A Wild Ride on Badnall's Famous Undulating Railway

By Joseph C. Meredith

If there is a special heaven for frustrated inventors, a place where everything works, surely the soul of Richard Badnall is there, riding around on the kind of railroad he envisaged for us all, designed according to his "undulating principle." Badnall lived in the springtime of the industrial revolution and its most exciting development: the use of steam power for land transport—not along country roads (unreliable) but along rails, and not by the use of relays of stationary engines pulling on cables (awkward) but by the use of moving engines to pull trains of cars wherever the rails might lead.

Men and animals had been pulling heavy loads along rails of wood and iron for centuries, and even the idea of steam propulsion was not exactly new. As early as 1641 the Frenchman Solomon de Caus declared that steam could propel carriages and even ships. He wrote a book about it, only to be locked up as a madman by Cardinal Richelieu.[1] In 1769, James Watt patented his steam engine, and in 1804 Oliver Evans invented a self-propelled vehicle. Others followed, with models, demonstrations, claims, and counterclaims, all groping toward a workable combination of machine and method. Such a combination was finally attained with the opening of the Liverpool & Manchester Railway (L&M) on September 15, 1830, a date that marked the beginning of the age of the railroad.

Richard Badnall was probably one of the ten thousand spectators at the grand opening, but he could claim no part in the triumph. Like many others,

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he may have ridiculed the self-taught man of the coal pits who had brought it off—one George Stephenson, whose main qualification was that he could make things work.

Stephenson's genius lay in his ability to recognize a good idea and to adapt it to a particular purpose. His first locomotive, patented in 1815, was simply an improved version of one built by John Blenkinsop in 1811. In successive versions over the next fifteen years, Stephenson incorporated the tubular boiler, spring suspension, and the "steam blast," whereby exhaust steam was used to draw air through the firebox. When the directors of the newly organized L&M sponsored a competition in 1828, his four-ton *Jupiter* ran off with the prize of five hundred pounds.[2]

Stephenson saw the locomotive as part of a complete system, all parts of which must work well together. Experience convinced him that cast-iron rails would always be breaking under the weight of engines and cars, and that only wrought iron—in spite of its cost—would do. He also rejected the popular idea of cog-wheel traction and considered smooth wheels and smooth rails better suited to reliable long-distance hauling, even though they limited positive traction and required a nearly level roadbed. Accordingly, the L&M route as designed by Stephenson was a marvel of cuts, fills, tunnels, and bridges. It was also a marvel of costs, but these were quickly compensated by revenues.[3]

Railroad projects blossomed on every hand, but much remained to be done to make the trains safe and reliable, to carry more freight and passengers, and to carry them ever faster, even to 25 miles per hour as envisaged by Stephenson. There was plenty of room for improvement, and ideas poured forth for all kinds of devices—brakes, couplings, signals, whistles—all the paraphernalia of a completely new system of land transport. Some ideas were useful and some were ludicrous, but they all made copy for a new breed of technical journals, notably the *Mechanics' Magazine, Museum, Register, Journal, and Gazette,* all of London, and the *Mechanics' Magazine and Register of Inventions and Improvements,* of New York. Their innocent enthusiasm makes these journals great fun to read even today.

Among all these schemes, none was more fanciful or aroused more controversy than the one proclaimed by Richard Badnall.

Inspiration

Our hero was a gentleman of sufficient means to enable him to publish long treatises such as *A View of the Silk Trade, with Remarks on the Recent Measures of Government in Regard to That Branch of Manufacture* (London, 1828).[4] The trouble with Stephenson's railway, he decided, was that it was too level. Stephenson had called for gradients no more pronounced that 1 in 200, having found that his locomotives spun their wheels on anything steeper. So why not start the train so that it would first be moving downhill, Badnall reasoned, in order to gain speed to carry a train over an opposite rise, then down again, and up again, and so on? Would this not permit using lighter engines, and save wear and tear on the rails?

To test the idea, he fashioned a plank 4 feet long, concave on one side to a depth of 4 inches, and flat on the other. He rigged a wooden cylinder so that it could be pulled along either surface by a string run through a pulley at the end of the plank. At the other end of the string he hung a small weight. He then compared the length of time it took the cylinder to traverse the concave plane and the time it took on the flat plane, and found to his delight that the former was quicker by half, even when he propped up one end of the plank to simulate an overall rise.

Badnall believed he had discovered a new scientific principle. He constructed a model railroad on which to run a tiny clockwork engine and carriage, with two tracks—one horizontal and the other "serpentine," as he called it, dipping and rising every 2 feet along its 32-foot length. At first the little engine gave him some trouble and he had to send it back to its maker for a stronger spring. Satisfied, he packed the contraption off to London and put it on display at the Gallery of Practical Sciences and Works of Art, on Adelaide Street. He also entered a patent application covering his discovery.

Proclamation

Badnall then published a *Treatise on Railway Improvements, Explanatory of the Chief Difficulties and Inconveniences Which at Present Attend the General Adoption of Railways, and the Means by Which These Objections May Be Overcome: As Proved by a Series of Interesting Experiments to Which Are Added, Various Remarks on the Operation and Effect of Locomotive Power* (London, 1833). After an obligatory bow to George Stephenson, he plunges into a discussion of "the imperfections of the present mode of railway conveyance, . . . the difficulty of ascending inclined planes . . . and the excessive weight of locomotives all hindering further development."

The solution, he said, occurred to him on June 7, 1832, and he went on to explain it in a numbing series of formulae, tables, diagrams, and "additional remarks and enumeration of advantages." The book ended with an appendix consisting of letters from "Mr. Rob't Stephenson Senior" to Badnall and to the *London Journal of Arts and Sciences, and Repertory of Patent Inventions.*[5]

Although the letters are not particularly relevant, the name of Stephenson was all that counted. Here Badnall may have deliberately obscured the fact that the Stephenson with whom he had the most contact was Robert. The Stephenson who had designed and built the L&M was *George,* the father. Robert had drafted much of his father's correspondence, however, and may have signed some of it himself. Badnall never bothered to explain that his only contact was with the son.

Badnall's treatise intrigued promoters, politicians, and armchair enthusiasts alike, because it promised a way around the major problems of cost and rights of way. The ensuing flood of letters, queries, and challenges amounted to a classic in the field of journalism, beginning as a stately gavotte, and ending—as we shall see—in a virtual free-for-all.

The first press notices were somewhat skeptical, and the March 1833 issue of the London *Mechanics' Magazine* carried a sarcastic piece by one "Junius Redivivus":

> I have been casually informed that there is exhibiting somewhere about town, a model of an undulating railway, whereby the inventor undertakes to convince the public that the notion of level surfaces being best adapted for wheeled carriages is entirely wrong; and, of course, if his position be correct, the road surveyors have wasted a "pretty amount of money" to make roads worse than they were before, by leveling the hills, which ought to be restored without delay.[6]

Clearly, he went on, undulation would produce no gain in power, "or of any thing but amusement." As for Badnall's claim to originality, the critic noted that from times past, the Russians had enjoyed winter fun on ice hills built on the Neva, which the French copied in a kind of roller coaster they called the *montagnes Russes*, set up on the Champs Elysées. In conclusion, the writer warned that "fallacies like the undulating railway tend to discredit all inventors as plotters of absurdities."

Badnall's response is a superb example of the haughty rejoinder addressed through an editor:

> Sir,—I should not have considered it worth my while to have noticed the letter contained in your last number . . . signed by "Junius Redivivus" had it not been accompanied by some remarks of your own, which I feel it necessary to reply to.[7]

Badnall trusts that the editor will do him justice. He has indeed invented and patented the undulating railway and has exhibited models of it in London and Manchester, "which engaged the anxious attention of some of the most scientific men in this kingdom." He invites the editor (not Junius) to see his engine perform at the Adelaide Street Gallery.

The editor then noted that not having yet seen the model or received a copy of Mr. Badnall's "pamphlet," he will not venture an opinion either way, even though the author's talents, information, and experience seem to "shake his incredulity" in the matter. Somewhere amid the courtly phrases lay a hint of derision.

The next letter came from Benjamin Cheverton, chiding Junius Redivivus for arguing beside the question and for failing to detect the error of the experiments. Cheverton then labored to explain the experiments' flaws, so that Badnall and his friends would not "allow themselves to be deceived, to their bitter cost."

All three communications—from "Junius Redivivus," from Badnall, and from Cheverton—were reprinted in the October 1833 issue of the New York *Mechanics' Magazine,* a younger, livelier version of its British counterpart. Publisher D. Kimball Minor filled its pages with spirited articles on mechanics, chemistry, agriculture, and natural philosophy (such as "Mallet's Plan for Cooking by Gas Flame" and "C. H. McCormick's Self-sharpening Horizontal Plough"), lavishly illustrated with wood-block engravings and nicely printed on a modern press. Wisely, Minor refrained from passing judgment on even the most chancy schemes and contraptions, preferring to let time and trial determine their worth.

Journals in those days freely reprinted each other's material, so that Minor's evenhanded coverage of the Badnall affair was probably as comprehensive as any. Of course the vagaries of postal service jumbled the sequence, and sometimes a reply appears in one issue before we encounter the item that inspired it, in the next.

Retorts Courteous and Discourteous

In a second letter, dated April 22, 1833, "Junius" expressed his resentment of Cheverton's calling him an "unpracticed thinker" whose views were "incomplete and superficial." As for Badnall ("who seems sore with me"), he declined to answer the questions posed, having "neither the time nor the inclination" to enter into the necessary calculations.[8] Soon afterward, having obtained a copy of Badnall's treatise, he fired off a third letter agreeing with Cheverton that the experiment was too crude to prove anything. Minor carried this letter in his next issue, along with a comment from "S. D." declaring that the amount of "friction" would not be any less on an undulating railway than on a horizontal one.[9]

"Friction" apparently meant more than just the resistance of surfaces rubbing together and was taken to include foot-pounds of work. Likewise "velocity" covered all aspects of motion—speed, momentum, acceleration, deceleration—making it easy to overlook how passengers might feel about riding on such a railway.

Demonstration

Badnall was not about to take any of this criticism without a fight. Somehow he persuaded George Stephenson's son Robert to arrange a full-scale trial of his theory, using an L&M engine and cars. The trail would be conducted on the "Sutton plane," a section of rail line near the town of Rainhill with a grade of 1 in 96.

Since the Sutton plane amounted only to half an undulation, Badnall planned to make it do double duty by comparing the times of ascent and descent. First, the train would be brought to top speed before beginning the ascent, and would be timed from a mark at the foot of the slope to the point where it slowed to a standstill at the top. The engine would then be reversed and would push the train down the incline. The time would be measured again for the same distance. If the descent took less time than the ascent, Badnall asserted, the soundness of his principle would be proved.

On the appointed day, several officials and other spectators gathered to watch the experiment. A train of thirteen cars weighing about 72 tons was moved into position about ¾ mile from the marker at the foot of the incline. The engine used was none other than Stephenson's *Rocket,* which had won the famous £500 competition. After getting off to a good start, the engine, the cars, and all finally clattered to a stop 278 yards up the slope, clocking 90 seconds from the marker to that point. The trip back downhill took 50 seconds, indicating that the train acquired enough speed to have carried it to an even greater height in an opposite ascent, had their been one. Badnall was delighted, repeated the test twice, and averaged the results: 81 seconds up, 46 seconds down. No one bothered to measure the time it took the train to reach top speed from a standing start on the level.

A few days later, Badnall and his supporters gathered to conduct additional tests. The crowd this time included nine observers sent over by the French government. The train was twice as long and twice as heavy, and it started a full mile down the track and was brought up to speed by two engines, *Firefly* pulling, *Pluto* pushing. When it reached the foot of the incline, traveling at about 19 miles per hour, *Pluto* dropped away and *Firefly* pulled it on up the slope before coming to a stop 575 yards from the marker, in 1 minute 56 seconds. The trip down took only 14 seconds. The second and third trials produced similar results. For the fourth and most curious test, *Firefly* shut off her steam at the beginning of the ascent, coasted with the train up the slope in 70 seconds, then pushed the train down in 66 seconds.

Almost everyone was impressed. John Knight, the newly hired editor of the New York *Mechanics' Magazine,* was enthusiastic:

> The experiments undoubtedly proved two most important facts, not only that a locomotive can convey, on an undulating line, double the load which it is capable of conveying at the same velocity on a level, *but that it can accomplish this* by the employment of *only half its power*. . . . Admitting the possibility that the use of steam may ultimately be superseded by this plan, the immense saving which would be accomplished in fuel, carriages, machinery, &c. fills an amazing gap in the contemplation, and would be sufficient to counterbalance any attendant disadvantages. Among the principal of these would be the additional capital and labor required for the construction of such a railway, in which a level tract of country, so important a desideratum under the present method, would present one of the most formidable obstacles.[10]

In other words, where no hills existed, railroads would have to create them. Was he joking? Apparently not, as his report had none of the usual rib-poking signals of contemporary satire.

A month later came Badnall's own report, conveying the same information and prophesying that the public, in spite of earlier prejudice and erroneous opinions, would soon acknowledge, appreciate, and benefit from the undulating principle. The same issue carried an endorsement from an American reader, A. Canfield, of Paterson, New Jersey, predicting that the invention would prove to be one of the most substantial improvements ever made to railroads.[11]

In the March issue, however, came a dose of common sense from "a Civil Engineer" of Albany, New York:

> Mr. Editor,—You must pardon me—my patience is exhausted—I can no longer look on and see your respectable and useful paper countenancing an absurdity which none but the blindest species of infatuation (that of an inventor for his favorite project) can support after a moment's serious reflection. . . . I allude to Mr. Badnall's "undulating railway", and *especially to his late experiments on the Liverpool road,* which, it would seem, were seriously witnessed by Mr. Stephenson, the Engineer of that great work.[12]

He went on to say that the trials proved something that needed no proof—that a locomotive could push a train downhill faster than it could pull it uphill. Without bothering to disguise his low opinion of Badnall, he wondered if the English and French seriously approved of all this, or did they smile and shake their heads?

From other letters, it seems there was already a good deal of head-shaking going on, and Knight may have wished that he had shaken his own instead of heralding the trials as a triumph of genius. Oddly enough, English commentators continued to pick over details that Badnall had no trouble dealing with, such as the unevenness of the gradient at Sutton plane, the effect of diameter on locomotive drive wheels, the measurement of speed by counting piston strokes, and so on. But at length the London *Mechanics' Magazine* carried a letter by Benjamin Cheverton, who came down hard on the whole scheme. Badnall was goaded into a reply:

> Mr. Cheverton in a most unwarrantable manner accuses me of withholding the truth when I have the power of publishing it, which truth *if exposed* would (he says) *prove* the poverty of my scheme. . . . He endeavors to sweeten this bitter observation by saying "I cannot believe there is any intention to deceive, *yet it suits his* (Mr. Badnall's) purpose.". . . I am not one, Mr. Editor, who feels disposed to quibble about trifles, or, in discussions of this kind, to be disturbed by every burst of anger from an opponent whom, in this instance, *I feel within my grasp,* but I offer my unqualified protest against the right or propriety of any man attributing unjust motives to another, without a cause which he is unable to substantiate.[13]

Along with more words in the same vein, Badnall begged Cheverton to exempt Mr. Stephenson and other engineers from his remarks, which was a neat way of dragging them in as supporters.

But even among those partly convinced by the demonstrations, there grew a sense of distrust of this man who pressed his claims with such fervor. One wrote suggesting that Badnall had too much of the "man of the world" in his composition, that is, that he was a crook. Many, on the other hand, continued to support the inventor, since the promotion of new lines had become a business in itself, and Badnall's theory could sometimes be turned to advantage. The debate overflowed into newspapers like the *Manchester Guardian* and the *Liverpool Mercury*. Letters signed "Saxulus," "Champion," "S. Y.," "Professor Crackwell," and "Friend" abounded.

Badnall Rampant

Amid the welter, Badnall produced his masterpiece, a three-thousand-word polemic that rose like a rococo fountain among the squirts and dribbles of his enemies. He had something for everyone: injured virtue, manly fortitude, patience toward the uninstructed, humility, pathos, anger, pity, and contempt. He described Cheverton as a clever man:

> but a clever man occasionally errs; and never is he more likely to do so than when inflated with that unhappy quantity of combustible matter,—vulgar abuse, self-sufficiency, and extreme vanity,—which have been so conspicuously displayed

> in the disjointed lectures which Mr. Cheverton has directed to me on this subject. . . . Unless we draw in our horns, the undulating controversy will not only become sickening, but, judging from Mr. Cheverton's last letter, disgusting.[14]

He then veered off to proclaim a new theory of air resistance: that instead of increasing with velocity it actually decreases, as shown by the tendency of all bodies "to rise from the surface of the earth when in rapid motion, such as in the flight of birds." He realizes that such a view is diametrically opposite to received opinion, "but so was the undulating railway!"

Sure of having overwhelmed his critics, he rushed on to predict that within a year, engineers and mathematicians would have an opportunity to make up their minds, and that from that time forward, "*we shall never have another level railway laid down in Great Britain.*" The L&M would always be a monument to British spirit, British perseverance, and British ingenuity, he added, but posterity would smile and exclaim, "Could you have believed it! They expended hundreds of thousands of pounds to make a railroad level!"

The implied slight to the L&M was Badnall's first real blunder, and its effect on the Stephensons and the directors of the L&M can well be imagined. Badnall ended the diatribe by promising more tests and announced that he would shortly publish a new treatise on railroads, with George Stephenson as coauthor.

Frustration

For his new tests, Badnall wanted to use part of a line being built between London and Birmingham under the supervision of the Stephensons. A rail link between the two cities had been proposed as early as 1826, but was not finally approved by Parliament until 1832, after noble landowners along the projected route had been amply paid to withdraw their protests.[15] Since the directors of the L&M were heavily committed to the undertaking, Badnall figured that they could be persuaded to save cut-and-fill costs by letting the new line freely undulate. He reckoned that the directors might overlook his critical remarks about the L&M if they could be convinced of an economic advantage. And so they were. At least they entertained his proposal that 10 miles of the road be built according to his specifications.

Badnall nevertheless failed to reckon as cannily on the Stephensons. Although the elder Stephenson had held Badnall's theory in silent contempt from the beginning, his son's cautious interest had enabled Badnall to snuggle up to the Stephenson name whenever it suited him. Robert apparently did bother to object. Badnall probably did not blame Robert for the flatness of the L&M; it was only his father's notion to have it run level.

Before responding to Badnall's proposal, the newly constituted London and Birmingham board of directors called on Robert Stephenson for an opinion. His report, duly rendered on May 5, 1834, spelled disaster.

Stephenson began by saying that he had been favorably impressed by the model exhibited at the Adelaide Street Gallery, and that he had paid special attention to the experiments made at Sutton plane. On careful consideration, however, he concluded that the apparent advantage in Badnall's scheme was illusory, because for one thing it made no account of the initial velocity. A train could get off to a better start going downhill, of course, but that could not always be arranged. What really mattered was the average performance over distance, and nothing in the formulae or the results showed any gain through undulating.

Turning to practical aspects, he asked what would happen if a train were forced to stop at the bottom of a dip. How would it manage to climb out of it? The only solution offered would be to work it back and forth until it got up enough speed to attain the next summit.

What about the locomotive, flailing downhill one minute and laboring uphill the next? Nothing could be more destructive to the engine. As the world's leading manufacturer of locomotives, Stephenson noted that although steam power was wonderfully flexible, locomotives performed best within a very narrow range of speed. Throughout the report, Stephenson knew just where to apply a very sharp chisel to weaken Badnall's case. At last, he brought down the entire argument, ending with, "No saving in power could by any possibility be effected."[16]

A man less resilient than Badnall would have given up. But Stephenson had left an opening, either because of some lingering doubt or perhaps wishing to bestow a little comfort. Whatever the reason, Stephenson said that a trial on some branch line might be worth considering, since the saving of first costs on such lines was "of paramount importance."

Badnall pounced on the remark. He wangled permission from the little Whiston Branch Railway to use a segment of track being laid out on the natural contours of the land to serve a local colliery. He then appealed to the directors of the L&M for the loan of one of their locomotives. They declined. Finally he located the *Manchester*. Built elsewhere than at Stephenson's Newcastle works, the engine was available—as Badnall would learn—possibly because it was virtually unfit for ordinary service. With customary fanfare, he announced a new series of tests on a truly undulating railway.

The *Manchester,* although said to be powerful, was also considered unsafe, with a regrettable habit of galloping off the rails at high speed, as had been shown by a recent mishap on the Sutton incline. The descent from the colliery would be twice as steep, and since the owners of the engine insisted that it be returned in good condition, Badnall faced a problem. His theory required that full power be applied downhill as well as on the upgrade, but he was warned that a solitary car had careened 30 miles an hour down that particular slope. It began to look as if he were arranging the most spectacular wreck of the decade.

With these doubts about the *Manchester*, he applied again to the L&M for a suitable engine, guaranteeing to pay for any damage, only to receive the following reply:

> Dear Sir:
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> I submitted to the Board your renewed application for the loan of a locomotive engine for your proposed experiment on the Whiston Branch Railway, and am required to inform you that the Directors regret they cannot comply with your request. They gave the matter due consideration previous to their former decision, and they do not see reason to alter the determination they came to. I am, dear Sir, yours most obediently,
>
> H. T. Booth, Treasurer [17]

At last Badnall got the message.

So the test went ahead on October 24 with the *Manchester* alternately pulling and pushing a load of 80 tons back and forth through a dip in the line, first a distance of 760 yards, then 794 yards, and successively 824, 862, 900, 1,071, and 1,167 yards. By now the poor engine was in sad shape, "almost an encumbrance." The engineer was terrified and kept spoiling things by applying the brakes. The test had to be abandoned, having proven only that a locomotive could push a train.

Badnall took to his bed in October and was no more heard from until the end of the year, when he published a long letter blaming the *Manchester* ("from every point of view unsuitable") and hinting that H. T. Booth had earlier misled him. Castigating the Whiston Branch Railroad for not providing an accurate survey, Badnall apologized for not having proven his theory as promised. For the first time, he conceded that "for practical purposes a dip of about fifteen feet in a curve of 1,000 to 1,200 yards [i.e., 1:200 to 1:240] should seldom be exceeded." This was exactly the standard on which George Stephenson had insisted from the beginning.

Beyond Badnall

The notion of an undulating railway faltered to a stop. The New York *Mechanics' Magazine* reprinted Badnall's last letter and quietly let the whole matter drop, perhaps embarrassed at having ever credited the idea. Moreover, it was obvious to railroad builders in America that they had plenty of natural undulations to contend with, without creating artificial ones for the sake of a dubious theoretical advantage.

In fact, railroading in America quickly branched away from the English model. There were greater distances, hills, and rivers for the railroads to contend with. On the other hand, there was less local opposition calling for circuitous routing and fewer costly viaducts and bribes. American locomotives soon displaced English imports. Better traction was gained by doubling and tripling the number of drive wheels. When combined with greater power and weight and stronger rails, these measures went far to overcome the difficulties of terrain that gave American railroads their unique character.

Special conditions called for special fittings and equipment, and Yankee ideas for improved brakes, valves, couplings, wheels, carriages, bridge trusses, and rails spilled across the pages of Minor's *Mechanics' Magazine* and other technical journals. It was the age of the amateur inventor. Huge profits beckoned, and everyone got a hearing. The railroad was seen from the beginning as a harbinger of prosperity and growth, compensating for the deplorable state of American roads.

By 1836, the railroad mania was in full swing on both sides of the Atlantic. With new lines being planned wherever shares of stock might be sold, promoters in top hats and frock coats proclaimed glorious opportunities to eager audiences. Fortunately, the panic of 1837 nipped the American version of the mania in time. The *Mechanics' Magazine* passed through some hard times, but survived under the editorship of engineer George Schaeffer after Minor merged it with the *American Railroad Journal*. Minor himself sold out to his printer in 1839, only to resume control in 1843, and finally to sell out again in 1848 and depart for the California gold fields.

During this same time, the railroad fever in England continued unabated. A Parliamentary committee continued to control approvals for new lines, but proposals came in faster than they could be properly considered, while speculators traded merrily in the stock of projected roads. Prospectuses flowered with the names of the high and mighty. At one time, 157 members of Parliament were listed as subscribing to various issues, often for huge amounts.

Old George Stephenson would have nothing to do with these joint stock companies, but other engineers were not as fussy. One even sold his name for a thousand guineas. There grew a school of "fast engineers" who ridiculed Stephenson's conservatism and promised all kinds of innovations, such as the "pneumatic railway," which was to be powered by a piston in a long vacuum tube.

In 1845 Parliament approved construction of 2,883 miles of new railway, and in 1846 an additional 4,790 miles. More than 620 new lines were projected when at last the market in shares began to falter, and Parliament called for complete surveys of all proposed lines. Suddenly it was discovered that there were not enough surveyors in England to meet the deadline, and most of the projects went under. For Richard Badnall and his adherents, it was the end of the line. □

Notes

[1]Samuel Smiles, *The Life of George Stephenson, Railway Engineer*, 2nd ed. (London, 1857), pp. 60–61.

[2]Ibid., pp. 79–82, 136.

[3]The L&M carried 445,047 passengers and 99,374 tons of freight in its first full year of operation and regularly paid 10 percent on capital thereafter. Richard Tames, *The Transport Revolution in the Nineteenth Century, a Documentary Approach*, vol. 2, *Railways* (Oxford, 1970), pp. 15.

[4]Badnall's name appears in "List of Men of Science, Engineers, and Mechanics," in *Mechanics' Magazine* (London) (March 1831): v–viii, as follows: "Badnall, Richard, Esq., Silk Manufacturer, Inventor of several improvements in Silk Machinery, Author of 'A View of the Silk Trade,' and other Works."

[5]Merged in 1832 with *The London Journal of Arts, and Sciences; Containing Reports of All New Patents, with a Description of Their Respective Principles and Properties; Also Original Communications on Subjects Connected with Science and Philosophy, Particularly Such as Embrace the Most Recent Inventions as Applied to the Arts.*

[6]*Mechanics' Magazine* (New York) (October 1833): 208–11, reprinted from *Mechanics' Magazine* (London) (March 1833): 419–22.

[7]*Mechanics' Magazine* (New York) (October 1833): 211–12, reprinted from *Mechanics' Magazine* (London) (April 1833): 29–31.

[8]*Mechanics' Magazine* (New York) (November 1833): 265–68, reprinted from *Mechanics' Magazine* (London) (April 1833): 72–76.

[9]*Mechanics' Magazine* (New York) (December 1833): 317–18, reprinted from *Mechanics' Magazine* (London) (May 1833): 107–8.

[10]*Mechanics' Magazine* (New York) (January 1834): 27. Knight had been hired away from the London *Mechanics' Magazine* and probably witnessed the tests before leaving England.

[11]*Mechanics' Magazine* (New York) (February 1834): 67.

[12]*Mechanics' Magazine* (New York) (March 1834): 161–63.

[13]*Mechanics' Magazine* (New York) (March 1834): 163–64, reprinted from *Mechanics' Magazine* (London).

[14]*Mechanics' Magazine* (New York) (April 1834): 196–201, reprinted from *Mechanics' Magazine* (London) (November 1833).

[15]Smiles (n. 1 above), p. 321.

[16]*Mechanics' Magazine* (New York) (week ending 21 March 1835): 169–72, reprinted from *Journal of the Franklin Institute* (January 1835): 1–6.

[17]*Mechanics' Magazine* (New York) (May 1835): 257, reprinted from *Mechanics' Magazine* (London) 22: 253.