southern Diesels: How did the costs compare?," The Arrow: Norfolk and Western Historical Society Magazine, September / October 2004, 11-23.

2) D. Wardale. "The Red Devil and Other Tales from the Age of Team," Scotland: Highland Printers, 2002.

3) M. Bane. "Porta Treatment, an Advanced Internal Boiler Water Treatment Regime", correspondence with author and owner of establishment.

4) H.F. Brown. "Economic Results of Diesel Electric Motive Power on the Railways of the United States of America". Proc. Inst. Mech. Eng. 175 (1961) p. 257-317.

"Locomotive Repair Costs and their Economic Meaning to the Railroads of the United States". ASHE/AIEE Railroad Conference" Pittsburgh, April 20-26, 1960.

"The Diesel Locomotive - The Other Side of the Coin". Circulated in 1968 by Gibbs and Hill, consulting engineers.

Stay Up-to-Date on the Coalition for Sustainable Rail

Email List | Join our email list at the top of any of our web pages: www.csrail.org

Facebook | www.facebook.com/csrail

Mail | Coalition for Sustainable Rail | P.O. Box 120361 | New Brighton, MN 55112