

The forgotten discovery of gravity models and the inefficiency of early railway networks

Andrew Odlyzko

School of Mathematics
University of Minnesota
Minneapolis, MN 55455, USA
odlyzko@umn.edu
<http://www.dtc.umn.edu/~odlyzko>
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Abstract. The routes of early railways around the world were generally inefficient because of the incorrect assumption that long distance travel between major cities would dominate. Modern planners rely on methods such as the “gravity models of spatial interaction,” which show quantitatively the importance of accommodating travel demands between smaller cities. Such models were not used in the 19th century.

This paper shows that gravity models were discovered in 1846, a dozen years earlier than had been known previously. That discovery was published during the great Railway Mania in Britain. Had the validity and value of gravity models been recognized properly, the investment losses of that gigantic bubble could have been lessened, and more efficient rail systems in Britain and many other countries would have been built. This incident shows society’s early encounter with the “Big Data” of the day and the slow diffusion of economically significant information. The results of this study suggest that it will be increasingly feasible to use modern network science to analyze information dissemination in the 19th century. That might assist in understanding the diffusion of technologies and the origins of bubbles.

Keywords: gravity models, railway planning, diffusion of information

JEL classification codes: D8, L9, N7

1 Introduction

Dramatic innovations in transportation or communication frequently produce predictions that distance is becoming irrelevant. In recent decades, two popular books in this genre introduced the concepts of “death of distance” [7] and “the Earth is flat” [25]. In the first half of the nineteenth century, the railroad, later accompanied by the electric telegraph, gave rise to the frequently cited mantra of “annihilation of time and space.”

However, while distance has become less important, it is still significant, and continues to be underestimated. For example, in the early days of the ARPAnet (the direct ancestor

of today’s Internet), the high volume of local traffic was unexpected and was regarded as embarrassing, so was suppressed in official reports ([26], p. 26). Even in modern social networks, it has been found that there is a strong locality, in that people who live close to each other tend to interact more than those far away [35].

Since World War II, many fields have come to rely on what are called “gravity models of spacial interaction,” which provide a quantitative estimate for the degree of locality in transportation or communication. In the simplest form, these models say that two populations P_1 and P_2 at distance D apart interact (as measured by number of plane flights, phone calls, emails, or similar activities) with intensity proportional to

$$\frac{P_1 P_2}{D}. \quad (1)$$

A recent book declares that “engineers, economists, and planners alike have had a love-hate relationship with” gravity models ([34], p. 76). The problem is that they are very rough guidelines, never exact. Very often, in order to obtain a better fit, variants of them are used, such as

$$\frac{P_1 P_2}{D^\alpha} \quad (2)$$

for some constant α , typically with $1 \leq \alpha \leq 2$. Frequently, even more elaborate versions are used, occasionally with D replaced by some generalized measure of cost or distance separating P_1 and P_2 . Still, even though gravity models are not as accurate as their users might hope for, they are extremely useful, just like Pareto’s and Zipf’s “laws” are.

Nothing will be said here about the huge modern literature on gravity models, their applications, limitations, and justifications. (Some references are in [34].) We consider just their history, and how they could have affected the economy had they been used properly from the beginning.

Gravity models came into widespread use only after World War II. However, they have a longer history, and current literature attributes the first statement of something like a gravity model to the American economist Henry Carey in 1858 ([8], vol. 1, pp. 42–43). Carey’s was a very imprecise formulation, and he provided no empirical evidence to substantiate it. The next known instance of something like a gravity model occurs in the work of the geographer and demographer Ernst Ravenstein [47,48] in the 1870s and 1880s, who, relying on data from UK censuses, came up with rules for migration that were similar to Eq. (1). There seems to be no evidence that anyone tried to apply the works of Carey or Ravenstein to any practical problems in the 19th century.

This paper shows that gravity models were discovered in 1846, a dozen years before Carey published his book, by Henri-Guillaume Desart, a Belgian civil engineer [19]. By analyzing an extensive and unique for that time set of data, the detailed statistics for passenger travel on Belgian railways, he came up with a version of a gravity model (Eq. (3) in Section 7), and then, a year later, with essentially Eq. (2). Desart’s investigation was motivated by a very practical problem, the design of the Belgian railway system. Had his results become widely known, and interpreted properly, railway systems around the world would surely have been built far more efficiently. The problem was that railway planners

did not have a proper appreciation of the locality of traffic, and were expecting most of the demand to come from long distance travel. This led to pursuit of what were called “direct lines” and associated branches (see Section 2 for more detail), typically focused on a handful of the largest cities. Local and cross-traffic was neglected. Gravity models would have shown this was an inefficient strategy.

How large were the losses from reliance on faulty design principles? That is impossible to tell with precision. However, a suggestive estimate is offered by the recent work of Mark Casson [9]. He designed an alternate railway layout for Britain, which satisfies the traffic demands of 1914 at a construction cost about 25% lower than the actual system that existed then, and with about 35% lower route mileage. Since cumulative railway investment in Britain amounted to about 60% of GDP, a 25% saving of that would have been about 15% of GDP, a huge amount. It seems reasonable to assume that a substantial fraction of those savings might have been realized had gravity models (which were a key tool in Casson’s work) been used in railway design in Britain in the 19th century¹.

Desart’s first work on gravity models was published in early 1846, and was publicized in Britain in the summer of that year, just as some of the key railway investment decisions were being made. Hence it presents an interesting “what if?” question. With just a little more publicity and support from some influential figures this novel conceptual breakthrough could have led to a dramatic improvement in the efficiency of the economy (including saving many investors from ruin). But that did not happen, as Desart’s findings were misinterpreted to a large extent (including by himself) and more than anything were ignored.

This paper makes several contributions. One is to give credit to Desart for pioneering work, far ahead of that of his contemporaries. Another is to document a failure of significant economic ideas to diffuse properly, resulting in huge inefficiencies in railway design. Yet another is to show how digitization of historical material is making it possible to employ techniques from modern network science to study information transmission in the past, which may lead to better understanding of economic growth, technology development, and booms and busts.

Section 2 describes the erroneous notions about the nature of demand for railway service that were dominant in the first half of the 19th century. Most of the space, sections 3 through 11, is devoted to showing how various items of information about the importance of local traffic kept appearing in various places with increasing frequency, yet were never combined into a comprehensive presentation of the falsity of the dominant paradigm, and of the damaging implications of this failure for the design of the British rail network. Section 12 has some informed speculation on the reasons for the slow spread of information about sources of demand for railway service, and the chances it might have been changed by actions of some individuals and press organs. Section 13 outlines how the findings of this paper should become the core of a comprehensive picture of the information flows concerning the locality of rail traffic, as more digitized material from that period becomes available. Finally, Section 14 has the conclusions.

2 The direct line paradigm

Initially, railways were short and isolated lines, and were universally understood to be built to serve local traffic, typically from a mine to the nearest navigable waterway. What changed public opinion, and gave rise to the (smaller) British railway mania of the mid-1830s, was the technological and, more important, financial success of the Liverpool and Manchester Railway, which opened in 1830. Although initially envisaged as a slow carrier of heavy goods, its success came from fast transport of passengers. This sent imaginations soaring, and the business plans of the lines projected in the 1830s and built over the next decade were based primarily on revenues from passenger transport. Furthermore, the primary source of those revenues was expected to be travel between terminal cities, and a secondary source the travel of people in the vicinity of the line to and from those terminal cities. Branches were called “feeders,” and were expected to funnel traffic to the cities at the ends of the trunk line. Construction of such branches was therefore justified, even if traffic on them was going to be too small to make them profitable by themselves, on the grounds those passengers would contribute substantially to revenues of the main lines. Often analogies were drawn to river systems, where streams would coalesce into rivers and those would merge into the main river on its way to the sea.

Under those conditions, it is natural that direct lines would be preferred. This thinking was not particular to Britain, it dominated throughout Europe and the U.S. as well. This was not entirely unreasonable in the early days of the railways, when little was known on how well they would work and how they would be used. The world is now building a variety of high speed rail lines, starting with the Japanese “bullet trains” of half a century ago. Those are direct lines in the sense those were envisaged in the first half of the 19th century, with track as straight and level as economically feasible, and few stops. However, to justify them, it is necessary to have very high travel volumes, which simply did not exist 150 years ago.

An illuminating example of early thought about railways is the 1836 English translation [41] of a book by Claude-Louis Navier, 1785–1836, a famous engineer and physicist who is remembered today primarily for the Navier-Stokes equations, basic to fluid mechanics. The translator was John Macneill, 1792/3–1880, an eminent Irish civil engineer, professionally active on railway and other projects throughout the UK [36]. Both the author and the translator were highly respected members of the engineering fraternity. Navier wrote ([41], p. 8):

It is superfluous to remark, besides, that the condition of diminishing, as much as possible, the time of transit between two given points, requires that we should endeavour to reduce also the length of the Rail-way which is proposed to be constructed between these two points. ... The same principle which rendered the establishment of a Rail-way desirable, in order to obtain a mode of transport quicker than any other, requires that the shortest lines be sought after, and even to prefer them when sometimes they appear to be disadvantageous in other respects.

Navier’s neglect of local traffic was typical, and affected railway design. Even a casual inspection of contemporary literature provides a multitude of examples where even a mild

appreciation for the importance of locality would surely have affected early Victorian design decisions about their evolving railway network. As just one example, consider the 1843 report of two railway engineers, G. Johnson and N. Wood, on routes from England to Scotland². They claimed that “[i]t cannot for one moment, we presume, be contended” that accommodation of an intermediate population should carry more weight than that of far larger populations in the terminal cities. But that is precisely what gravity models show can be “contended,” if the distance and density conditions are right. (Whether that was so for the case considered by Johnson and Wood would require more detailed investigation, which has not been attempted.) Take a very simple example, with four cities almost in a straight line, as depicted below:

$$A \text{ — (100 miles) — } X \text{ — (50 miles) — } Y \text{ — (100 miles) — } B$$

Suppose the populations of X and Y are 25,000 each, while those of A and B are 100,000 each, and that a gravity law such as that of Eq. 2 holds with $\alpha = 2$ for the number of trips. Then, if fares are proportional to distance (as was common), the revenues will obey a law of the form Eq. 2 but with exponent $\alpha = 1$, and so total revenues will be a constant times $16/250 = 0.064$ for trips from A to B, $8/100 = 0.08$ from either A to X or from B to Y, $8/150 = 0.0533$ from either A to Y or from B to X, and $1/50 = 0.02$ from X to Y. So of total revenues of 0.2173 times that common constant, less than a third will be derived from trips between the terminal cities A and B. This argues for paying more attention to the travelers to or from X and Y, and for routing the line through those cities. But the early Victorian railway designers did not have such quantitative tools at their disposal. They were predisposed to choose more direct lines between A and B that bypassed X and Y, and served those smaller cities via inconvenient branches.

Some people had the right intuition about the importance of local traffic early on. The best example of that is the railway engineer John Hawkshaw. In his report to the Great Western Railway in 1838, and in his testimony to the Gauge Commission in 1846, he expressed explicitly his vision of the main function of railways being to serve local traffic³. But he was a pioneer, far ahead of his contemporaries. Furthermore, it does not appear that he ever presented any quantitative evidence to substantiate his vision.

It should be said that few of the railways built by the mid-19th century fully met the ideal of “direct lines.” Even modern ultra-high speed lines are designed by taking into account the costs of tunnels, bridges, real estate, and so on, and do make deviations in order to keep costs under control or to serve large populations near the route. Similarly, the engineers in the 19th century had to optimize their design subject to numerous constraints. (They included some political ones, such as not disturbing certain influential aristocrats’ fox hunting grounds, for example.) What we can say, based on comments from experts in Britain in the 1850s after the crash of the Railway Mania (such as the one from Samuel Sidney that is quoted in Section 11), is that far too much weight was placed on directness and on serving intermediate populations through branches, and not enough on routing the lines through the large intermediate centers. Just how much difference this made, compared to the optimal design, is hard to determine without carrying out an exercise as extensive as that of Casson [9], but with the information available to the early Victorians.

3 Railway traffic theories in Britain

There was never any systematic inquiry by anyone about locality of traffic in Britain. The likely reasons for this are discussed in Section 13. Still, some people did wonder and speculate. An interesting case is that of John Herapath, 1790–1868 [36]. He was a mathematical physicist of note, a pioneer in the development of the kinetic theory of gases. However, by the 1830s, his energies were directed primarily to railway journalism. He became the owner and editor of *Herapath*, the first serial in Britain to specialize in this novel technology. In early 1838, he was intrigued by some statistics about traffic on the Grand Junction Railway (discussed in more detail in Section 4). He used that, as well as a few scraps of data he obtained from other lines, to develop a theory⁴ that the number of passengers from a large city who traveled a distance d was basically $\exp(-\beta d)$ for a constant β . Thus he derived an exponential decrease, in the correct mathematical meaning of the word “exponential,” whereas gravity models now tell us the decrease obeys a power law.

Within two years, Herapath changed his mind, and came up with a different theory, one that emphasized importance of long distance travel. In 1839 it was observed that on several lines that were only partially open, traffic was lighter than expected, but that there was a rapid increase as more sections were placed in service. Herapath came up with a plausible explanation, and a semi-quantitative rule that emphasized the role of long-distance traffic⁵. Herapath’s “law” was based on scant evidence, and applied to only a limited range of situations. He even noted that “[i]t would be absurd to deduce general laws from so limited an experiment.” But this work was then stretched to support theories that went far beyond what was justified. According to a laudatory piece published in 1846 in the *Railway Register* (most likely written by Hyde Clarke, the editor of that serial, who will be quoted later), it was used to justify interconnection and extension of the railway system. The reason was that passengers connecting from other lines were expected to travel over most of the length of a given line⁶. Herapath’s theory also helped explain away an awkward fact, namely that traffic on railways continued to increase year after year. The general expectation in the first half of the 19th century was that of a generally static economy. Occasional jumps were hoped for, such as those caused by the construction of a railway, but they were expected to lead to an essentially constant level of revenues after a short period of “traffic development,” cf. [42]. The continued increase that was observed on many lines could be made to fit this mental model by attributing it to the effect of traffic coming in from new branches and other lines that were being placed in service.

Nothing more sophisticated than the two conflicting theories of John Herapath has been found in the British literature before 1850. This illustrates how little attention was paid to locality of traffic. It also illustrates the lack of data on which to build useful theories. Herapath came up with his ideas in response to just a few fragments of solid traffic information. British railways generally did not collect detailed statistics on traffic, and published even less.

4 Railway traffic evidence in Britain

Although there was little systematic collection of railway traffic statistics in Britain, as time went on, evidence kept accumulating that went counter to the prevailing dogma that terminus to terminus traffic dominated. Eventually, as more material from that period gets digitized, and better tools are developed for extracting rough meaning from text, it should be possible to obtain quantitative measures of the volume of such discordant data, and of the degree to which it sowed doubts in the minds of contemporary observers. For the time being, we consider some snippets that illustrate what was known, and how various people reacted.

Much of the contrarian data that accumulated could be fit into the dominant paradigm of long distance traffic dominating. There was far more traffic at intermediate stations than had been anticipated, for example⁷. But this could be explained away by saying that more people in the countryside than anticipated wanted to travel to terminal cities, as opposed to traveling between those intermediate stations. But sometimes the data was awkward enough that contemporary observers had to admit they could not explain it away. As an example, at a shareholder meeting of the Manchester and Leeds Railway in early 1840, extensive statistics were presented on the operations of this line, which at that time was open for only 13.5 miles of its entire 50-mile length. John Herapath commented on the “curious fact, but given in a way we cannot make much of, ..., that of '346,412 passengers travelling during six months, only 244,500 arrived at or left Manchester'”⁸. He clearly expected almost all those passengers to go through the terminal in Manchester.

When it suited railway managers, they did collect and announce some fragmentary traffic data that demonstrated locality of traffic. One incident of this nature occurred very early in the history of the industry. The Grand Junction Railway (GJR), the first long (87 mile) trunk line to open in Britain, had been in operation for only about two months in 1837, when, at the regular half-yearly meeting, the directors presented a report on operations up to that point⁹. They included a table of receipts for various types of trips, and noted:

From the foregoing analysis are elicited two facts, highly important to the interests of the company, namely, the large amount received in what is called road money or short fares, a portion of the revenue which cannot easily be alienated; and the small receipts, whether considered positively or relatively, of the Manchester part of the traffic. This latter result, though it has disappointed the expectations of the directors, may be looked upon as having a favourable bearing upon the permanent prosperity of the concern. It has not only shown how exaggerated were the estimates of the Manchester business, but it has added another to the many proofs of the fallaciousness of Parliamentary evidence; and by removing the delusion which has so long existed on this subject, it may tend to limit the views of the subscribers to railways for which acts have been lately obtained.

So the directors of the GJR recognized, after just a few weeks of operation, that actual traffic patterns were not what had been expected, and that local traffic dominated. And

they realized what this meant, namely that competitors coming in to the large cities would not be able to grab this business (“alienate” it) away from the GJR.

It is not clear whether GJR managers persuaded many skeptics, as their claims were clearly self-serving. They were trying to demolish a proposal for a direct line from Birmingham to Manchester, and so they had strong incentives to (i) persuade their shareholders that a new line, if built, would not divert too much of their traffic, and, more urgently, (ii) find evidence to show that the new line would not be viable, which would hopefully make Parliament kill the proposal. And locality of traffic served to do both. Once the incentive disappeared, the key observation about the nature of traffic and the insight about what it meant seemed to be forgotten, only to be rediscovered by other managers when the necessity arose again¹⁰.

The GJR continued publishing relatively detailed statistics that demonstrated the dominance of local traffic for a while, and one of them motivated John Herapath to come up with the theory of railway traffic cited in Section 3. After a while, though, the details in the GJR reports diminished. However, in the meantime, a variety of other, less detailed, statistics from other lines started proliferating. In response to shareholder demands for better information on their fortunes, British railways started releasing to the press weekly “traffic returns.” Initially they varied a lot in format, in that some lines would announce the number of passengers in a week, others just revenue (either broken out into passenger and goods categories or just the total), and some both. If we consider the table in the 15 August 1840 issue of *Railway Times* as just one example, we find from it that on the Midland Counties Railway, which was 57 miles long, the average trip was 16.5 miles¹¹. Thus the public had available to them information that did demonstrate the importance of local traffic, although this was not stated explicitly, and required a little calculation.

Soon even explicit statements about locality of traffic started appearing. In the early 1840s, the Railway Department of the Board of Trade (a British government department) started collecting statistics on railways. Starting with its 1843 annual report, it started publishing data on average passenger trip lengths¹². Samuel Laing cited some of those numbers in his report for the 1844 Gladstone railway committee [30], in particular that the average trip length was 15 miles in the UK (and 22 in Belgium).

There were also some more scholarly studies that considered locality of traffic, or at least the average length of passenger trips. So far two papers have been found on this topic, both presented to the Statistical Society of London (which later became the current Royal Statistical Society). In April 1844, G. R. Porter presented a variety of statistics about railways [46]. He did not devote much attention to lengths of trips. Still, at the end of his paper, he did note (citing Laing) that the average distance traveled by a passenger was 13.3 miles in the UK. The Statistical Society usually had two papers presented at each monthly meeting. Porter’s paper was the only one of the two in his session that received any attention, and it received a lot. Moderately detailed reports were published (mostly reprinted from other sources) in many papers¹³. Most of the accounts of the April 1844 meeting cited a variety of the statistics that Porter had collected, and in most cases they ended up mentioning that the average passenger trip in the UK was 13.3 miles. However, that was just one statistic among many, and may have been treated as just an amusing

but unimportant curiosity¹⁴. There was no discussion at all about the extent to which this statistic contradicted widely held beliefs and had implications for the design of the British railway network.

A year later, W. A. Graham, inspired at least in part by Porter's work, presented a paper with detailed statistics for various railways, and how those evolved over the preceding couple of years [28]. Distance distribution of passenger trips was a prominent part of his work, and demonstrated that on most lines, average trips were just fractions of the lengths of the lines. However, Graham did not draw any implications for railway system design from his research, nor did any of the writers who cited his work. Further, press coverage of the meeting where he presented his paper was heavily biased towards the other paper from that meeting, one by E. Balfour on mortality of British troops in the colonies. It would be nice to understand why Porter's paper caught so much more attention than Graham's.

5 British Railway Mania and direct lines

The preceding section showed that at the time of the Railway Mania there was a growing volume of evidence that railway trips were mostly local, and that building direct lines was not advisable. At the same time there was a conflicting trend, a rising tide of enthusiasm for direct lines. Practically all the railways built as a result of the smaller railway mania of the 1830s were making profits, and investors were willing to pour huge amounts into new construction. Hence there was a feeling that there was no need to compromise by accepting "circuitous lines," and that direct lines were finally becoming achievable.

The Times was very skeptical about direct lines at the end of 1844, but turned into an ardent advocate of them by the end of the next year¹⁵. Another example of such a transformation is presented by Hyde Clarke, who was mentioned in Section 3. During the 1840s he was primarily a railway journalist. In December 1844 he started editing the monthly *Railway Register*. The inaugural issue had a review of a book [17] by the engineer G. D. Dempsey. It seems safe to attribute this review to Clarke:

Beginning *ab initio*, Mr. Dempsey lays down the abstract principle that the theory of a perfect railway requires that it should follow a right line on the plan, and be uniformly level from end to end. This condition is, however, liable to modifications from local circumstances, and more particularly from the necessities of the traffic. This limitation is, in our opinion, the most important, for the greatest blunders have been committed by inattention to it, and by the erroneous idea formerly prevalent of running crow-flying lines, regardless of traffic. The Brighton, the Grand Junction, and the South Eastern, are examples of this; and however profitable one of them may have hitherto been, and however profitable it may hereafter be, there can be little doubt that its resources would have been much augmented by following the line of population.

This was a clear denunciation of direct lines (although "the erroneous idea ... of running crow-flying lines, regardless of traffic," was still "prevalent," when this passage was written). But as time went on, the tone of the *Railway Register* changed. Towards the end of 1845, we find enthusiastic support for direct lines¹⁶.

6 Minard and ‘parcours partiel’

Charles Joseph Minard, 1781–1870, was a French civil engineer¹⁷. He is known today primarily for his contributions to information visualization. Edward Tufte wrote of Minard’s famous flow map of the march of Napoleon’s army into and out of Russia in 1812–1813 that it “may well be the best statistical graphic ever drawn” ([52], p. 40). Minard had been a pioneer in visualization since the 1820s, stimulated by the issues he encountered in his career as an engineer of the French government’s Corps des Ponts et Chaussées (CPC) and as instructor and administrator at the École Nationale des Ponts et Chaussées (ENPC).

In February 1842, Minard published a short, 15-page, pamphlet [37] on the importance of ‘parcours partiel,’ or travel that did not go from one endpoint of a line to another. It was clear he felt he was taking a contrarian view. He argued that altering a line to go through substantial towns not far from crow’s flight straight line “would not be the great evil it was thought to be, but might lead to beneficial results.” To substantiate his claim, he produced a table for 6 French routes, 14 Belgian, and 2 English, showing what fraction of their revenues was coming from ‘parcours partiel.’ Minard claimed that “in the presence of such results, one cannot ignore the importance of relations of intermediate points among themselves and with the terminal cities.” He argued that it was better to deflect the main line to go through populous towns than to build branches from them to a ‘direct line.’

A remarkable fact was how little data was in Minard’s pamphlet, a reflection of how little was available anywhere. It is especially noteworthy that most of what little he was able to find came from Belgium. That small country was the world leader in creating a unified railway system [12]. It was built and operated by the Belgian government. Since it was run by the government, and its pricing and other policies were subject to debate among the public and in the legislature, systematic reports on its finances were prepared each year, and Minard was able to exploit those.

In May 1843, Minard followed his first pamphlet with a second, 45-page, one [38]. He explained that his 1842 work failed to persuade many people, who continued to regard traffic between terminal cities as the most important. They “looked at the facts [Minard] cited as exceptional.” Therefore he collected more data in order to substantiate his claim that his 1842 results were of general applicability. He concluded that it required special circumstances for ‘parcours partiel’ not to dominate. In May 1846 he published another short pamphlet on this topic [39].

The main attack on Minard’s theory was launched in August 1843, just three months after the publication of his second pamphlet, by C. Courtois, the chief engineer of the CPC. Courtois mounted a spirited defense of direct lines [11]. He admitted that there was a rise in favorable sentiment towards laying out railway routes that would deviate from the direct principle so as to include substantial population centers in the vicinity of the line, and that support for such moves was provided by the “talented” Monsieur Minard. However, he claimed such proposals were dangerous, and had to be prevented from being put into effect.

Courtois attacked Minard’s work on a variety of grounds. A vigorous debate appears to have followed. Various experts provided varying opinions, but at least initially it seems that the balance of opinion was in favor of Courtois. The review of A. Blaise in 1847

was negative on Minard's theories, and especially negative about his observations about international travel, where it called "his conclusions ... false and his figures inaccurate" [5]. Even as late as 1858 we find Armand Audiganne claiming that Minard's "conclusions [had been] drawn from isolated facts" and his "opinions ... refuted by [Courtois]" ([4], vol. 1, p. 340).

Much deeper investigation of Minard's 'parcours partiel' work and its reception in France is called for. It should be conducted by someone fluent in French, and should also cover some work that preceded Minard's, in particular Teisserenc's 1838 observations about locality of traffic on Belgian railways. It will require looking at the press coverage of the controversy, but even more than that, at the archives of the ENPC and CPC, and possibly other agencies of the French government, since Courtois, Minard, and Teisserenc were all civil servants, and much of what they wrote was meant to influence public policy by influencing other civil servants and politicians. Further, such an investigation should consider how the work on locality of traffic fit into the remarkable development of microeconomics by the "econo-engineers" of the ENPC and CPC, which is described by Ekelund and Hébert in their book [23].

Minard's work does not seem to have caught any notice in Britain. This is rather surprising, since there was quite a bit of coverage of it in the *Journal des Chemins de Fer*, the French railway paper, which was widely read in Britain and cited in the press there¹⁸.

The next section shows that Desart, in Belgium, went far beyond Minard in the analysis of railway traffic. But his findings did not appear to have attracted much notice in France¹⁹.

7 Desart and the discovery of gravity models

We next consider the work of two Belgian civil engineers, Henri-Guillaume Desart, 1807–1880, who was the chief engineer of the Belgian Corps des Ponts et Chaussées in the mid-1840s, and his opponent, (François) Auguste Lamoral Delaveleye (sometimes spelled de Laveleye), 1800–1865. By 1843, the Belgian government-built 345-mile railway system was fully operational and making modest profits. There was demand for expansion, and there was debate about which lines to build, and whether that should be done by the government or by private enterprise.

Desart and Delaveleye were both involved in planning the new lines, cf. [18,14]. This necessarily involved looking not just at the engineering aspects of the problem, but at the demand for railway service. Just as in France, in Belgium this task was usually given to the engineers. (In Britain, starting already in the mid-1830s, the specialized "traffic takers" took over this role, cf. [42].) That led naturally to the problem of determining the utility of railways, and we find Delaveleye grappling with this question in a book published in 1844 [13]. Desart also faced this question that year in connection with a specific project, that of a line from Tournay/Tournai to Jurbise/Jurbeke. His report on it was a remarkably detailed document of over 250 pages, of which about 150 pages were tables with statistics of traffic on various Belgian lines [18]. This appears to have been by far the most detailed collection of traffic data anywhere in the world at that time. As was noted in the previous section, Minard and his colleagues in France had to make do with just scraps of evidence,

collected from various railways around the world. Desart’s report was a quantum jump in terms of volume of information. It would have been extremely helpful to Minard in his arguments over ‘parcours partiel,’ but it does not appear that Minard and his fellow “econo-engineers” of the ENPC ever learned of it.

The 19th century is when statistical thinking really started to flourish. There was hardly any methodology at the start (with the method of least squares invented by Gauss in 1795, but first published by Legendre in 1805), and very little reliable data. Some of the noteworthy “Big Data” projects of that time included Matthew Fontaine Maury’s collection of ships’ logs, which enabled him to deduce wind and ocean current patterns, and thereby increase the efficiency and safety of sea travel. Desart’s efforts rank in the same category, but have not received any public recognition so far.

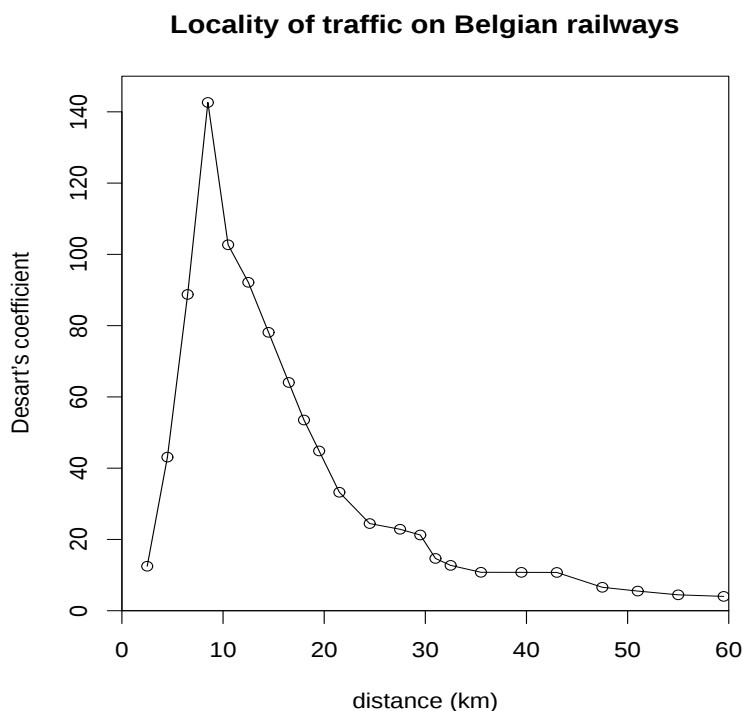


Fig. 1. Desart’s coefficient for volume of railway travel up to 60 km.

Desart’s big step forward was his March 1846 report on a projected railway from Brussels (Bruxelles/Brussel) to Ghent (Gand/Gent) [19]. This was an official report, written in his capacity as the government’s railway engineer, recommending construction by the state, and presenting detailed plans with cost and revenue projections. The bulk of the approximately 330-page report consisted of tables, analyzing the flow of passengers on Belgian lines, deriving a model for that traffic, and using that model to project the traffic on the proposed line (and some alternate designs). Desart had arranged to collect detailed statistics on travel between pairs of stations on the Belgian network in 1845, and analyzed it in

a novel way. He discovered that the number of trips between two towns with populations P_1 and P_2 at distance D apart was approximately

$$c(D)P_1P_2 \quad (3)$$

where $c(D)$ is a constant depending just on the distance D . Desart had to exclude the Southern line, which was disconnected from the others, as well as trips involving the capital, Brussels, which he argued had special features, and for which he prepared a separate table. Other than that, he claimed to obtain a general result. Desart prepared a table (actually several tables, the one used here is from p. 25 of [19]) giving values of $c(D)$ for various values of D from 2 to 250 km. A typical entry was that $c(D) = 44.83$ for D between 19 and 20 km. (Desart measured populations in units of 1,000 inhabitants, and distances in kilometers.) Figure 1 gives Desart's constant for D up to 60 km.

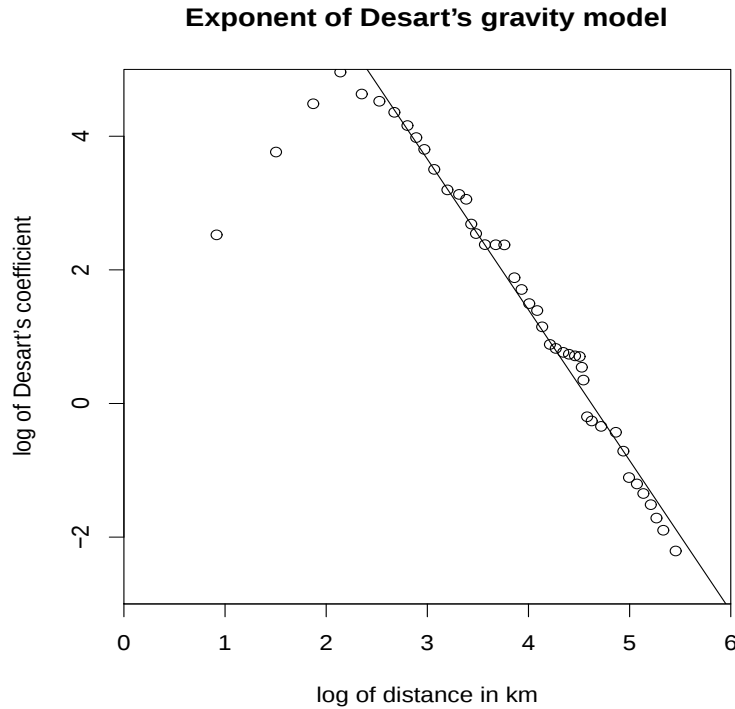


Fig. 2. Log-log plot of Desart's coefficient for entire range up to 250 km.

If we plot Desart's $c(D)$ on a log-log scale (for D going all the way to 250 km), as is done in Figure 2, we find that the values for $D > 11$ km fall almost on a straight line, and a least-squares linear fit computation shows the best slope of this line is almost exactly -2.25. Hence for $D > 11$ km, Desart's findings corresponded to a gravity model of the form of Eq. (2) with $\alpha = 2.25$. It took Desart another year to realize this. As was mentioned earlier, statistics was not very sophisticated in those days, so this step, which to us is obvious, represented highly original thinking at the time. But even his

earlier work, without the standard gravity law form, was remarkable, far more sophisticated than anything being discussed in contemporary railway circles. He also provided extensive quantitative evaluations of the goodness of fit of his model.

Before considering reactions to Desart’s discovery, it is worth noting that a gravity model of the form of Eq. (2) with $\alpha = 2.25$ corresponds to very high degree of locality. Further, since fares tended to be proportional to distance, for this high a value of α , even revenues are greatly dominated by local traffic, which argues even more strongly for more attention to intermediate nodes, and less to direct lines.

However, Desart used his discovery to argue for a direct line from Brussels to Ghent! He interpreted his finding as showing that it was fast transit that stimulated rail travel the most. As is shown in the next section, the English promoters who popularized Desart’s discovery in Britain interpreted his findings in ways more consistent with our modern views (and also far more consistent with the objectives of those promoters).

Delaveleye’s August 1846 rebuttal [15] appeared unable to find any redeeming features in Desart’s work. As part of his detailed attack, Delaveleye presented a list of several points, with one column describing “what common sense tells us” and the other “what Desart’s theory says” ([15], pp. 15–16). Delaveleye’s attack brought forth a defense from Desart, the pamphlet [20] written in October 1846. This in turn brought forth in early 1847 another pamphlet by Delaveleye [16], which was not available for examination in this project.

In February 1847, Desart published another treatise [21] on railway passenger transport²⁰. It claimed to be in response to a proposal for granting a concession to a private company to build a railway to Luxembourg, and it does not appear to mention Delaveleye at all. But it seems to have been inspired at least in part by a desire to respond to Delaveleye’s accusation that Desart’s 1846 model represented by Eq. (3) was too simplistic. This work by Desart analyzed traffic data more carefully than before, and it even stated explicitly the classical gravity model of Eq. (2), although in a more elaborate form, with $\alpha = 3$ for $D > 47$ km, and $\alpha = 2$ for shorter distances (and even more variations in constants of proportionality, see [21], p. 71). (For trips to and from Brussels, Desart fitted other power laws, with exponents either 1.5 or 2.2, depending on distance.)

This project does not get into technical details, so no judgment is rendered on the merits of the Desart and Delaveleye arguments. Those, as well as many other aspects of what happened in Belgium, should be the subject of a more detailed investigation. There was apparently considerable press coverage in Belgium, as well as debates inside government agencies and in the legislature, some tied to the question of public versus private ownership of railways, and those are not explored here. For the purposes of this paper, it is sufficient to note that Desart had access to what was at that time a uniquely detailed collection of data, and that he showed great diligence in analyzing it, and great originality in discovering gravity models.

8 British Railway Mania and Desart’s gravity models

Desart’s first gravity model work was published in early 1846, which was a crucial time for the Railway Mania in Britain. In the Parliamentary session of 1845, 2,700 miles of new

railways were authorized (more than were in service at that time). Many of those projects were just getting started, and so most could have been aborted with modest financial losses. The session of 1846, which ran from late January to August, was in the process of authorizing additional 4,538 miles of railways (to be followed by 1,354 in 1847, as the early enthusiasm of the Mania was dying out). All of those could have been modified or aborted, had the shareholders decided they were unwise, which Desart's work, properly applied, could have told them in many cases.

The first Desart gravity model results [19] were published in March 1846. They were brought to the attention of the British public just three months later, at a shareholder meeting of the West Flanders Railway (WFR) in London on 3 July 1846. Although this line was being built in Belgium, the project was a predominantly British one. The work had not progressed very far yet, and, following the collapse of the most exuberant phase of the Railway Mania at the end of 1845, shares of WFR were dropping in price. At the time of the meeting, shareholders had paid £6 on each of the £20 shares, but those shares were selling for about £3.5 each. Naturally some investors were getting cold feet about investing the additional £14 per share that they were supposed to do. Their concern was likely magnified by the fact that although this line was to run through a densely populated area, there were no large cities on its route, so it did not fit the dominant model of a connection between a pair of large terminal cities. Fortunately for the promoters, they learned of the Desart work, and used it to justify a rosy outlook for the WFR. They prepared an extensive printed abstract (in English) of Desart's book for their shareholders, and included many of his statistics. Hayter, the Vice-Chairman of the line, chaired the meeting, and devoted a considerable part of his speech to praising the novelty, reliability, and importance of Desart's work. He cited the example of Brussels and Ghent. For such large cities, "there would of course be found a certain travelling movement; but if the same population were scattered in towns along the whole route, that movement, M. Desart has shown, would be multiplied ten times. ... Now, gentlemen, it is a remarkable fact, that this state of affairs does exist on our line, for there the towns are situated in exactly the position which M. Desart has shown to be most beneficial and nutritious to a railway."

Most of the London-based railway papers had reports on the WFR meeting, in most cases with the full details on Desart's work that were cited by WFR managers²¹. Some had leaders that touched on this subject. For example, *Railway Times* noted that it had received many letters about the meeting, discussed Desart's novel results, and stated that it "[had] no doubt whatever, that a similar investigation would elicit the same result in English railways, and, indeed, we could ourselves adduce many instances of it, although we have not figures at hand to give the exact amount of such intermediate traffic." A slightly critical note was sounded by *Herapath*, and a very negative one by *Railway Herald* (which was edited by Hyde Clarke, and who was therefore most likely the author), but neither paper went into the reasons for its dissent.

Thus the British railway press provided extensive publicity and details to Desart's work on importance of local traffic. There was also substantial coverage in the general press. Papers varied in the amount of detail they provided (in many cases no mention was made of the Desart findings), but none claimed Desart's work was incorrect²².

Even the most detailed accounts in the British press appeared to present incomplete descriptions of Desart’s work, most likely because they relied on the report of the WFR directors. None mentioned the P_1P_2 dependence on population, and Desart’s table was described in rather confusing terms. On the other hands, most reports cited several pairs of Belgian cities, with populations and traffic between them, which supported the main narrative of the WFR report, namely that local traffic was of paramount importance.

What is interesting here is that Desart’s first report on gravity models [20], which was relied on so heavily by the WFR directors, actually argued in favor of direct lines. But WFR promoters interpreted the data as supporting the case for serving local traffic. With the benefit of hindsight, we can say their conclusion was correct, but it is hard to escape the guess they were inspired by the need to find anything at all plausible that would sound encouraging. It is quite likely that many attendees at the WFR meeting, and readers of the press reports, discounted the claims as just something that the directors dredged up to bolster the case for their project.

That the public did not accept Desart’s traffic laws as an important piece of relevant information is suggested by the price of WFR shares, which did not vary much in June and July of 1846. Construction proceeded, and segments of the line were placed in service, starting in October 1846. At the 27 March 1847 shareholder meeting in London, directors professed themselves happy with the results of the partial opening, and claimed their “opinion ... remains unaltered, and the calculations of Mr. Desart have been fully borne out by the results”²³. This meeting was covered extensively by the general press²⁴, which in some cases cited Desart, as in the *Daily News* reference to his “excellent method.” However, no description of his method was given in the general press.

The railway press provided more detail. All of the London-based railway papers that were still in existence provided some coverage (all in their 3 April issues), and several (*Herapath*, *Railway Gazette*, *Railway Record*, and *Railway Times*) appear to have printed the directors’ report in full (while others abbreviated it). This report provided more precise details of Desart’s findings (all from his first 1846 publication [19]), and they were endorsed enthusiastically by WFR managers.

Most of the railway papers also had leaders in the same issue about the WFR. They were generally short, and did not discuss Desart’s theory. The outstanding exception was the *Railway Herald*, which was in its death throes, with the next issue, that of 10 April, apparently being the last one to be produced. Hyde Clarke, the editor and owner, was surely the author. He launched a scathing attack on Desart’s traffic model, and talked of “the monstrous proposition that railway traffic depends solely upon population and distance, and is independent of every other influence.” Circulation of the *Railway Herald* was negligible at that time, so it is not clear how many people read Clarke’s critique. No references to it have been found so far in the contemporary literature. But in any case it demonstrates what was likely a wide reaction to Desart’s theories in Britain, namely rejection as being too far from the mainstream.

So far we have considered coverage of Desart’s novel theories of railway traffic that resulted directly from two of WFR meetings, those in July 1846 and March 1847. But there were other references to his work, some of which continued into the early 1850s. Some of

the most prominent resulted from a hearing of a House of Commons committee on railway policy that was chaired by James Morrison in the summer of 1846. (For more on Morrison and his railway policy activities, see Section 12.) During the 15 July session, Morrison asked Samuel Morton Peto, the famous railway contractor, some leading questions about demand for railway service and Desart's findings²⁵. This was just 12 days after the WFR meeting, which was also held in London. Both Morrison and Peto were aware that Desart had some novel results, and it is possible this was derived from the WFR report, although the testimony suggests they had seen the Desart book [19]. However, Morrison and Peto appear to have had a distorted view of Desart's finding, and ended up talking of rural inhabitants traveling more than urban ones²⁶. This is also what Morrison put into his "2nd report," including the credit given to Desart for the careful collection of data and novel conclusions²⁷. This report was widely reprinted²⁸. It was even more widely quoted, and the quotes usually mentioned Desart²⁹. What is important about the Morrison report is that it had an explicit statement from a highly visible and respected figure that in at least some parts of England, local traffic was more important than popular opinion expected. Thus, if one accepted the Morrison report as accurate, Desart's observations were not peculiar to Belgium.

The big unknown is the extent to which the public, the railway managers, and the policy makers were paying attention to these items about importance of locality. Some clearly did devote serious thought to it. For example, the first edition of Sir William Patrick Andrew's pamphlet [1] was dated July 1846, but it cited both the WFR meeting, held on 3 July, and Desart's report (even though it misspelled his name as "Dessart"). The second edition of [1], dated October 1846, was much expanded, and included, in addition to the previous remarks (with Desart's name spelled correctly this time) also a citation to the Morrison "report," quoting Peto. Both these passages were also included in the 3rd edition of Andrew's pamphlet [2], two years later.

It is likely that many readers of such items took them as cute surprising facts that had no practical relevance, or else curiosities peculiar to Belgium. We can detect such reactions among journalists. For example, the *Morning Chronicle* on 12 September 1846 had a short article, based on two official reports from Belgium and France, which claimed that:

It is a curious fact that in case of continental lines, that the shortest railways pay the best. M. Desait, who was appointed by the Belgian government to inquire into the comparative traffic on long and short lines, gives as the result of a most careful investigation, that the number of passengers proceeding by railways rapidly decrease after the first six or seven miles have been travelled. ... It is the reverse in England; the longest lines are by far the most productive.

This article was reprinted (including the misspelling of Desart's name, and the misstatement of his findings, which did not claim anything about the dependence of profitability on length) in the *Leeds Mercury* on 3 October, and the *Manchester Times* on 9 October. So this observation did pique the interest of some other observers, but was apparently taken just as a Belgian curiosity, and contrary to the British experience. (There were precedents for the opinion that the nature of British railway traffic might be different than that in

Belgium, as can be seen by the comments of Robert Stephenson in 1841 at a North Midland Railway meeting³⁰.)

9 Dionysius Lardner on locality of traffic

As was shown in Section 8, the Desart discovery of gravity models did catch a fair amount of attention in Britain, even though often in distorted ways. There was another item that caught public attention around that time, and which also pointed out the importance of local traffic. This was Dionysius Lardner's "Railways at home and abroad" [32], a survey of the railway industry around the world, published (anonymously, although many observers deduced it was authored by Lardner) in October 1846. It was a very remarkable work, far more comprehensive than anything else available at the time, and far more insightful, too.

Lardner's paper attracted substantial attention. In addition to its intrinsic merits, it appeared in the *Edinburgh Review*, one of the most prestigious serials of the time. It was also the last item in that issue, which was regarded as the second most prominent place in a magazine, which showed that the editor of that publication regarded it as important. Further yet, *Edinburgh Review* was regarded as a semi-official organ of the Whigs, who had come into power just a few months ago. There was widespread curiosity and some anxiety as to what the railway policy of the new administration might be. Hence the policy recommendations of "Railways at home and abroad" were scrutinized carefully, and attracted a mixture of praise and criticism, depending largely on the political leanings of the reviewers. But there was much more to "Railways at home and abroad" than the policy part.

In the middle of Lardner's survey there were statistics on railway travel, showing explicitly that average trips were short, and those statistics were accompanied by some emphatic messages, such as the concluding passage of that section:

It is clear, then, that the terminal populations have but little connexion with the financial success of railway projects. The main support is short traffic.

Lardner certainly felt that this was a novel observation, one that his readers would find surprising. And to a large extent they did. To be precise, we can say that many British journalists found it surprising, as we can tell by the extensive reactions in the press, some likely stimulated by the attention in other newspapers, in the usual herding, or mass psychology, effect.

Some of the about two dozen citations that have been found already in the British press to Lardner's survey did not mention or quote his discussion on "short traffic." As an example, the *Morning Post*, one of the main daily London papers, did include a substantial quote from Lardner about history of land transport and the social and economic gains from railways. But about the quantitative parts, it just said that the paper "contains a body of curious statistics," and that "[e]verybody knows that statistical figures can be so arranged as to prove anything, and of course [Lardner] proves what he desires to do"³¹. However, most of the papers that reviewed Lardner's survey did cite or partially reprint the passage about importance of local traffic, in many cases in ways that showed they

found it particularly interesting. As an example, when the *Perthshire Courier* got around to reviewing “Railways at home and abroad,” it first printed an excerpt from the historical part to Lardner’s piece, about the great improvements that had taken place in speed and comfort of travel in Britain. Then, in the next issue³², it reprinted a local traffic excerpt, prefacing it with an editorial note that emphasized its significance. Thus much of the British press pretty clearly thought that Lardner was pointing out something novel, contrarian, and important. But did they realize what it meant for railway investments? That is less clear. As happened during the telecom bubble, to mention just one example, when people are in the deep trance induced by a powerful mania, it takes a very hard collision with reality to make them aware of how obvious facts around them contradict their delusions. Neither Lardner nor any of the newspaper writers who cited him made an explicit connection between his message and the wisdom of direct lines or branches.

In addition, the average length of a passenger trip being short does not by itself mean that short trips are the most important ones for the financial health of a railway. If half of the passengers travel the full 31-mile length of a line, and half travel just one mile, possibly moving from one station to another in a city, the average length of a trip will be 16 miles, but it will be the long-haul passengers who will provide the bulk of the revenues. To really appreciate the relative importance of long and short traffic one needs something more sophisticated than average trip length, something like Desart’s gravity model. Even Minard’s measure, the fraction of revenues that come from ‘parcours partiel,’ is more meaningful than just the average length of a trip.

10 Slow recognition of importance of locality in Britain

The understanding that local traffic was more important than had been thought originally continued to grow among British observers. In some cases it may have come from direct observations, independent of the Desart and Lardner items³³.

It seems very likely that the growing awareness of locality of traffic contributed to the first railway share crash of the Railway Mania, towards the end of 1848, discussed in [43]. (This smaller crash was preceded by a slide in prices over the preceding couple of years, and was followed by a partial recovery, and then the big crash in early 1849, which was associated with the end of the Railway Mania.) The decline in railway share prices in mid-1848 which unnerved so many investors and other observers, as it was occurring in the midst of dramatic recoveries in other financial markets, was likely caused by a rising awareness, or at least suspicion, that the rosy profit projections of both new lines and the numerous branches and extensions of existing lines were based on false premises, which ignored the importance of locality. The big crash of 1849 came about as the bulk of the investing public had to acknowledge this unpleasant reality.

Awareness of locality of traffic almost surely also helped mitigate the financial losses of the Railway Mania by curtailing construction. In very rough numbers, at the start of the Mania, in 1844, Britain had just about 2,000 miles of operating railways. During the ebullient phase of the Mania, say 1844–47, promoters received authorizations from Parliament to build about 10,000 additional miles. By the early 1850s, just about half, or 5,000 miles had been built. The other half was abandoned, largely because of the growing

realization they would not be profitable. This realization appears to have been stimulated to a substantial extent by the growing knowledge that traffic was largely local, and so the original business plans were unrealistic.

As time went on, and the mistakes of both direct lines and fast branch expansion became impossible to ignore, there were attempts to find positive angles to locality of traffic. The *Economist* in late 1848 took the same approach as the management of the Grand Junction Railway had in 1837 (see Section 4). It claimed that competition would not be as destructive as many feared, since locality of traffic meant that

[u]nless ... two railways were actually running parallel to each other through the same country, and serving the same towns, any actual competition which can exist between them must be limited to a very small portion of their passengers³⁴.

A similar argument was made by Smiles ([50], p. 44).

11 Aftermath: The “suckers not feeders” mantra

The mistakes of the Railway Mania appear never to have been analyzed carefully by any contemporary observers, and the importance of locality of traffic was absorbed in distorted forms that led to railway planning that continued to be flawed. This section illustrates what appear to have been the dominant reactions to disappointing investment results of the Mania in Britain, as well as of railway constructions in other countries.

The mistake of concentrating on direct lines was widely recognized, at least for a while. One example comes from a book published in 1851 by Samuel Sidney, who wrote extensively on railways in the 1840s. He observed ([49], p. 137):

Direct lines have generally proved a great mistake, except so far as they have accommodated the local traffic through which they passed. To the shareholders they have been most unprofitable wherever the original shareholders were not lucky enough to bully the main lines into a lease, and, to the average of travellers very inconvenient, by dividing accommodation. But shareholders should look at the local traffic of a proposed direct line, on which alone good dividends can be earned.

Similarly, Smiles ([50], p. 37) talked in his 1849 pamphlet of the “great fallacy [that] prevailed during the railway mania, that the essential point requisite for a paying line of railway was, that it should have two large towns for its termini,” whereas by the time of his writing “experience abundantly prove[d] ... railways ... generally depend mainly upon their *local* traffic—upon traffic from town to town, and even from village to village,—for the chief part of their revenue,” and discussed the burden that branches caused.

But even that lesson faded with time. Thus a British book of 1891 claimed that “[i]f there be a well established principle in modern railway policy, it is that it pays best to go as direct as possible to your destination” ([33], p. 33). On the other side of the Atlantic, we find similar sentiments expressed by a noted railroad authority ([29], p. 46).

The lesson that observers around the world appeared to draw from experience with early railways was a fallacious one, namely that branches were almost universally damaging to

major lines. A substantial contributor to the prejudice against branch lines may have been a catchy phrase that apparently originated in Britain in 1848, but afterwards seems to have jumped across the Atlantic, and kept resonating for decades. This phrase was that branches were “suckers, not feeders.” Desart’s piles of dry statistics, not even graced with a cute name, such as that of “gravity models,” were quickly forgotten. It was different with “suckers, not feeders.” That mantra caught public attention and was retained in people’s memories. Recall that the original conception was that trunk lines would serve primarily to connect pairs of major cities, and that branches would bring in passengers who would then take those trunk lines to the terminal destinations. Thus branches were constantly referred to as feeders. Now this was turned around, and the “sucker” designation stuck.

The earliest occurrence of the “suckers, not feeders” meme that has been found is in the anonymous pamphlet [3], where it is attributed to an unnamed individual, presumably at a meeting of shareholders of some line. This pamphlet was published in October 1848, just as the railway share market was experiencing its first crash of the Railway Mania [43], which resulted from investors becoming anxious about the profitability of all the extensions they had been underwriting, and which were only slowly being put in service. This phrase then kept getting quoted over and over again, and not only in Britain, but also in the United States, Canada, and Australia. As a result of the popularity of this opinion, managers had to work hard to justify new constructions. For example, in 1866, the Chairman of the Caledonian Railway in the UK reassured shareholders that a particular branch is a “very good feeder, and not a sucker,” and in the United States in 1887, Charles Francis Adams complained that “uninformed critics are continually speaking of the branch lines, which permit [main line] traffic, as being ‘suckers and not feeders,’ and as burdens which a competent management would cut off”³⁵.

The truth is that branch lines were sometimes feeders, and sometimes suckers. Further, a relatively steady growth in traffic, which took a long time to be recognized as a general phenomenon, cf. [45], tended to transform suckers into feeders. Gravity models could have been used to make moderately accurate predictions of which category a particular branch would fall into. But Desart’s discovery had been forgotten. Smiles in 1849 already had a balanced view, recognizing that branches through populous areas were often profitable, while those through less densely populated regions were less likely to succeed ([50], p. 35). However, he did not offer any quantitative way to tell the difference. It was only a few decades later that a better understanding of the role of locality developed. The earliest post-1850 work towards something like gravity models that has been found in this project was by Arthur Mellen Wellington (1847–95), an American railroad engineer [53].

Among many other contributions, Wellington provided recipes for estimating the effects on the economics of a line that result from shifts in route to accommodate intermediate locations. “The loss of distance from even very considerable deviations from an air-line is commonly absurdly over-estimated, even in the minds of engineers, in a way and for reasons more fully discussed later ...” (p. 237 of the 2nd edition of 1887). He also enthusiastically endorsed branch lines (pp. 731–32) because of their contributions to the main line, in other words their role as “feeders.” Here he may have been overenthusiastic because of his missing out on the correct formulation of the gravity models. He did note (p. 709) that “the

volume of traffic ... will be at least inversely as the distance;" hence he was saying that the exponent α in the second formula in the Introduction should be at least 1. But in that same chapter, before and after that passage, he derived a formula that ignored distance, and was basically Metcalfe's Law (and thus could instead be called Wellington's Law, or perhaps the Metcalfe-Wellington Law), which says that the value of a network is proportional to the square of the elements in it. (See [6] for arguments why that is not appropriate in most cases, and for an alternative formula. Had Wellington thought more carefully about the problem, and combined his insights, he might have come up with the same alternate.) Had he devoted more attention to this area, he might have rediscovered gravity models, and might have helped improve the efficiency of railway systems even further than he did.

12 Slow and faulty diffusion of information

Why did the importance of local railway traffic take so long to be recognized? And why was it not analyzed systematically even after the investment disaster of the Railway Mania? These questions are of historical significance, and in addition they are relevant for understanding spread of technologies, economic development, and bubbles. Diffusion of economically important information is key to all of them, and to gain a better understanding of it, it helps to systematically study what happened at various important instances. As an example, the dangers of high real estate valuations and of obscure derivatives were recognized by many observers before the crash of 2008, but most regulators, policy makers, and even investment managers were unaware of them. Was this the result of some simple defects in the information systems that could be remedied, or was it an inherent limitation of a system as complex as the modern economy, where nobody has complete knowledge, and the main dangers can be pinpointed only after the crash? To obtain good insights and ideally models of such phenomena, it appears important to collect detailed information on as wide a variety of economic crashes as possible.

There was never any systematic inquiry by anyone about locality of traffic in Britain. This may seem surprising, but it becomes more understandable when placed in context. There were many other questions about railway economy that were never studied carefully. The atmospheric propulsion system and the gauge issue were subjects of official government inquiries in the 1840s, since they appeared to pose pressing policy issues. (Neither report was completely conclusive, it should be remarked, which reflects how poorly railway technology and economics were understood at that time.) Other problems were known to have some importance, yet never received even that level of attention. For example, in the mid-1840s, it was usual to assume that operating expenses on railways would be 40% of revenues. Some promoters were promising lower costs, while as time went on, and evidence began accumulating, others started worrying that this was overoptimistic, and in any case would vary substantially depending on the railway³⁶. There was also considerable debate about the relative importance that passengers attached to speed, frequency of service, comfort, and price. For example, at the British Association for the Advancement of Science meeting in 1836, Dionysius Lardner claimed that the increase in travel by rail as opposed to coach "depended infinitely more on the saving of time than money," but this was disputed by several participants in the discussion³⁷.

And then there was perhaps the greatest uncertainty of all. That came from reliance on engineers. They had in the past been consistently wrong in underestimating expenses. By the time of the Railway Mania they were claiming they had learned from those pioneering ventures of the 1830s, and could be relied upon to complete projects on time and within budget. Investors could do little but accept those assurances and hope and pray. As it turned out, the hope was misplaced, the engineers for the most part again missed on costs (by being overoptimistic, as has been the rule through all of history), even if less so than in the previous decade.

If we bear these uncertainties in mind, it becomes easier to understand why not much attention was paid to locality of traffic, especially since most people did not feel there was any uncertainty there at all. Yet this is not an entirely satisfactory explanation. The Belgians and the French, who were devoting far less effort and money to railways, did produce perceptive studies on locality of traffic. Further, both Minard and Desart were led to this question by the very practical issue, namely whether it was better to build direct lines, or ones that went through cities along the route. Those British observers who did touch on this question, and whose comments have been preserved, seemed to treat this issue as a theoretical one, or as a mere curiosity. Yet it was British investors who were pouring huge sums into railway construction.

The lack of systematic attention to locality of traffic, or even to a stream of items that contradicted the consensus view, is illustrated by the *Morning Chronicle*, one of the leading London daily papers. When it reported on the 3 July 1846 meeting of the WFR, it did not say anything of the extensive discussion in the directors' report about Desart's findings. But in its 31 August extended summary of the Morrison "report," it did cite Desart's work as new and important. Then, on 12 September, it presented a distorted version of his findings, but just as a foreign curiosity with no implications for Britain. This was followed a week later by a correct, but inadequate version. And a month later this paper printed Lardner's discussion on importance of locality. But none of these stories referenced any of the others. It was as if different people were writing them, and they either had not been reading their paper, or had short memories. And none of those stories stated explicitly that the still-dominant desire for direct lines was leading investors astray.

The *Morning Chronicle* treatment of locality of traffic was characteristic of what happened in Britain as a whole. There were many news items pointing out that the dominant dogma about nature of railway traffic was wrong, as well as various statistics that, with just a modest amount of calculation, led to the same conclusion. What was lacking was a comprehensive synthesis of all the evidence, and a presentation in a format and forum that would catch public attention as having real implications.

There did not appear to be any systematic efforts to reinforce the prevailing prejudice in favor of direct lines, of the kind that had been mounted by tobacco companies to raise doubts about the dangers of smoking, say. Just the opposite, the organized efforts that have been found, such as that of the GJR (Section 4) and WFR (Section 8) aimed to persuade investors and the public of the importance of local traffic. It seems that the main problem was the widespread and deep-seated conviction that terminus to terminus traffic was dominant. It is very hard to change people's opinions, even when there is convincing

evidence, and even when no deep religious or political dogma is involved. This has been established even for very smart and highly trained researchers. Historians of science have produced numerous instances of resistance to novel ideas or contrarian evidence in such circles. Today we see instances of that in the anti-vaccination movement, and many other situations.

Could the public view about locality of traffic have been changed in the Britain of the 1840s? The one person who had the greatest chance to sway public opinion was James Morrison. It appears that his personal views were shifted by Desart's work, as he had been an ardent advocate of direct lines in early 1846 [40], but during his committee hearings in July of that year, he was citing Desart and emphasizing local traffic.

Morrison was a remarkable person. He rose from poverty to be one of the richest men in Britain, and although largely self-educated, his intellectual merits were recognized by election to the Political Economy Club [27,42,36]. He was also one of the most prominent opponents of the Railway Mania. An enthusiastic supporter of railways as a technology, he was concerned that without regulation, this rapidly growing industry would be able to choke the British economy through excessive fares and excessive profits. As a result, his calls for reining in the Railway Mania may have been counterproductive, as investors may have accelerated their projects in order to avoid any constraints that Morrison and his allies might persuade Parliament to impose. Had Morrison instead used Desart's findings to show investors their dreams of high profits were illusory, he might have been far more effective in limiting railway construction. Such an approach might have had an even greater chance of success had Morrison persuaded *The Times* to join such a crusade. This paper, which had an unrivaled influence, with circulation larger than that of all the other London dailies, was also an opponent of the Railway Mania, and was usually regarded as the most dangerous foes of this instance of investor exuberance. In the fall of 1846, it published a series of about two dozen letters by "Cato" (pseudonym of the journalist John Black [27]), which were arranged for by Morrison, and argued for the drastic changes in British railway policy that Morrison was advocating. But those letters still had some positive comments about direct lines, and were primarily about the dangers of excessive profits. Not exactly a message to discourage investors from putting their money into construction! Had Morrison, *The Times*, and "Cato" instead come up with a catchy name like "gravity models" (invoking the enormous prestige of Isaac Newton), and argued that an investment disaster was looming, history might have been different. (The importance of memorably cute names should not be neglected, as we can see in the remarkable spread and persistence of the "suckers instead of feeders" mantra, and more modern examples.) But that did not happen, and so we are left with an interesting case of "what might have been" to go with a solid record of failed diffusion of solid economic information.

13 Network science and the 19th century

The investigation in this paper has similarities to many in the history of science, which trace the spread of new theories. It differs from most of them in that it concerns much wider strata of population, all the railway investors, promoters, engineers, government decision makers, as well as general observers of the huge new infrastructure that was being

built. But there are many similarities, in the resistance to new ideas, and in many missed opportunities.

The research for this paper depended heavily on the increasing digitization of materials from the 19th century. It also shows the promise that a continuation of this trend offers in terms of providing much deeper insights into diffusion of information in the past. Britain in the mid-19th century had over 500 newspapers, in addition to comparable numbers of other serials (as well as a large output of pamphlets and books). Furthermore, most of these papers were very thinly staffed, with many having just one or two permanent employees doing the editorial and reporting work, cf. [44]. Hence much of what they published was reprinted from other papers. Much of what was reprinted was edited in order to shorten it, so we can deduce what those editors thought was important (or at least what they thought their readers would find of interest). Whereas modern scholars study information dissemination by checking which rumors or news items get blogged, linked-to, tweeted, or re-tweeted, to study this in mid-19th century Britain we can explore how various items propagated through the press. (Of course, this should be combined with the more traditional methods of checking original press coverage, letters from readers, and other sources.) At the moment only a small fraction (under 10%) of that kind of literature has been digitized, but we can already obtain promising results, as this paper shows. We can discern phenomena such as herding, information cascades, and social contagion. In the future, as more information is digitized (initially primarily newspapers, and then likely also various private correspondence archives and the like), OCR is improved, and automated text analysis advances, we should be able to map the information flows and their impacts more comprehensively and more precisely.

14 Conclusions

Gravity models were discovered by Desart a dozen years earlier than the first formulation of them that until now had been known to the modern literature. They were found on the basis of collection and analysis of what was then an unparalleled collection of empirical data about railway transport. Furthermore, Desart applied them to railway planning long before any one else. Had these models become widely known and accepted, they would likely have produced substantially more efficient railway systems around the world. They might even have decreased the huge economic losses of the Railway Mania in Britain. However, Desart's data and analysis attracted only a modest amount of attention, and were quickly forgotten.

Aside from pointing out Desart's priority in discovering gravity models, as well as in collection and analysis of "Big Data," this paper presents an interesting and early case of economically important factual information that was very slow to diffuse. There are analogies to studies on diffusion of technologies, as well as modern work on herding, information cascades, social contagion, and many other ones that are being investigated in the context of social networks. As is shown here, such methods can also be applied to historical settings, and, as more material from earlier eras is digitized, we should be able to get more complete pictures of what happened, and thereby obtain insights into how the economy and society as a whole evolve.

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Notes

¹Casson claimed that a railway system about as efficient as his would have resulted had the British government made a slight change of policy in 1845, at the height of the Railway Mania. This seems rather questionable, for the two main reasons discussed in [45]. One was that the vast majority of the planners who might have been selected in 1845 to design the railway system would have shared the dominant ignorance of the importance of locality in rail travel.

²*Herapath*, 16 December 1843, pp. 1283–86. This serial started out as the *Railway Magazine*, and then became *Herapath's Railway Journal*, with a few variants. It is usually referred to as just *Herapath*, as is done here.

³*Railway Times*, 5 and 8 January 1839, and *Parliamentary Papers*, 1846 [699] [700] XVI.29, 383, Q5607.

⁴*Herapath*, March 1838, pp. 137–142.

⁵*Herapath*, 30 November 1839, p. 374.

⁶*Railway Register*, vol. 4, September 1846, pp. 136–145.

⁷At hearings of a House of Commons committee in 1839, Robert Stephenson explained that the huge cost overruns were due to a substantial extent to the need for better stations. He had “no hesitation in saying that the expense of stations has been eight or ten-fold beyond that originally contemplated,” *Parliamentary Papers* 1839 (517) X.127, Q4694.

⁸*Herapath*, 21 March 1840, pp. 215–16. This line furnishes many interesting examples of hard evidence colliding with preconceived notions.

⁹*Morning Chronicle*, 15 September 1837. More detailed version in *Herapath*, Sept. 1837, pp. 271–278.

¹⁰See, for example, the ad attacking the proposed Manchester and Birmingham Extension Railway in *Manchester Times*, 9 September 1839, p. 3, or the Glyn speech in *The Times*, 22 February 1851, p. 8.

¹¹This computation assumes that passenger fares averaged about two pence per mile, which was not stated in the table, but was typical at that time.

¹²*Parliamentary Papers*, 1843 (440) XLVII.1.

¹³Among them: *Morning Post*, 18 April 1846, p. 6; *Economist*, 20 April, p. 702; *Railway Chronicle*, 20 April, p. 9; *Athenaeum*, 27 April, p. 384; *Sheffield Independent*, 27 April,

p. 3; *Glasgow Herald*, 3 May, p. 2; *Railway Times*, 4 May, pp. 512–13. It was the *Morning Post* coverage that appears to have been reprinted most frequently.

¹⁴*West Kent Guardian*, 18 April 1844, p. 7 referred to all of Porter’s lecture as presenting “curious details with respect to railways.”

¹⁵A skeptical view is represented by the article “The Railway System and the Board Of Trade” *The Times*, 16 December 1844, p. 5. A very positive attitude is shown in the leader on 19 November 1845, p. 4.

¹⁶For example, in the report on the Sheffield, Nottingham, and London Direct Railway in *Railway Register*, October 1845, pp. 342–343.

¹⁷For brief biographies, see [24,10] as well as the Minard entry in Wikipedia and <http://www.datavis.ca/gallery/minard/biography.pdf>.

¹⁸For example, in issues of 10 June 1843, pp. 560–61; 29 July 1843, pp. 628–29; 26 August 1843, pp. 659–60; 9 September 1843, p. 674; 30 May 1846, pp. 484–85.

¹⁹There were some people who were aware of the investigations of both Desart and Minard, cf. *Journal des Chemins de Fer*, 12 September 1846, pp. 758–59. But there is no sign that Desart and Minard knew of each other.

²⁰The last publication by Desart that has been found does not appear to discuss the influence of distance on travel [22].

²¹In most cases in the 4 July issues, in a few cases in the 11 July one. The only London railway paper that was checked that did not appear to have any coverage of this meeting was *Bradshaw’s Railway Gazette*. The ones that did, aside from *Railway Record*, were *Herapath*, *Railway Chronicle*, *Railway Herald*, and *Railway Times*. The quote is from *Railway Record*, July 4, 1846, pp. 693–96.

²²There was coverage in the 4 July issues of *Morning Chronicle*, *Morning Post*, *Standard*, *Economist*, as well as the 5 July issue of *Era* and 6 July issue of *The Times*.

²³*Morning Post*, 29 March 1847, p. 2.

²⁴In addition to the *Morning Post* report cited earlier, there was coverage in *Standard*, 29 March, p. 4; *Daily News*, 29 March, p. 4; *The Times*, 29 March, p. 3; *Morning Chronicle*, 29 March, p. 2; *Era*, 4 April, p. 9.

²⁵*Parliamentary Papers* 1846 (687) XIV.5, Q3415ff.

²⁶To be fair, it is possible to interpret their exchange as indicating that most of the evidence for higher frequency of travel in rural areas was coming from Peto’s unquantified evaluation of what he observed in agricultural areas of England, and not from Desart’s report.

²⁷The quotes around the phrase “2nd report” reflect the fact that this was not a properly sanctioned committee report, but Morrison’s own collection of recommendations for British government policy, which he managed to have printed as an official document [27].

²⁸For example, in *The Times*, 29 August 1846, p. 7 and 31 August, p. 3; *Morning Post*, 29 August, pp. 2–3; *Morning Chronicle*, 29 August, p. 2 (brief summary), 31 August, p. 2 (extended abstract, which cited Peto citing Desart); [51], written in December 1846, as well as the 9th edition of this work.

²⁹For example, Smiles' 1849 pamphlet [50], p. 39; W. Harding, "Facts bearing on the progress of the railway system," *J. Statistical Society of London*, vol. 11, 1848, p. 335; [31], p. 18.

³⁰*Railway Times*, 28 August 1841, pp. 902–907.

³¹*Morning Post*, 15 October 1846, p. 2. Hyde Clarke, who is again presumed to be the author of the anonymous piece, had the most scathing review of Lardner's piece, in the *Railway Herald*, 31 October 1846, p. 518. After enumerating what he felt were some serious errors, some of which were indeed errors, he concluded that "[t]he whole is a collection of trash, on which not the least dependence can be placed."

³²First piece is in the *Perthshire Courier*, 28 October 1846, p. 2, the second is in the 5 November issue, p. 4. The second piece, in addition to the passage about "short traffic" (about one-third of what Lardner had written), also included other material.

³³For example, see the passages about importance of local traffic in *Caledonian Mercury*, 18 February 1847, p. 3 and *Morning Herald*, 26 June 1848, p. 2.

³⁴*Economist*, 18 November 1848, pp. 1297–99.

³⁵*The Times*, 17 September 1866, p. 5; *Report ... of the United States Pacific Railway Commission ...*, U.S. Government Printing Office, 1887, p. 979.

³⁶For example, see the strong warnings of Robert Lucas Nash the elder (cf. [43]) in *Money Market Examiner*, 2 December 1848, pp. 2–3 and 5, and 9 December, pp. 13–14.

³⁷*The Athenaeum*, 3 September 1836, pp. 626–27.

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