Market Imperatives and Innovation Cycles: The Effects of Technological Discontinuities on the Twentieth-Century Locomotive Industry

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For more than a hundred years, from the 1830s through the 1940s, steam locomotives symbolized the power of the railroad industry, just as their manufacture formed one facet of a booming American industrial economy.[1] Beginning in the 1920s, and culminating in a "dieselization revolution" during the 1950s, efficient diesel locomotives replaced steamers en masse. Diesels represented a radical technological discontinuity, since they did not share any significant technology or components with steam locomotives and since their manufacture demanded vastly different organizational routines and managerial competencies.

The radical technological discontinuity inherent in diesel locomotive technology accompanied not one, but several distinct cycles of innovation in the diesel locomotive industry. The timing of these cycles, based on both exogenous and endogenous factors, served largely to define the parameters of corporate participation in the diesel locomotive industry. Each innovation cycle established key elements of diesel locomotive technology, brought new producers into the industry, or drove established firms from the market. Those companies who timed their entrance into or redefinition of the market with the current innovation cycle tended to thrive, those companies that did not were often forced out of business.

By the early years of the twentieth century, mergers and reorganizations had established the oligopolistic structure of the steam locomotive industry. The Baldwin Locomotive Works and the American Locomotive Company (ALCo) each averaged approximately 40 percent of the steam locomotive

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[1] For an analysis of the evocative overtones of steam locomotive technology, see Wachhorst [1987].

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market, although market shares could vary widely from year to year in this volatile producer-goods industry. The Lima Locomotive Works captured the remaining 20 percent of the market, often by acting as an overflow producer, by offering specialty products such as Shay-patent logging locomotives, and by serving as the leading technological innovator in the industry.[2]

All three of these steam locomotive producers ultimately manufactured diesel locomotives, but they were overwhelmed by new entrants into the field – the General Motors Electro-Motive Division (EMD) and General Electric.[3] The ability of these two companies to master diesel engine and electrical equipment technology partly explains their rise to market dominance. Their ability to time their technological and manufacturing advances to match swings in industry innovation cycles provides an equally important reason for their success.

Studies of innovation have assumed considerable importance in the scholarly literature of business history and the history of technology. As early as the 1940s the economist Joseph Schumpeter recognized that technological innovations could create, in his elegant phrase, "gales of creative destruction" which might sweep established producers completely out of an industry.[4]

Christopher Freeman has provided an excellent theoretical discussion of innovation strategies and patterns of innovation. He distinguishes between product innovations, process innovations (of considerable importance to the locomotive industry), energy innovations, and materials innovations [Freeman, 1982, p. 19; Nelson and Winter, 1977, pp. 36-76]. In addition to discussing the differences between product and process innovations, James Utterback's case studies and theoretical works have analyzed the performance of established and invading products and the resulting creation of a dominant new product design

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[2] In spite of widespread popular interest in railroads in general and steam locomotives in particular, comparatively little historical research has been conducted on the American locomotive industry during the mid-twentieth century. Aside from my own work, the only recent scholarship concerning the diesel locomotive industry has come from Marx [1973, 1976]. Marx, an economic historian, studies issues that are considerably different from those addressed here, in that his primary interest lies in the realm of prescriptive macroeconomic policy analysis. In addition, Marx did not have access to the vast wealth of company records relating to individual firms now available to historians. Most of the other secondary works that describe the locomotive industry are intended primarily for the railfan market. They contain many photographs and exhaustive amounts of detail concerning specific locomotive types, experimental models, and railroad assignments, but provide little historical analysis. To a large extent, these works suffer from a common failing in that their primary focus is on the product rather than on the process of production. Nevertheless, they sometimes provide information not readily available elsewhere. Three of the most useful of these books have been written by John F. Kirkland [1983, 1986, 1989].

[3] Both GM and GE are still very much involved in diesel locomotive production and, as such, neither company has granted access to their corporate archives. Nevertheless, other sources provide a wealth of information on the activities of these two companies, particularly during the formative years of the locomotive industry.

[4] For example, see Schumpeter [1942, 1947]. For other analyses of innovation cycles, see Abernathy and Utterback [1978]; Utterback and Suarez [1993]; and Anderson and Tushman [1997].

[Utterback, 1994, pp. 26-32, 80-91, 158-62]. Richard Foster [1986] has shown that new entrants into a particular industry often enjoy an "attacker's advantage" because they are free of the financial constraints, physical facilities, and operational routines that limit the innovative abilities of established producers. Other scholars, such as Clayton Christensen and Richard Rosenbloom, have advanced this argument, showing that established producers often fail to innovate because they do not see the need to explore a new set of performance characteristics and market applications (what Christensen and Rosenbloom define as a "value network") for innovative technology.[5]

Michael Tushman and Philip Anderson [1986] have differentiated between incremental (competence-enhancing) and radical (competence-destroying) innovations in the context of the minicomputer, cement, and airline industries. Rebecca Henderson and Kim Clark [1990] have created a more complex innovative matrix, in part by emphasizing the relationship between modular and architectural innovation in the creation of incremental technological discontinuities. The first of these produces substantial changes in product components, but has little effect on the way in which these components fit together into the product's "architecture." In architectural innovation, however, basic components remain essentially unchanged, but are put together in a new way. Architectural innovations, while seemingly minor, can require substantial changes in organizational routines, and thus can be nearly as devastating to a firm as radical discontinuities.

Five distinct innovation cycles emerged within the context of the diesel locomotive industry. During the 1890s Rudolf Diesel began the development of the technology that bears his name but, despite his interest in railroad propulsion, early efforts to apply diesel engines to railroad equipment met with scant success.[6] The first innovation cycle occurred after Diesel's patents expired in 1912, as more than one hundred companies began to experiment with diesel engine technology.[7] Most of these firms were woefully under-

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5 Christensen [1993, 1994]; Rosenbloom and Christensen [1994], Christensen and Rosenbloom [1995].

6 Even though railroad locomotives are often called "engines," the phrase "diesel engine" refers to the power plant alone, while a "diesel locomotive" includes the electrical equipment, carbody, underframe, trucks, and other components necessary for railroad use. Diesel's 1892 patent was predated by an 1890 patent, issued to Herbert Ackroyd Stewart, for a semi-diesel engine. Unlike a true diesel, this engine required the fuel to be heated before it was injected into the cylinder. Several British scholars, with perhaps a touch of patriotism, have suggested that this British engine represented the true origins of the diesel. For more information on the career of Rudolf Diesel, see Thomas [1987]. This book, part biography and part history of technology, discusses the growth of a new profession, engineering, and the resistance to this by older established professions. It also examines the role of engineers as agents of change and solvers of social problems. Three articles by Bryant [1969, 1976, 1978] are also useful. Also see Diesel [1949] and Cummins [1993].

7 Nelson C. Dezendorf, "Diesel Engines or Gas Turbines for Locomotives?" paper presented to the Pan-American Railway Congress, Mexico City, October, 1950, AAR; *Fortune* 38 (July 1948), 76-81, 144-49.

capitalized, and only one – electrical-equipment giant General Electric – demonstrated any potential for success. GE attempted to exploit economies of scope by transferring streetcar and interurban electrical equipment technology to the production of diesel-powered self-propelled railcars. These railcars, outwardly similar to standard railroad passenger cars, lacked the power to challenge steam freight and passenger locomotives, yet still pushed against the outer limits of primitive diesel engine technology. While GE technicians favored continued research and development efforts, GE management realized that diesels were a money-losing proposition. Preferring to concentrate their efforts on electrical-equipment technology, and feeling increased pressure from wartime orders, GE de-emphasized diesel railcar and locomotive production, and temporarily left the industry in 1918.[8] Despite the limitations of early diesels, this first innovative phase established the standard method of power transmission – the product architecture – for diesel locomotives, one still in use today. With a very few exceptions, all diesel locomotives are actually diesel-electrics, employing an electrical generator to power the locomotive wheels, rather than using a direct-drive power transmission system. GE's R & D efforts during the first innovation cycle set this particular standard.

A second innovation cycle emerged during the mid-1920s, establishing the dominant design of the diesel locomotive. At the same time, this innovation cycle brought three new producers, including the two largest steam locomotive manufacturers, into the diesel locomotive industry. Two distinct, yet equally important factors combined to create this second wave of innovation. The first of these stemmed from government action. In response to public outcries following several horrific accidents in the congested railroad tunnels that lay under the streets of New York City, the state of New York, in 1923, passed legislation banning the use of steam locomotives in Manhattan. The city of Baltimore passed similar legislation in 1929, and Chicago set a target date of 1927.[9] While railroads quickly electrified their main-line trackage into those cities, this option was not economically viable on lightly used switching lines. This situation encouraged ALCo, in a production partnership with GE and Ingersoll Rand, to develop diesel switching locomotives for the New York Central System. The first of these units entered service in 1925.[10] By 1928, Baldwin, in cooperation with Westinghouse, had begun the production of

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[8] "Statement by Harold L. Hamilton," Congress, Senate, Committee on the Judiciary, Subcommittee on Antitrust and Monopoly, *A Study of the Antitrust Laws: Hearings before the Subcommittee on Antitrust and Monopoly of the Committee on the Judiciary*, 84th Cong., 1st sess., 1955, November 10, 1955, 2403; *Railway Age* 75:14 (October 6, 1923), 633-34; Cummins, [1993, pp.695-98]; Berge and Loftus [1949, pp. 2-3]; Kirkland [1983], 67, 71-3; Garmany [1985, pp. 33-4, 53]; Reck, [1948, p. 16].

[9] Martin Clement to John Deasy, November 29, 1927; Deasy to Fred W. Jankins; both in the Pennsylvania Railroad Collection, Hagley Library, box 334, file 416/15. Although the Chicago legislation (passed in 1912) set a time limit of 1927, the city later extended this to 1935.

[10] *Railway Age* 76:23 (May 10, 1924), 1159; 83:19 (November 5, 1927), 890-91; 85:3 (July 21, 1928), 98-100; 86:12 (March 23, 1929), 663-67; Garmany [1985, p. 74].

diesel switchers for the rival Pennsylvania Railroad.[11] This second innovation cycle was of scant benefit to either ALCo or Baldwin, however, since their co-producers, GE and Westinghouse, were the principal innovators of diesel locomotive technology. This innovation cycle resurrected GE's interest in diesel locomotive technology, and that company has remained in the locomotive industry until the present. GE adopted a cautious approach to the uncertainties of diesel technology, at first producing small switching locomotives on its own and supplying electrical equipment for larger freight and passenger locomotives manufactured by ALCo. It was not until 1960 that GE (in response to yet another innovation cycle) committed to the in-house production of large diesel freight locomotives.

Another factor contributed to the second innovation cycle of the 1920s. By the middle of that decade the proliferation of the Model T and other automobiles, along with the growing political power of the good roads movement, had made private automobile travel a viable alternative to public rail travel, even in rural areas. Railroads faced mounting passenger train losses, yet were often legally required to maintain service, and at the same time attempted to retain lucrative mail contracts. Self-propelled railcars offered a solution to the high operating costs of steam-hauled passenger trains, and this led to a resurgence of interest in railcar technology. While more than a dozen companies flirted with railcar production, none was more successful than the Electro-Motive Company (EMC). EMC's strengths lay primarily in the realm of design and marketing, since it subcontracted railcar production to outside manufacturers. Still, the company had managed to dominate the railcar industry by the end of the decade, only to face market saturation and the onset of the Great Depression. Even General Motors' decision, in 1930, to purchase EMC could do little to alter market conditions.[12]

During the 1930s a third innovation cycle saved EMC from extinction and catapulted it into market dominance in the fledgling diesel locomotive industry. Even before that decade began, GM research scientists, including Charles Kettering, attempted to develop diesel engine technology for the vast

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[11] *Railway Age* 84:25 (June 23, 1928), 1451-454; 85:23 (December 8, 1928), 1125-127; 86:14 (April 6, 1929), 787-90; 88:24 (June 14, 1930), 1427-429; 89:25 (December 20, 1930), 1347; G. Maertz to W. W. Atterbury, December 11, 1928; J. H. Harvey, PRR Collection, box 598, file 8.

[12] *Railway Age* 132:11 (March 17, 1952), 90-1; 132:15 (April 14, 1952), 57-8; Railway Progress 12:2 (April 1958), 32-43; Harold L. Hamilton, "Historical Background and Notes on the Development of Electro-Motive," November 22, 1946, "Research Report TI-8: Diesel Development at the GM Research Laboratories, 1920-1938," (Warren, Michigan: GM Research Labs, 1967), General Motors Institute Alumni Foundation's Collection of Industrial History, Flint, Michigan (hereafter referred to as GMI), folder 76-16.1, 19-20, 25, 28; Reck [1948, pp. 14, 22, 58-60]; Reck [1954, pp.32, 39]; Berge and Loftus [1949, pp. 5, 7, 9-10]; "Statement of Harold L. Hamilton," Senate Hearings, November 10, 1955, 2421-422; Hamilton, interview by members of the GM Research Laboratories, October 14, 1957, in "Research Report TI-8," GMI, 90.

automobile and truck markets.[13] While these efforts were initially unsuccessful, GM was able to apply its research concerning high-strength steel alloys, fuel injectors, and other equipment to the construction of diesel submarine engines. These lightweight, high-horsepower engines, sized to fit submarines, were coincidentally a near-perfect fit for locomotives.[14] When railroad officials, such as Burlington president Ralph Budd, saw stationary versions of these engines in operation, they encouraged GM to apply them to locomotive propulsion – an example of customer-driven innovation.[15] Thus, even though GM had purchased Electro-Motive in 1930, it was not until 1935 that GM committed to the diesel-locomotive industry by launching a standardized diesel locomotive line and by building integrated manufacturing facilities for its EMC subsidiary.[16] EMC utilized both product and process innovations during the 1930s but, of these, the former were more important, since the company struggled to standardize production methods throughout the remainder of the decade.[17]

EMC's modular innovations were well-timed, since the mid-1930s constituted a critical, if narrow, window of opportunity in the diesel locomotive industry. Prior to 1933, diesel engine technology was still too primitive to permit widespread application in railroad service. By 1940 improvements to diesel locomotives had made that technology commercially viable, and Electro-Motive had attained market dominance through its investments in research and development programs, manufacturing facilities, and marketing initiatives. Electro-Motive enjoyed the classic "attacker's advantage" during this decade, since its corporate culture, operational routines, and manufacturing facilities were not tied to the production of steam locomotives. ALCo, and to a greater extent Baldwin, lacked this attacker's advantage and remained overly committed to incremental improvements in traditional steam-locomotive

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[13] T.A. Boyd, provisional draft, "Advances in Engines and Fuels: A History of Vital Pioneering in the Field," 1958, GMI, folder 18/3, 71. Leslie provides an in-depth study of the life and career of Charles F. Kettering. Only a small portion of this book (pp. 267-73) is devoted to diesel locomotives, an indication of the breadth of Kettering's interests and abilities. For additional information on Kettering and tetraethyl lead, see Loeb [1995].

[14] "Research Report TI-8," GMI, 80-84, 139, 148, 169, 291-92. Clyde W. Truxell interview, The Kettering Archives, 1965 Oral History Project, March 10, 1961, GMI. An untitled history of the Cleveland Diesel Division, ca. 1962, describes "close cooperation and study" between GM and Navy officials between 1933 and 1940, including, in 1934, the establishment of "the first Navy Training School for Diesel Specialists" at Cleveland Diesel (untitled history, 11-12, GMI, folder 76-16.1).

[15] Cyrus R. Osborn interview, The Kettering Archives, 1965 Oral History Project, June 9, 1964, GMI; Nelson C. Dezendorf interview, The Kettering Archives, 1965 Oral History Project, April 6, 1961, GMI; Speech by Ralph Budd at EMD's Silver Anniversary Dinner, Chicago, October 24, 1947, GMI, folder 76-16.2.

[16] *Railway Age* 101:19 (November 7, 1936), 696; 102:23 (June 5, 1937), 960; 105:19 (November 5, 1938), 680; Boyd, "Advances in Engines and Fuels," 85; GM-EMD, *The Diesel Locomotive: Preface of a New Era*, ca. 1951, GMI, folder 83-12.101, 16; Reck [1948, pp. 90-94, 120-21].

[17] EMD, "Conference Leader's Outline," Subject III, Unit 3C, GMI, 11-12.

product lines. As a result, even though ALCo remained in the diesel locomotive industry until 1969, and Baldwin until 1956, neither company was able to establish the first-mover advantages necessary to guarantee success in that industry.

World War II spawned a fourth innovation cycle that raised the possibility of substantial process innovations at Electro-Motive, GE, ALCo, and Baldwin, although only the first two of these companies took advantage of that opportunity. Intense wartime demand for strategic materials and manufacturing space placed a premium on production efficiency. Both GE and GM's newly created Electro-Motive Division responded by reorganizing work routines and by standardizing manufacturing practices through a system of jigs and fixtures.[18] These efforts lowered manufacturing costs and improved product quality. Baldwin, above all the other builders, remained committed to familiar small-batch custom manufacturing techniques, and its inability to standardize wartime production quickly led to serious quality control problems and a concomitant erosion of customer loyalty.[19] As a result, even though the War Production Board did regulate locomotive production, process innovations in response to heightened demand shaped the locomotive industry more than any other factor during the war years.

By the end of World War II, most U.S. railroads purchased replacement diesel locomotives as quickly as time and finances would permit.[20] This "dieselization revolution" launched a fifth innovation cycle, one that persists to this day. By 1945 the overall design parameters and functional specialization of the diesel locomotive had long been established, and in this final phase, incremental product innovations became of paramount importance in shaping competitive patterns within the locomotive industry. Companies, such as GM-EMD and GE, that were well capitalized and possessed integrated

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[18] "The Development and Growth of General Motors," statement by Harlow H. Curtice before the Subcommittee on Antitrust and Monopoly of the U.S. Senate Committee on the Judiciary, Washington, December 2, 1955, GMI, folder 83-4.2; Borland, "Research Report TI-8," GMI, 293; GM-EMD, *Diesel War Power: The History of Electro-Motive's Diesel Engines in the Service of the United States Navy*, 1945(?), 24-26, 50-51; Reck [1948, pp. 143-44, 152-53, 158-59]; *Railway Age* 113:13 (September 26, 1942), 509; 114:26 (June 26, 1943), 1278-279; 115:6 (August 7, 1943), 239-40; 116:10 (March 4, 1944), 478; 117:4 (July 22, 1944), 176; "Statement of Cyrus R. Osborn," Senate Hearings, December 9, 1955, 3959-962; *Business Week*, November 10, 1945, 44-6; November 12, 1949, 68-74; EMD, "Conference Leader's Outline," Subject III, Unit 3C, 13, 15, 23, 25-26, 28, 34, 39; EMD, "Conference Leader's Outline," Subject IV, Unit 1 & Unit 2, GMI, folder 76-1.61; GE press release, October 13, 1943, Association of American Railroads Library, Washington, D.C., hereafter referred to as AAR.

[19] F.B. Adams to J.B. Hill, July 23, 1945, Louisville and Nashville Railroad Collection at the University Archives and Records Center, University of Louisville, box 56, folder 1870-B; C.J. Bodemer to E.O. Rollings, January 30, 1943, L&N Collection, box 94, folder 51170, part 1B; Hill to Adams, July 25, 1945, L&N Collection, box 56, folder 1870-B.

[20] American railroads did order a few additional steam locomotives after 1945, but, for all practical purposes, the steam locomotive industry had expired by V-J Day. *Barron's* 28 (October 18, 1948), 29-30; 33 (May 11, 1953), 15-16; *Coal Age* 52:12 (December 1947), 74-78; *Railway Age* 123:20 (November 15, 1947), 829-31; 146:14 (April 6, 1959), 10; 152:2 (January 15, 1962), 16, 103; GM-EMD, "Why America Needs *More* Diesels *Now*," 1950, AAR.

manufacturing facilities and a thorough knowledge of diesel engine and electrical equipment technology were able to make sustained incremental improvements to their product lines. Companies that lacked these organizational strengths, and this included all of the established steam-locomotive builders, fell further and further behind.[21] ALCo, thanks in part to its production partnership with GE and to its attempt to keep pace with Electro-Motive during the third innovation cycle of the 1930s, survived until 1969 as a secondary producer. Still, ALCo became increasingly unable to match product innovations at EMD, and this situation led to a widening disparity in quality and reliability between the locomotives offered by the two builders.[22] Since ALCo diesel locomotives were actually marketed as joint "ALCo-GE" products, ALCo's relative failings proved increasingly embarrassing to GE. This situation in turn persuaded GE to dissolve its joint production agreement with ALCo and, in 1960, to enter the large diesel locomotive market on its own account, eventually driving ALCo out of that industry.

Baldwin, already the victim of quality control problems during the World War II years, was in no position to match EMD's product innovations and suspended locomotive production in 1956. The undercapitalized Lima Locomotive Works entered the diesel locomotive industry in 1949, but had little choice other than to merge with Baldwin a year later.[23] A final competitor, Fairbanks-Morse, delivered its first diesel locomotive in 1945, began full-scale production in 1946, and exited the industry in 1959. Fairbanks-Morse was a railroad-equipment supplier that had never produced steam locomotives and, even though it entered the market after the principal design and production parameters of the diesel locomotive industry had been established, it could not equal EMD's rapid, if incremental, product innovations.[24]

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[21] Leonard-Barton postulates that four key characteristics influence organizational core capabilities: employee knowledge and skills, technical systems, managerial systems, and values and norms. Leonard-Barton emphasizes that "All four dimensions of core capabilities reflect accumulated behaviors and beliefs based on early corporate success." The steam locomotive producers developed considerable skills in all four of these dimensions, yet all were inappropriate for the diesel locomotive industry. The last of these, in particular, proved quite difficult to modify. In the case of the locomotive industry, "values and norms", in the form of management's corporate culture, constrained the ability of these companies to adapt to radical technological change.

[22] J. M. Budd to Robert S. Macfarlane, May 10, 1955, Northern Pacific Railway, President's Subject Files, Minnesota Historical Society, box 898, file 2981, 137.G.2.8(F); *Railway Age* 121:16 (October 19, 1946), 636-41; *Diesel Railway Traction* 15:348 (May 1961), 191-97; GM-EMD, "Conference Leader's Outline," Subject III, Unit IB, GMI; Garmany, 161.

[23] Lima-Hamilton, 1948 annual report, 5; 1949 annual report, 4-5; *Railway Age*, 126:16 (April 16, 1949), 802; 129:7 (August 12, 1950), 75; 129:21 (November 18, 1950), 76; Baldwin-Lima-Hamilton Corporation, Consolidation of Baldwin Locomotive Works and Lima-Hamilton Corporation, December 5, 1950, AAR; Baldwin-Lima-Hamilton, 1950 annual report, 3-5; *Business Week*, August 12, 1950, 80; November 11, 1950, 115.

[24] *Railway Age* 137:10 (September 6, 1954), 16; 143:12 (September 16, 1957), 7; 147:11 (September 14, 1959), 68; Kirkland, *The Diesel Builders, Vol. 1*, 53, 65, 67; "Statement of V.H.

Conclusion

Several factors are evident in a long-term analysis of innovation patterns within the locomotive industry. The first is the astonishing frequency of innovation cycles during the formative years of the diesel locomotive industry, followed by a slowdown as that industry matured – a pattern often seen following the emergence of new technologies. The first innovation cycle began in 1912 and ended with increased wartime demand in 1918. The second phase began in the early-to-mid-1920s and ended with the onset of the Great Depression in 1930. The third lasted from 1933 until 1940 and the fourth between 1942 and 1945, the years of heaviest U.S. involvement in World War II. The final innovation cycle, however, began in late 1945 or early 1946, and has lasted until the present. While the third innovation cycle (of the 1930s) enabled Electro-Motive to attain market dominance, it was the final phase that established the ultimate competitive pattern in the industry by weeding the failures from amongst the successes.

Many of the factors that initiated these innovation cycles were exogenous, that is, external to the locomotive industry. Governmental action and the ascendancy of automobile technology initiated the second phase, GM's search for reliable automotive diesel engines began the third, and wartime demand for military ordnance launched the fourth. Only the first and final innovation cycles were directly attributable to factors within the locomotive industry, its suppliers, or its customers.

The most intense period of industry turnover (that is, the number of firms entering or exiting the industry) occurred during the fifth and final innovation cycle, particularly between 1945 and 1969. This finding supports the assertions of such scholars as Philip Anderson, Michael Tushman, Steven Klepper, and Kenneth Simons, who demonstrate that firm turnover is greatest during periods of product, rather than process, innovation.[25] As Henderson

Peterson," Senate Hearings, November 9, 1955, 2356; *Barron's* 31 (April 16, 1951), 27; United States of America vs. General Motors Corporation, April 12, 1961, 7, 10.

[25] Klepper and Simons [1996] examine three models relating technological change to industry shakeouts. They label these the innovative gamble theory, the dominant design theory, and the evolutionary theory. In their study of the automobile, tire, television, and penicillin industries, the authors conclude that the evolutionary model best explains observed industry competitive patterns. Even though the locomotive industry contained far fewer producers than any of the industries studied by Klepper and Simons, the same conclusions hold true. A dominant diesel locomotive design had been established well before the shakeout began, and both product and process innovations had likewise slowed prior to the shakeout. Instead, Electro-Motive, as an early entrant and as the dominant producer, could effectively employ R&D programs to steadily distance itself from its smaller competitors. In other words, Baldwin, Lima, Fairbanks-Morse, and, to a lesser extent, ALCo, simply could not keep pace with Electro-Motive's incremental improvements and instead fell further and further behind as the diesel locomotive industry evolved. Market shakeout in the locomotive industry also supports the conclusions of Tushman and Anderson [1986, p. 460] that "Competence-enhancing discontinuities result in greater product-class consolidation, reflected in relatively smaller entry-to-exit ratios

and Clark suggest, seemingly minor architectural innovations can prove fatal to established producers. Even after builders had established the dominant design of the diesel locomotive, Baldwin, Lima, Fairbanks-Morse, and finally ALCo proved unable to keep pace with incremental innovations or with the reapplication of established components to new locomotive designs.

The five cycles of innovation that helped to shape the past – and the present – of the locomotive industry served to establish the basic elements of diesel locomotive technology and design and to delineate the parameters of participation in the diesel locomotive industry. Companies, such as GM and GE, that responded to technological innovations in a timely manner helped to shape the direction of these innovative cycles and, in the process, ensured their long-term survival in the locomotive industry. Those companies that did not respond effectively to the "gales of creative destruction," and this included long-time steam locomotive producers ALCo, Baldwin, and Lima, lost control over the innovative process and ultimately failed to survive.

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and decreased interfirm sales variability." In other words, as EMD made incremental changes to the dominant technology, railroads tended to standardize on its products and this, in turn, increased firm exits and decreased the variety of locomotive models available.

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