The contribution of the diesel locomotive to trainmen's safety on US railroads, 1927–1954

Mark Aldrich Smith College, Northampton Massachusetts

The historian Maury Klein has pointed out a 'continued neglect' of the diesel locomotive in nearly all facets of railroading. Diesels were the sort of transformative innovation made famous by the economist Joseph Schumpeter. They changed nearly everything about American railroads and the lives of American railroad workers, and one neglected aspect of this transformation has been the safety of work. 'For the first time in . . . forty-four years, a full fiscal year has elapsed without the occurrence of a steam locomotive boiler explosion,' the Bureau of Locomotive Inspection of the US Interstate Commerce Commission (ICC) announced in 1955.[1]

While it was hardly a coincidence that the end of boiler explosions coincided almost exactly with the eclipse of steam and the triumph of the diesel, the change-over in fact did comparatively little to improve trainmen's safety. Well before the triumph of the diesel, a host of small improvements to steam power had sharply reduced its dangers. As historians of technology have stressed in other contexts, incremental technical change, not great innovations, held the key to safety progress.[2]

American locomotive safety in the nineteenth century

In 1911, when the Bureau of Locomotive Inspection opened for business, locomotive safety had been improving for decades. While no hard figures exist on accidents to nineteenth-century American locomotives, anecdotal evidence suggests that they were common during the early decades of American railroading. The first train accident involving a fatality was the boiler explosion to the locomotive *Best Friend of Charleston* on 17 June 1831 that resulted when the fireman tied down the safety valve. Soon after, investigations by the Franklin Institute and others dismissed many fanciful explanations of boiler explosions (for example, that water under pressure decomposed into an explosive mix of hydrogen and oxygen) to focus instead on boiler design, low water, excessive pressure, and corrosion, in addition to dangerous operating practices. Despite their findings, the scientific and railroad press continued to report a sprinkling of similar disasters. Thus in October 1851 the Philadelphia & Reading's *Minnesota* blew, killing her fireman,

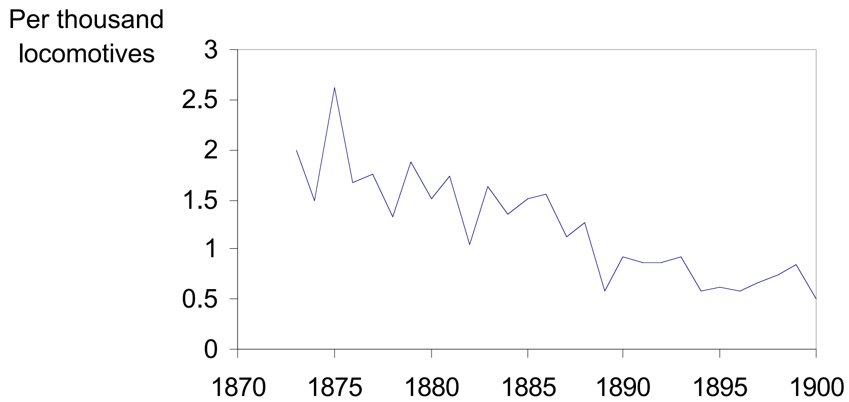

Figure 1 Locomotive accidents from explosions and broken rods, 1873–1900.
Source see text

because the engineman had shut off the pump. Several years later when a Baltimore & Susquehanna locomotive exploded, investigation found that the firebox had corroded to only a third of the original thickness.[3]

Beginning in 1873, and continuing to 1900, the *Railroad Gazette* compiled data on train accidents, including those involving locomotive boiler or cylinder explosions and broken rods. These figures included most locomotive accidents that resulted in fatalities or injuries, and while not comparable to modern data they can be employed to spot trends. As Figure 1 suggests, the early days were dangerous indeed, with annual accident rates sometimes exceeding two per thousand locomotives. From 1873 to 1886 the *Railroad Gazette*'s data yield an average yearly accident rate of 0.8 per thousand locomotives, which was admittedly a considerable undercount. In 1887, a typical year, the *Railroad Gazette* reported thirty-three locomotive accidents; sixteen of them were explosions that killed fourteen trainmen. Locomotives were long-lived; over two decades such an annual risk implied the sobering fact that 2 per cent of all locomotives would experience a serious accident. In Britain, by contrast, much more complete reporting yielded a rate of 0.46 per thousand over the same period.[4]

Despite the Franklin Institute's warnings, accidents continued to reflect an array of bad design and operating practices. Carriers routinely exceeded designed boiler pressures, which, in a rickety old locomotive, might bring disaster. In 1868 the *American Railway Times* reported a boiler explosion on a Grand Trunk locomotive that was twenty years old and which had boiler iron corroded to one-third its original thickness. In 1870 one engineman claimed his road ran such long trains that if he followed the rules on steam pressure he could not start the train. Raising boiler pressure remained a temptation well into the twentieth century. In 1927 the Rio Grande's mechanical engineer explained that raising pressure from 185 p.s.i. to 200 p.s.i. exceeded allowable stresses on a host of working parts and probably was the source of increased frame failures the company witnessed.[5]

Low water remained a fruitful source of disaster (Figure 2), but locomotives had many other ways of killing or maiming trainmen as well. Bad maintenance routinely took its toll. *Locomotive Engineering* reported one carrier that had locomotives with hollow stay bolts intended to leak when broken simply plugged the leaks. 'We are surprised that engineers can be found who are fearless enough to run locomotives treated in this reckless fashion,' the editor sputtered. Failure to fix broken stay bolts was probably what caused the engine *Jupiter* to blow up on the Fall River Railroad on 3 November 1880, for the company sent it out knowing that there was a leak. Gilbert Lathrop reported that one engineer on the Rio Grande was killed when the reversing lever failed to latch and hit him in the stomach when he opened the throttle. The engineer J. Harvey Reed reported that, when the main connecting pin broke on a Rogers Mogul locomotive he was on, the side rod acted like a flail, tearing up the cab. In 1887 the *Gazette* reported seventeen

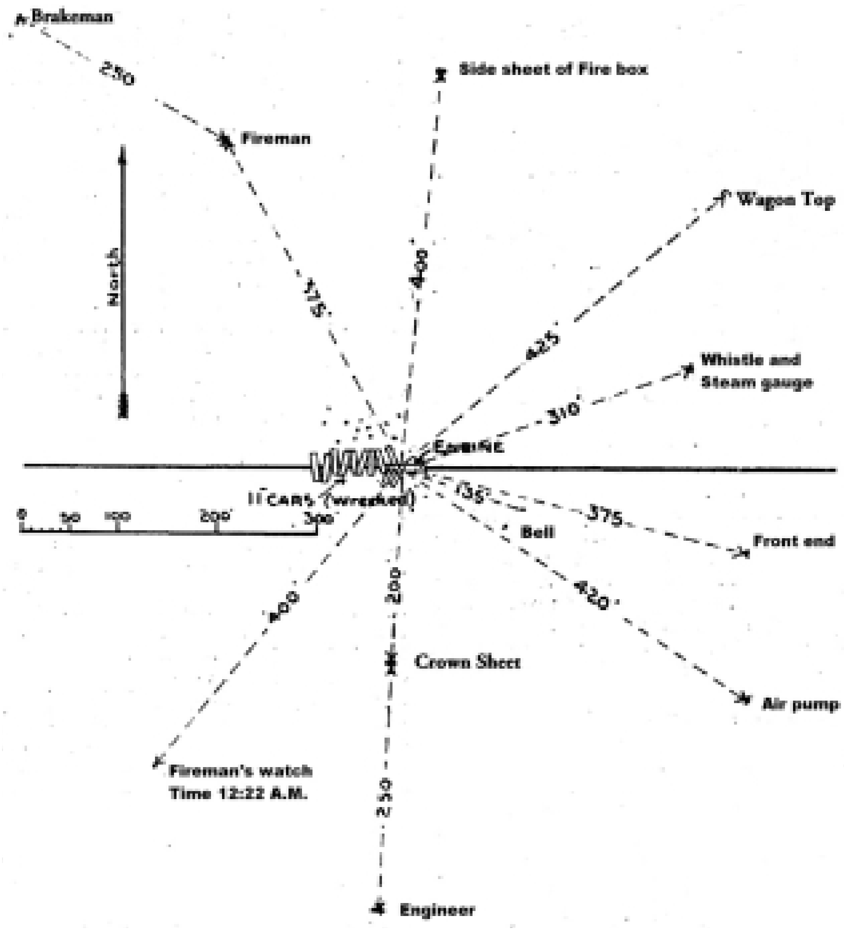

Figure 2 Diagram of the result of a boiler explosion on the Atlantic & Pacific Railroad, 1 November 1887, probably caused by low water

such accidents; one of them, to locomotive No. 72 of the Rome Watertown & Ogdensburg on 16 July, killed the engineman as it was drawing a special train containing President Cleveland and his wife. Some companies were especially accident-prone. The Reading had six boiler explosions in 1892, a rate of 4.29 per thousand locomotives, and it killed twenty people, while nationwide the failure rate that year was 0.37 per thousand.[6]

The men in charge of the steam locomotive were the master mechanics, and most were members of the Master Mechanics' Association. By the 1880s, while old-style cut-and-try mechanics still dominated the organisation there was a sprinkling of scientifically inclined, often college-educated, members. The Mechanics' activities largely consisted of what Steven Usselman has described as 'running the machine'. That is, their main concern was in increasing locomotive efficiency and hauling capacity through incremental technological change or improved work practices. Safety was also an indirect concern, for a dangerous locomotive that broke down or blew up was also an inefficient one. Hence, while improving safety was not the dominant motive, most innovations in locomotive technology and operation reduced risks.[7]

Mathias Forney was a mechanical engineer and inventor of a tank engine, and from 1870 to 1883 he was editor of the *Railroad Gazette*. He was therefore both an expert on locomotive design and thoroughly familiar with that journal's accident data. While largely self-taught, he was representative of the newer breed of scientifically inclined railroader. Forney thought many boilers poorly designed and their construction 'wretchedly defective'. At the Master Mechanics' 1880 meeting Forney proposed a discussion of how to secure boiler crown sheets. He explained that British builders employed stay bolts attached from the crown bars to the boiler shell, concluding that 'boiler construction in England is ahead of American practice'. A representative of the Lake Shore agreed, saying they followed British practice, while another member claimed that it 'was fast coming into use in this country'.[8]

The journal *Railway Master Mechanic* also wondered 'how long will it be before locomotive boilers will be properly stayed to meet the requirements of the heavy modern pressures', and complained that the threads on stay bolts were not upset, thereby weakening the rod. Forney noted that American locomotive construction was defective in other ways as well. American builders employed riveted lap joints, and the normal expansion and contraction during heating and cooling led to metal fatigue and failure. British builders employed butt joints with plates over top and bottom that were less prone to bending and also placed less shear on the rivets. British locomotives also had fireboxes and steam domes with fewer, stronger, joints, and they used heavier boiler iron than did the Americans.[9]

In a few instances builders modified designs simply to improve safety. In 1881 Forney read a paper to the Master Mechanics in which he cited a dozen accidents from the pages of the *Railroad Gazette* in which steam from the boiler killed or maimed trainmen or passengers. Forney pointed out that it was rare for the boiler shell to rupture; instead the damage was done by an attachment that broke off, perhaps in an otherwise minor collision or derailment. In one wreck the engineer died when a broken gauge cock driven into his side steamed him alive. There were twenty-three openings in the boiler with attachments that might break off, Forney noted: a design that resembled a porcupine, as he later remarked. Forney's plea got results. By the 1890s usual practice was to place all the attachments on a single stand attached to the boiler. In addition, some roads also installed check valves to the attachment inside the boiler so that an abnormal flow of steam would automatically close it.[10]

Gradually both methods and materials improved as a result of a host of cumulative modifications in design, construction, operation and maintenance. These included the use of thicker, better-quality iron, and in the 1890s the introduction of steel for both boilers and rods that was purchased by specifications and tested for quality. Cast steel frames also appeared about the same time, while alloy steels arrived in the twentieth century. Companies began to employ vibration tests of stay bolts to guard against metal fatigue, while hollow stay bolts also reduced risks (Figure 3), as did better boiler staying and washing, and improved lubrication. While some of these innovations were patentable, most were not. They were the result of trial and error, reported on by many individuals and railroads. Locomotive improvement was therefore much like the sort of collective invention that Robert Allen has described in iron and steel making. Locomotive design also became much more scientific when, in 1891, Professor W. F. M. Goss of Purdue University developed the first locomotive testing laboratory. Other locomotive test facilities were established on the North Western in 1895, at Columbia University in 1899, on the Pennsylvania Railroad in 1904 and finally at the University of Illinois in 1914. In the twentieth century Goss's work would allow locomotive builders to optimise all aspects of locomotive design (see below).[11]

Between 1873 and 1900 accidents declined about 75 per cent from two per thousand to one per two thousand locomotives. By the twentieth century, steam locomotives were far larger and carried steam at much greater pressure than a generation earlier. They were also far better designed and built, employing much more steel of higher quality, and were subject to more care-

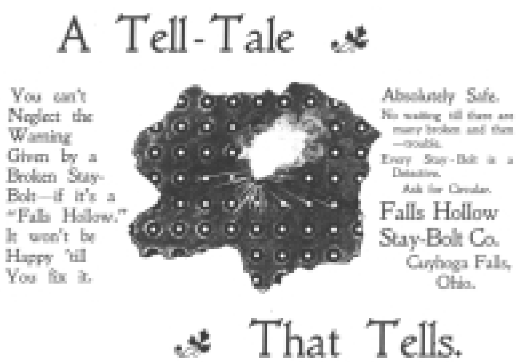

Figure 3 The Falls Hollow Stay Bolt Company, of Cuyhoga Falls OH, advertised that its bolts gave warning of the possibility of an explosion by leaking steam if they broke

ful inspection and maintenance. The combined effect of these incremental changes was not only a more efficient locomotive but a much safer one as well.

The Interstate Commerce Commission and the dangers of steam

Despite such improvements, boiler explosions continued to kill thirty to forty trainmen a year and after 1900 the increasingly powerful rail brotherhoods began to press for state and federal regulation. They achieved this goal at the national level when the ICC Bureau of Locomotive Inspection opened for business in 1911. Working with the carriers, the bureau developed rules for the maintenance and inspection of boilers that effectively made best practice the industry-wide standard. In 1912 it also began to publish detailed statistics of accidents, injuries and defective locomotives (Figure 4).[12] As the figure reveals, safety improved briefly after 1911, largely as a result of the bureau's formation, and then deteriorated during the First World War – although some of the apparent deterioration simply reflects a broadening of inspection in 1915 to include not just boilers but the entire locomotive. Beginning in the early 1920s, safety again began to improve and the progress continued until the Second World War. The inter-war gains had almost nothing to do with dieselisation or the use of electrics; in 1940 steam still accounted for about 96 per cent of locomotives in use. And while the ICC routinely took credit for all safety improvements, once again most of the gain reflected company efforts to enhance efficiency. In the phrase of *Railway Age,* it was largely an 'achievement of private enterprise'.[13]

Usselman has argued that after 1904 American carriers became 'reluctant innovators', and that they sometimes confused technical and economic efficiency. Glimpses of that reluctance may be seen in the story of locomotive

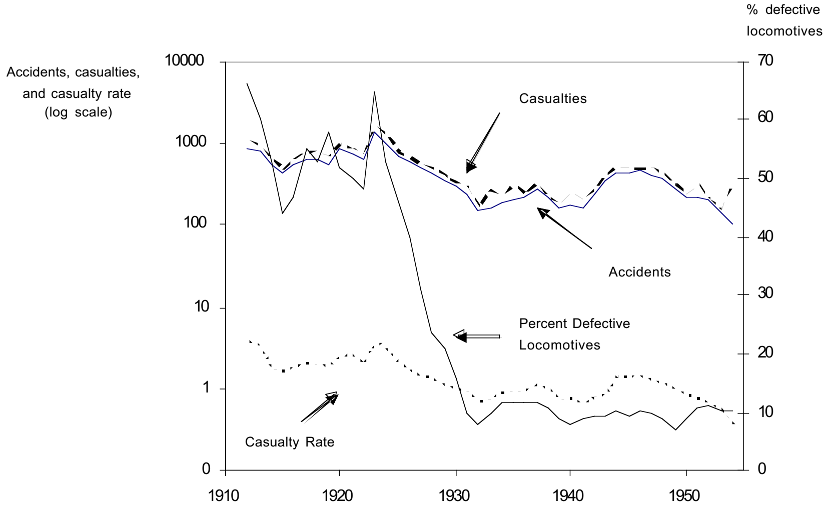

Figure 4 Defective locomotives, accidents, casualties and casualty rates, 1912–64

evolution between the wars, although in general the picture seems overdrawn. In the early 1920s increasing competition from automobiles and trucks reduced demand for both passenger and less-than-carload freight service. Along with rising wages, the new competition also raised the pay-off to speed, train size and reliability. As a result, the carriers scrapped much of their older motive power and bought newer, more efficient units. Between 1924 and 1940 the number of locomotives fell by 25,000, or about 36 per cent, and at the same time the carriers purchased newer power that by 1940 amounted to about 23 per cent of locomotives in use, and they extensively modernised older equipment, retro-fitting it with devices to enhance efficiency and safety.[14]

The work of W. F. M. Goss and others at locomotive test plants began to have a major influence on locomotive design just before World War I. As Usselman has observed, nowhere was engineering more enshrined than on the Pennsylvania Railroad. In 1914 the Pennsylvania brought out an improved Atlantic locomotive that *Engineering* termed 'a product of the test plant'. Yet the new power by no means emphasised engineering over economics; as its historian observed, 'this locomotive was expected not only to do a great job but to do it with highest efficiency and economy'. That same year Alco's designer Francis Cole published his *Tables of Locomotive Ratios*, based on the earlier work by Goss, that replaced cut-and-try methods of design with scientific proportioning. Employing Cole's analysis, Lima Locomotive debuted a new generation of 'superpower' locomotives in the early 1920s. The newer power was faster, more efficient, and far less failure-prone.[15]

The new or modernised equipment also came with many safety devices. Despite the claims of the railroad press, public and union pressures were responsible for some of the improvements. The Brotherhood of Locomotive Engineers had successfully pressed the bureau to require electric headlights in 1917. Records of the Pennsylvania Railroad also reveal many union petitions for safety equipment; locomotive window screens came in 1920 and automatic bell ringers in 1926, but the union was unsuccessful in its request for automatic fire doors and several other items. In 1921 the US Railroad Administration proposed to retro-fit locomotives with automatic fire doors but its tenure ended before much could be done.[16]

The Bureau of Locomotive Inspection rules required locomotives to be equipped with both water glasses and gauge cocks, and that they be properly installed. In 1914 the bureau condemned a lot of ten new Mikados that had the bottom of the water glass *below* the top of the crown sheet. This would register a safe water level when the crown sheet was entirely dry! And in 1922 the bureau published the results of an investigation showing the importance of proper placing of gauge cocks to ensure that they would yield accurate readings.[17]

Still, most modifications of locomotives during these years were motivated by the lure of private profit. The spread of thermic siphons was but one of a host of small changes that improved both locomotive efficiency and safety. These devices reduced fuel consumption, and by carrying a supply of water to the crown sheet they also diminished the risk of boiler explosions. Introduced about 1920, they soon proved their utility. In 1921 *Railway Age* reported 'a crown sheet failure without an explosion', due to use of a siphon. Such stories helped publicise the safety benefits and by 1930 siphons ran on 10,000 locomotives, or about 18 per cent of the total. In fact, given the value of these devices, they should have been retro-fitted on nearly every locomotive. Some carriers, at least, were the reluctant innovators that Usselman describes. It is also depressing to record that neither the Bureau of Locomotive Inspection nor the Brotherhood of Locomotive Engineers pressed for their use.[18]

Newer power was also more likely to have automatic fire doors, and other safety devices, while flexible stay bolts were widely used and made of tougher alloy steels. By the mid-1920s the Canadian National and Canadian Pacific had designed boilers to ensure that failure would be gradual rather than catastrophic. Some of the return on this investment came about seventy years later, on 15 June 1995. A locomotive that the Gettysburg Railroad had obtained from the Canadian Pacific to run for tourist excursions burst her boiler. Although the engineer and two firemen were burned, no one was killed. About 1932 the Santa Fe developed an improved blow-out plug that virtually ended boiler explosions on that line.[19]

In the 1930s the Association of American Railways' Mechanical Division and suppliers such as Timkin investigated ways to improve axles, crankpins, and reciprocating parts. There were also studies of the effect of boiler water on embrittlement, and boiler water softening also continued to spread; by 1933 the carriers treated about 40 per cent of all boiler water, reducing the risk of clogged injectors and burned or burst flues.[20]

During the Second World War, as the carriers faced the need to absorb large numbers of new men, they also improved training in locomotive safety. In the ethos of railroading, locomotive failures reflected badly on the engineman – especially at a time of patriotic pressure to get the train over the road – and crews would go to great lengths to make a station, even in the face of a low-water warning. Carl Peterson, an engineer on the New York Central, remembered that the low water alarm had been sounding on a 'Twentieth Century' locomotive just before it blew up in 1943. Such behaviour seems foolhardy but it also reflected the generally poor training the carriers provided engineers. Few trainmen had been instructed that when a water glass went dry there might be only 500 gallons over the boiler crown sheet. Since a large locomotive could evaporate 80,000 lb of water an hour, a crew might have five minutes before disaster. Lack of training also led to many dangerous myths about locomotive boilers. Hoke Rolinson, an engineer on the Central of Georgia, remembered engineers who liked to run with low water because 'you had hotter steam'. In a belated response to the need for better training, the Rio Grande used a replica of a locomotive to teach newly minted engineers about the dangers of low water, while the Milwaukee and Lehigh Valley developed an instruction book for the same purpose.[21]

As Figure 4 reveals, the combination of better locomotives and improving training yielded a substantial improvement in safety between the mid-1920s and the Second World War. In 1946 steam locomotives accounted for eight fatalities to trainmen, down from fifty-three in 1912 and resulting in an 82 per cent decline in the fatality rate.

The diesel and trainmen's safety

As the previous discussion indicated, locomotive safety improved sharply after 1912 and again after 1924. Figure 4 reveals a third major improvement in locomotive safety that began about 1947. It coincided with the wholesale replacement of steam power with diesels.

The spread of diesels affected the safety not only of trainmen but of shop men and maintenance of way men as well. Diesels changed nearly everything about railroading. They did away with the whole cumbersome process of handling coal and water. They also needed far less maintenance than did steam locomotives, and that tended to be parts replacement. George Broughton was a shop man on the Alton who witnessed the transition from steam to diesels. 'On steam,' he recalled, 'everything was heavy labor,' while diesels were 'like working on an ice box, you took out an injector, put in a new one. . . . Much lighter work.' Diesels also required a much cleaner shop environment than had steam, and much more electrical work. Their expense also put a premium on shop speed, leading to a host of labour-saving devices.[22]

Diesels had contradictory effects on the safety of railroad work. Without main driving wheels they caused less stress to rail and track. Yet diesels could also increase some risks; they were quieter than steam locomotives, and might sneak up on a track man more easily, and their smaller wheels were more failure-prone. Unfortunately, the overall effects of diesels on safety cannot be identified with any precision. However, the Bureau of Locomotive Inspection evidence on locomotive accidents and injuries reveals how the diesel directly affected the safety of trainmen's lives. Paradoxically, while diesels were far safer than steam locomotives, their triumph only marginally improved trainmen's safety.

While the 1920s were the Golden Age of steam, the bureau first took official note of 'locomotives other than steam' in 1927. These must have been almost entirely electrics or gasoline cars. That year companies filed reports on 951 such locomotives; they accounted for five accidents that injured five individuals, but killed no one.

These reports, separated by type of motive power, continue throughout the period of dieselisation until 1954, by which time the steam locomotive was all but extinct. The data are depicted in Figure 5 and, as can be seen, non-steam locomotives maintained a modest but significantly lower accident rating throughout the post-war years. And when there were accidents, diesels tended to be considerably less lethal than their steam counterparts.

Table 1 presents data on worker fatalities and accidents by type of locomotive from 1945 to 1954, and, as can be seen, the typical steam locomotive

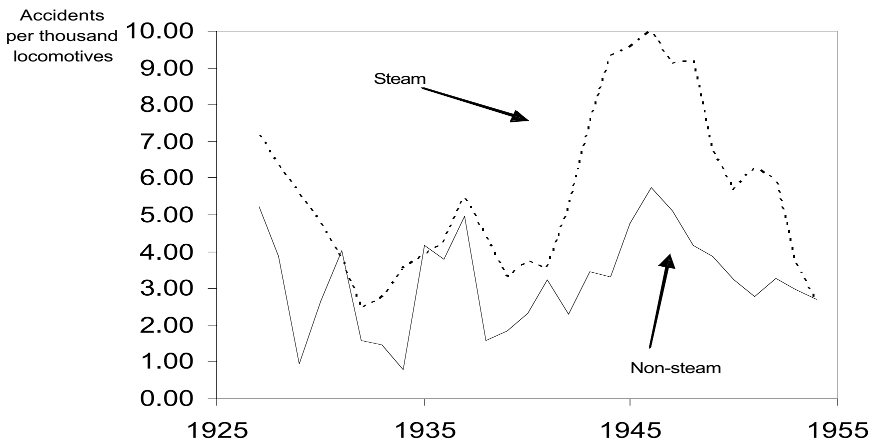

Figure 5 Accident rates, steam and non-steam locomotives, 1927–54

accident was abut 2.6 times as likely to result in a worker fatality. Such figures raise the question why diesel locomotives caused so many fewer accidents and fatalities. Some of the difference could have been in age. In 1950 only about 7 per cent of the railroads' nearly 26,000 steam locomotives were less than a decade old and a third of them were built before 1915! By contrast 97 per cent of all diesels were then less than a decade old. But age was not the whole story, for if diesels were less romantic than the iron horse they were also inherently safer.[23]

Table 1 Accidents and fatalities, steam and non-steam locomotives, 1945–54

	Steam	*Non-steam*
Accidents	2,307	524
Locomotive years	300,118	153,274
Worker fatalities	103	9
Accidents per thousand locomotives	7.69	3.32
Fatalities per thousand accidents	45	17

Source ICC Bureau of Locomotive Inspection, *Annual Report of the Chief Inspector* (various years).

The Bureau of Locomotive Inspection listed accidents to steam locomotives under fifty-five separate categories (plus 'miscellaneous'). Arch tubes, blow-off cocks, boiler checks, crankpins, crossheads, cylinder heads, grate shakers, injectors, stay bolts, valve gear, and water glasses all might injure or kill (Figures 6–7). And of course the most deadly of all accidents, for which there was no counterpart on a diesel, was a boiler explosion. From 1945 to 1954 sixty out of a total of ninety-three fatalities on steam locomotives resulted from this cause (Figures 8–9).

In contrast to the bewildering number of dangers from a steam locomotive, the bureau listed accidents to non-steam locomotives under just nine categories. As noted, diesel wheels were comparatively failure-prone. Diesel oil

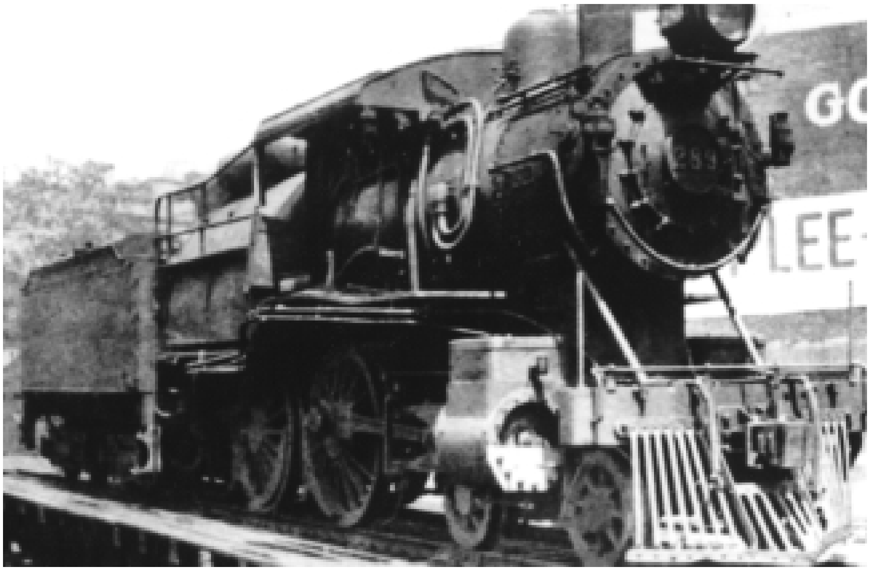

Figure 6 Steam locomotive accidents were spectacular and often deadly. Here are the results of a broken connecting rod . . .

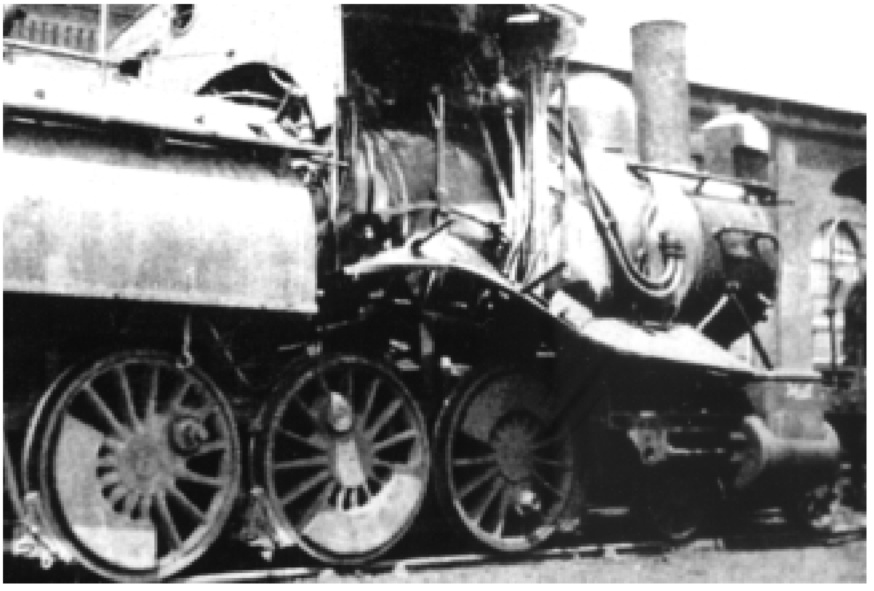

Figure 7 . . . and here of a broken crankpin. *Both photos courtesy* Interstate Commerce Commission

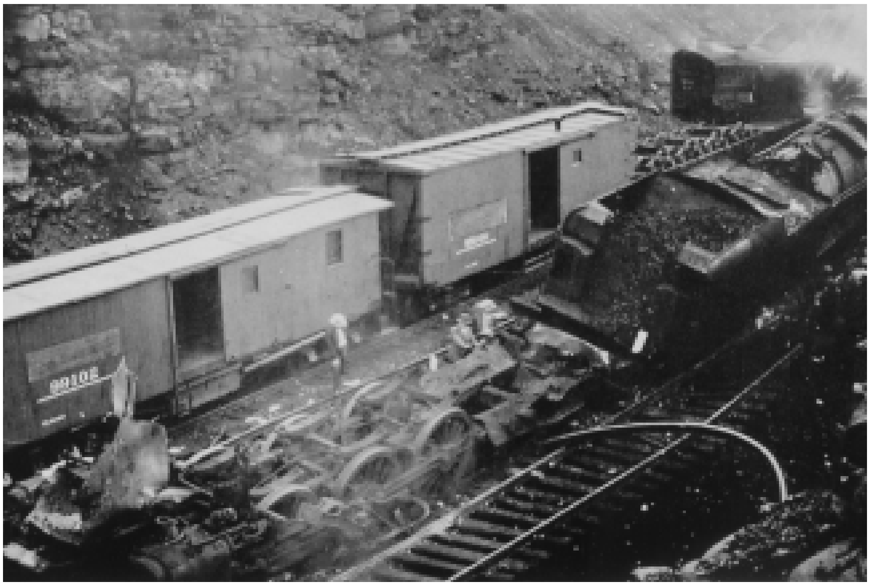

Figure 8 Boiler explosions, although fewer in number, continued to plague steam locomotives . . .

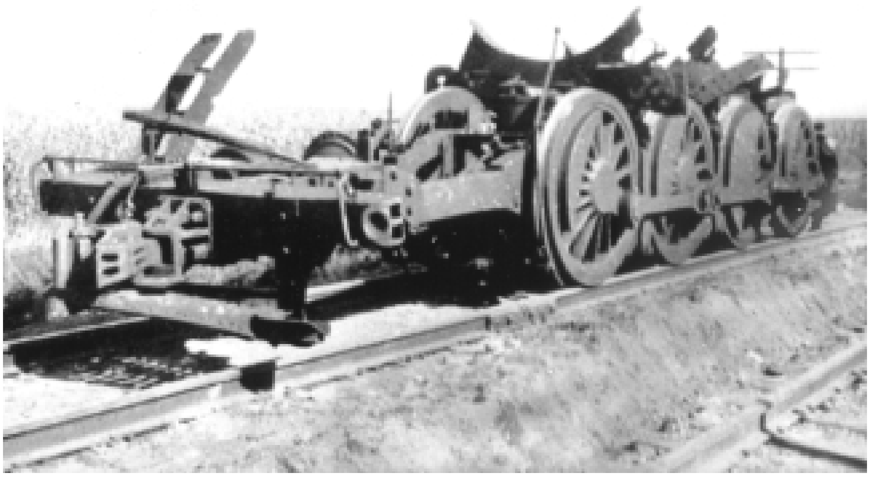

Figure 9 . . . until the end of their days. *Both photos courtesy* Interstate Commerce Commission

caused dermatitis, and it made floors and steps slippery, raising risks from falls. Batteries could also explode, dousing the men with acid. Diesels were also subject to fires, short circuits, and crankcase explosions, while starters and generators might also cause trouble. For example, the bureau reported that on 24 September 1950 the flash from a grounded shunt regulator injured one man on the Santa Fe. In December that year on the North Western a crankcase exploded due to an overheated bearing and it too injured a man (Figures 10–11).[24]

However, as the use of diesels spread, a combination of learning by doing and by using reduced these risks. And, as with steam, diesel safety reflected not only inherent technological advantages but incremental improvements and new safety procedures as well. Manufacturers improved design, making cabs stronger, with improved visibility and electronic 'deadman' protection. Both manufacturers and the Association of American Railroads' Safety Section developed safety codes for diesel operation and maintenance. Because of electrical dangers the carriers forbade men to use metal flashlights or wear jewellery or metal-frame glasses while working on the new locomotives, and required them to wear tight-fitting clothing to avoid the many revolving parts.[25]

Because diesel oil is not particularly flammable, both manufacturers and carriers initially overlooked fire danger, and early diesels carried only one tiny carbon tetrachloride extinguisher. But fires were not only dangerous; they were also expensive in terms of repair and down time. And, because diesels cost far more than steam locomotives, companies wished to minimise their time in shop. Consequently, as a rash of fires proved early protection inadequate, companies shifted to larger foam or carbon dioxide extinguishers.[26]

The expense of diesels and the need to maximise their productivity also encouraged the spread of train radio, which not only improved efficiency

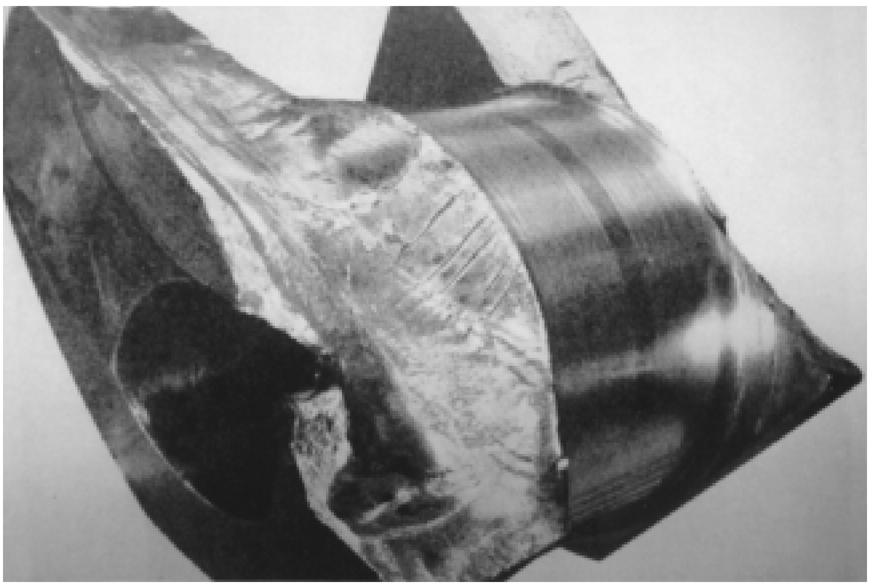

Figure 10 Diesel locomotive accidents were less dramatic and usually less lethal to trainmen than those of steam locomotives. Here a broken crankshaft resulted in serious injury to an employee . . .

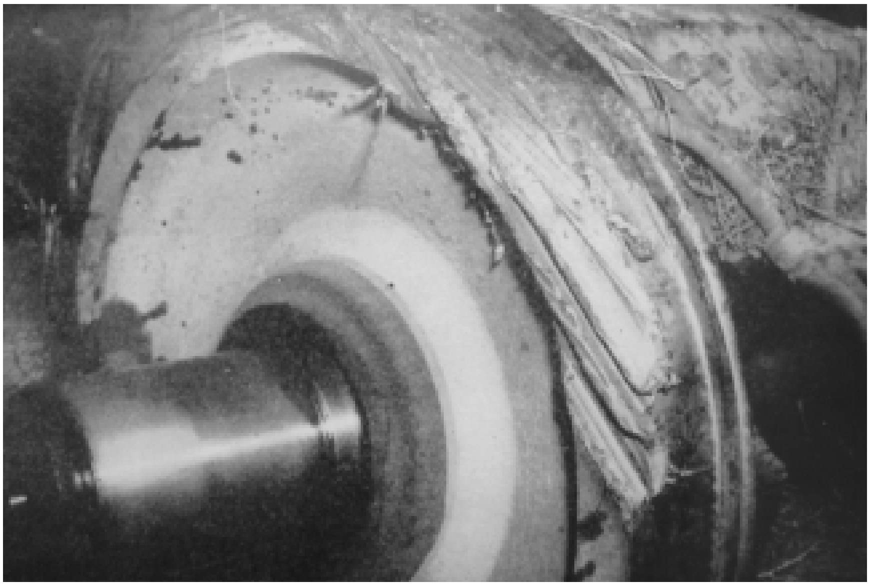

Figure 11 . . . and here a flat wheel resulted when the pinion bearing of a traction motor seized, causing a derailment that injured 189 passengers and employees. *Both photos courtesy* Interstate Commerce Commission

but reduced accidents as well. And while men had employed ladders to work on steam locomotives, the need for speed led companies to employ safer multi-level platforms in diesel maintenance. Companies also employed new non-destructive testing methods to find minute fatigue cracks or internal flaws in critical parts. For example, Magnaflux tests passed a heavy electric current through a part, causing a dusting of magnetic powder to 'find' any tiny cracks in the metal. An advertisement for the procedure proclaimed, 'Diesels are different. With diesels you must inspect many more precision parts for cracks than you ever had to with steam.' The Union Pacific used a similar process that employed a dye penetrant first employed to test jet aircraft turbines. Other companies employed black light, and ultrasound was used to test axles for internal defects. By the early 1950s many carriers systematically tested diesel axles, crankshafts, pistons, valves, and many other parts.[27]

By this time the Rio Grande, B&O and other large carriers were also using spectrographic analysis of lubricants to search for traces of worn parts or overheating that might presage a crankcase explosion. The Rio Grande also made wrist pins radioactive so it could check for particles in the lubricating oil, while manufacturers developed devices that would shut down power at critical crankcase temperatures. Sometimes the very safety of diesels caused problems: they did away with cinders, which had been a major source of eye injuries, but the Atlantic Coast Line reported that its trainmen responded by wearing safety glasses less frequently, and so that company had to step up monitoring and enforcement or rules.[28]

These inherent characteristics of diesels, along with the many improvements in design and work practices, help explain why the shift from steam locomotives to diesels after the Second World War reduced accidents per locomotive and diminished the severity of accidents by perhaps 60 per cent. Yet if these declines sound dramatic, in fact they must have yielded very modest reductions in trainmen's risks. For one thing, fatalities per locomotive accident could have declined because diesels required less labour in the cab and in shops and yards, and so the decline in fatalities may at least in part reflect a reduction in worker exposure. In addition, by the 1930s fatality rates to trainmen from steam locomotives were already very low – in the range of 0.04 to 0.06 per thousand workers, while injury rates were usually less than one per thousand. Even large percentage decreases in small accident rates will generate small safety gains.[29]

Unfortunately, we cannot directly measure the risks of working with non-steam locomotives because the division of workers or worker hours between types of locomotives is unavailable. Table 2 presents an alternative approach, which is to compare fatality rates to trainmen from locomotive accidents for two periods, from 1927 to 1930, when nearly all locomotives were steam, and from 1950 to 1954, when over half were diesel, gas, or electric. As can be seen, fatality rates declined by about two-thirds over the period, but the absolute decline was only 0.037 per thousand, and not all of it could be attributed to dieselisation. Over the same period trainmen's fatality rates from all causes fell from roughly 1.7 per thousand to 0.7 per thousand. Hence the greater safety of diesels accounted for at most 3.7 per cent of trainmen's safety gains.[30]

Table 2 Trainmen's[a] fatality rates from locomotive accidents, 1927–30 and 1950–54 (per 1,000 workers)

Period	*Fatality rate*	*% of non-steam locomotives*
1927–30	0.059	1.6
1950–54	0.022	56.3

Note *a* Trainmen include enginemen, firemen, brakemen, conductors and switchmen.
Source ICC Bureau of Locomotive Inspection, *Annual Report of the Chief Inspector* (various years).

Conclusion

Because the introduction of diesels changed so many aspects of railroading their overall impact on worker safety is unknowable. Their effect is clearest with locomotive accidents to trainmen. Here ICC data suggest that the combination of new motive power and modified work practices yielded considerably safer locomotives. Accidents per locomotive declined sharply, as did the severity of those accidents that did occur. The net effect was to improve trainmen's safety, but the gain was not large, because steam locomotives had already become much safer due both to regulation and to incremental improvements in technology and operating methods. Hence the risk reduction due to diesels constituted only a small fraction of the total improvement in trainmen's safety during the years when the Age of Steam came to an end. Clearly, whether the diesel was a 'revolutionary' technology depends on what you look at. Diesels changed nearly everything about railroading, yet their direct impact on trainmen's safety was anything but revolutionary.

Notes

1 Maury Klein, 'The continued neglect of the diesel locomotive', *Railroad History*, millennium special (2000), 6–15. US Interstate Commerce Commission (ICC) Bureau of locomotive Inspection, *Forty-fourth Annual Report of the Chief Inspector*, *1955* (Washington DC, 1955), quotation on p. 4.

2 On the role of incremental technological change see Nathan Rosenberg, *Inside the Black Box* (New York, 1982).

3 The *Best Friend* is from Robert Shaw, *Down Brakes: a History of Railroad Accidents*, *Safety Precautions and Operating Practices in the United States of America* (London, 1961). The Franklin Institute study is reprinted and evaluated in Bruce Sinclair, *Early Research at the Franklin Institute: the Investigation into the Causes of Steam Boiler Explosions* (Philadelphia, 1966). 'On the explosion of the locomotive *Minnesota*', *Journal of the Franklin Institute* 52 (December 1851), 415–16. The Baltimore & Susquehanna is from 'Locomotive boiler explosions', *American Railway Times* 8 (16 October 1856), 2.

4 For comparisons between ICC and *Gazette* statistics see 'Our accident statistics', *Railroad Gazette* 22 (13 June 1890), 419–20, and untitled, *Railroad Gazette* 31 (28 June 1899), 541. An annual accident rate of 0.8 per thousand implies that over twenty years 98 per cent of locomotives would not be in an accident (1 – 0.0008)20 = 0.98.

5 'Explosion of a locomotive boiler', *American Railway Times* 21 (17 April 1869), 127. Carrying excess pressure is from 'Locomotive explosions', *Railroad Gazette* 1 (4 June 1870), 220. Mechanical Engineer to W. J. O'Neill, 28 February 1927, RG 513, Denver & Rio Grande Collection, Colorado Historical Society.

6 Plugging stay bolts and the quotation are from 'Tempting boiler explosions', *Locomotive Engineering* 5 (March 1892), 4–7. The *Jupiter* is from 'The Massachusetts Railroad: commissioners on the Fall River boiler explosion', *Railroad Gazette* 13 (14 January 1881), 19. Gilbert Lathrop, *Little Engines and Big Men* (Caldwell ID, 1954), 67. J. Harvey Reed, *Forty years a Locomotive Engineer* (Prescott WA, 1913), 51. 'A broken locomotive parallel rod', *Engineering News* 18 (5 November 1887), 334–5.

7 Steven Usselman, *Regulating Railroad Innovation: Business Technology and Politics in America* (Cambridge, 2002), part 2.

8 For biographical data on Forney see 'Matthias Nace Forney' and 'Autobiographical notes by Matthias Nace Forney', *Railroad Gazette* 44 (17 January 1908), 76–7 and 82–4. See also *Dictionary of American Biography* VI, 527–8. 'Wretchedly defective' is from 'Boiler construction', *Railroad Gazette* 4 (13 July 1872), 298. American Railway Master Mechanics' Association, *Proceedings* 13 (1880), 72–4.

9 Untitled editorial, *Railway Master Mechanic* 10 (June 1887), 79. American Railway Master Mechanics' Association, *Proceedings* 13 (1880), 72–4. 'Locomotive boiler explosions', *Railroad Gazette* 12 (23 January, 6 and 13 February 1880), 48, 76–8, 90–1. Untitled editorial, *Railway Master Mechanic* 10 (June 1887), 79.

10 American Railway Master Mechanics' Association, *Proceedings* 14 (1881), 120–9.

11 'Stay bolt inspection and specifications', *Railroad Gazette* 25 (28 June 1893), 564–5. Testing is from 'Partially broken stay bolts', *Railway Age* 24 (23 June 1897), 597–98. 'Boiler steel specifications', *Railway Review* 38 (27 August 1898), 472. 'Reduction in the weight of reciprocating parts in locomotives', *Engineering News* 36 (13 August 1896), 99–101. 'Cast steel in locomotive construction', *Railway Age* 23 (29 January 1897), 80–1. A good general review is in 'The locomotive boiler: its growth and needs', *Railway Age* 36 (25 December 1903), 881–2. Robert Allen, 'Collective invention', *Journal of Economic Behavior and Organization* 4 (1983), 1–24. Lawrence Fry, 'The locomotive testing plant and its influence on steam locomotive design', American Society of Mechanical Engineers, *Transactions* 47 (1925), 1267–93.

12 Mark Aldrich, 'Safe and suitable boilers: the railroads, the Interstate Commerce Commission, and locomotive safety, 1900–1945', *Railroad History* 171 (autumn 1994), 23–44.

13 The quotation is from 'Some current lessons from the railway safety record', *Railway Age* 99 (20 July 1935), 65–7. Details on the proportion of steam and non-steam locomotives are from ICC, *Study of Railroad Motive Power Statement No. 5025* (Washington DC, 1950).

14 Usselman, *Regulating Railroad Innovation*, chapter 7. Twenty-three per cent is all locomotives purchased from 1924 to 1940 divided by all locomotives that were not in storage and were serviceable. Data are from ICC, *Statistics of Railways in the United States, 1940* (Washington DC, 1941).

15 For the Pennsylvania see Frederick Westing, *Apex of the Atlantics* (Milwaukee WI, 1963), quotation on 68; the quotation from *Engineering* is on 63. Cole is from J. Parker Lamb, 'Why steam failed', *Railroad History* 188 (spring–summer 2003), 73–81.

16 'The high-power headlight rule', *Railway Review* 60 (6 January 1917), 5–8. Union efforts on the Pennsylvania are from E. W. Smith to R. K. Rochester, 21 May 1920, box 429, J. T. Wallis to Elisha Lee, 1 November 1922, and C. S. Krick to G. L. Peck, 4 September 1926, box 868, Pennsylvania Railroad Papers, Hagley Museum and Library. The US Railroad Administration is from General Manager to I. W. Geer, 8 August 1921, box 759, Pennsylvania Railroad Papers, Hagley Museum and Library.

17 The Mikados are from 'Locomotive boiler inspection', *Railway Master Mechanic* 38 (January 1914), 13–17. For the location of gauge cocks see Aldrich, 'Safe and suitable boilers'.

18 'A crown sheet failure without an explosion', *Railway Age* 70 (8 April 1921), 885–6. See also 'An unusual locomotive crown sheet accident', *Railway Review* (9 April 1921), 574–5, and 'Thermic siphons used in combustion chambers', *Railway Age* 80 (13 March 1926), 819–20, which claimed that they had prevented boiler explosions in six known cases. On companies' failure to install appliances such as siphons see Robert A. Le Massena, 'Design it yourself locomotive', *Railroad History* 182 (spring 2000), 23–57.

19 On better steels see 'Reducing dynamic augment', *Railway Review* (6 May 1916), 634–6. 'Inspection of locomotive stay bolts', *Railway Review* 77 (5 December 1925), 844–7. 'Recent types of freight and passenger locomotives for Canadian National Railways', *Railway Review* 75 (8 November 1924), 744–5. US National Transportation Safety Board, *Special Investigation Report: Steam Locomotive Firebox Explosion on the Gettysburg Railroad near Gardners Pennsylvania, Pennsylvania, June 16, 1995* (Washington DC, 1995). For drop plugs on the Southern Pacific see 'Locomotive boiler explosions', *Railway Age* 115 (16 October 1943), 595.

20 'Report of the Committee on Locomotive Construction', Association of American Railways Mechanical Division, *Proceedings* 22 (1940), 405–71. For Timkin's work see 'Modern locomotive equipment' I, *Railway Locomotives and Cars* 111 (August 1937), 348–51. 'Cracking of boiler steel', *Railway Locomotives and Cars* 112 (September 1938), 331–6. For one of many articles on the value of better water see 'Great Northern reduces pitting of locomotive boilers', *Railway Age* 80 (3 April 1926), 951–8.

21 Peterson and Rolinson are from Stuart Leuthner (ed.), *The Railroaders* (New York, 1983), 34–7 and 134–7. 'An empty water glass requires decisive action', *Railway Mechanical Engineer* 117 (June 1943), 263–4. 'Reducing boiler explosions', *Railway Mechanical Engineer* 117 (August 1943), 353–5; 'How to guard against low water', *Railway Mechanical Engineer* 117 (October 1943), 470–3. 'Lessons from boiler explosions', *Railway Age* 115 (10 July 1943), 47–9. 'If there's no water kill the fire', *Railway Age* 115 (18 December 1943), 978–80. 'Boiler explosions', *Railway Age* 116 (12 February 1944), 339.

22 Broughton is from Michael Mateka and Greg Koos (eds), *Bloomington's C&A Shops: Our Lives Remembered* (Bloomington IL, 1988), 125. A good discussion of maintenance requirements is in Robert Aldag, 'Culture clash: diesel vs tradition', *Railroad History*, millennium special (2000), 89–99. John McCall, 'Dieselization of American railroads: a case study', *Journal of Transport History* 6, 2 (1985), 1–17, discusses the impact of the diesel on the Santa Fe.

23 Figures on numbers and ages of locomotives from ICC, *Statistics of Railways in the United States, 1950* (Washington DC, 1951), table 18. These figures probably overstate steam in use, for nearly 6,000 locomotives were listed as unserviceable and another 1,700 were stored.

24 Accident data are from ICC Bureau of Locomotive Inspection, *Thirty-ninth Annual Report of the Chief Inspector, 1950* (Washington DC, 1951).

25 Cab design is from Peat Marwick Mitchell & Co., *Preliminary Draft, Railroad Safety Assessment: Task IV, Analysis of Government, Industry and Union Railroad Safety Programs* (Washington DC, 1977), chapter 4. Problems with jewellery are from C. M. House,

'Safety in diesel maintenance', National Safety Council, Railroad Section, *Transactions* 40 (1952), 22–5.

26 'Fire protection for diesel locomotives', *Railway Age* 119 (27 October 1945), 684–5, and 'Fires in diesel locomotives', *Railway Locomotives and Cars* 120 (June 1946), 299–300. The importance of diesel costs is emphasised in 'Fire protection for diesels', *Modern Railroads* 3 (September 1948), 59–60, 62.

27 The role of diesels in encouraging train radio is from 'Train radio telephone is making rapid strides', *Modern Railroads* 4 (September 1949), 66–7. 'Diesels are different', *Modern Railroads* 10 (October 1955), 110. The Union Pacific is from 'Chemical inspection of metal parts', *Modern Railroads* 7 (April 1952), 129–30. 'Magnaflux test of diesel locomotive parts', *Railway Locomotives and Cars* 120 (June 1946), 304–7.

28 'D&RGW's atomic detectives', *Modern Railroads* 10 (April 1955), 63–4. 'How spectrographic analysis controls diesel engine maintenance', *Railway Locomotives and Cars* 126 (April 1952), 65–8. 'Eye injuries: what one transportation department does about them', *Railway Age* 131 (24 September 1951), 45–7.

29 The ICC divided total injuries and fatalities into four sub-groups: members of train crews, roundhouse and shop employees, other employees, and non-employees. Because most of the accidents occurred to train crews, and because the number of exposed roundhouse and shop employees cannot be estimated, I concentrate on train crews. A statistical analysis that estimates the impact of diesels on employment is Gilbert Yochum and Steven Rhiel, 'Employment and changing technology in the postwar railroad industry', *Industrial Relations* 29, 3 (1990), 479–503.

30 For the statistically minded, a regression analysis of trainmen's fatality rates per thousand workers against total locomotives and percentage non-steam for 1927–54 confirms the contention that diesels yielded modest risk reductions. The equation is:

$$\text{Fatality rate} = 0.089 - 0.573 \times 10^{-6} \text{ locomotives} - 0.783 \times 10^{-3} \text{ \% non-steam}$$
$$(-0.68) \qquad (2.31)$$

$R^2 = 0.29$, $n = 44$. Figures in parentheses are t statistics. Using this equation, an increase in the percentage non-steam from 1.6 to 56.3 yields $(54.7 \times -0.783 \times 10^{-3})$ = a 0.043 point decline in the fatality rate.

Address for correspondence

Department of Economics, Smith College, Northampton MA 10163, USA.
E-mail maldrich@email.smith.edu