The Minard System

The Complete Statistical Graphics of Charles-Joseph Minard

FROM THE COLLECTION OF THE ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES

Sandra Rendgen

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Preface

The Story Behind the Masterpiece

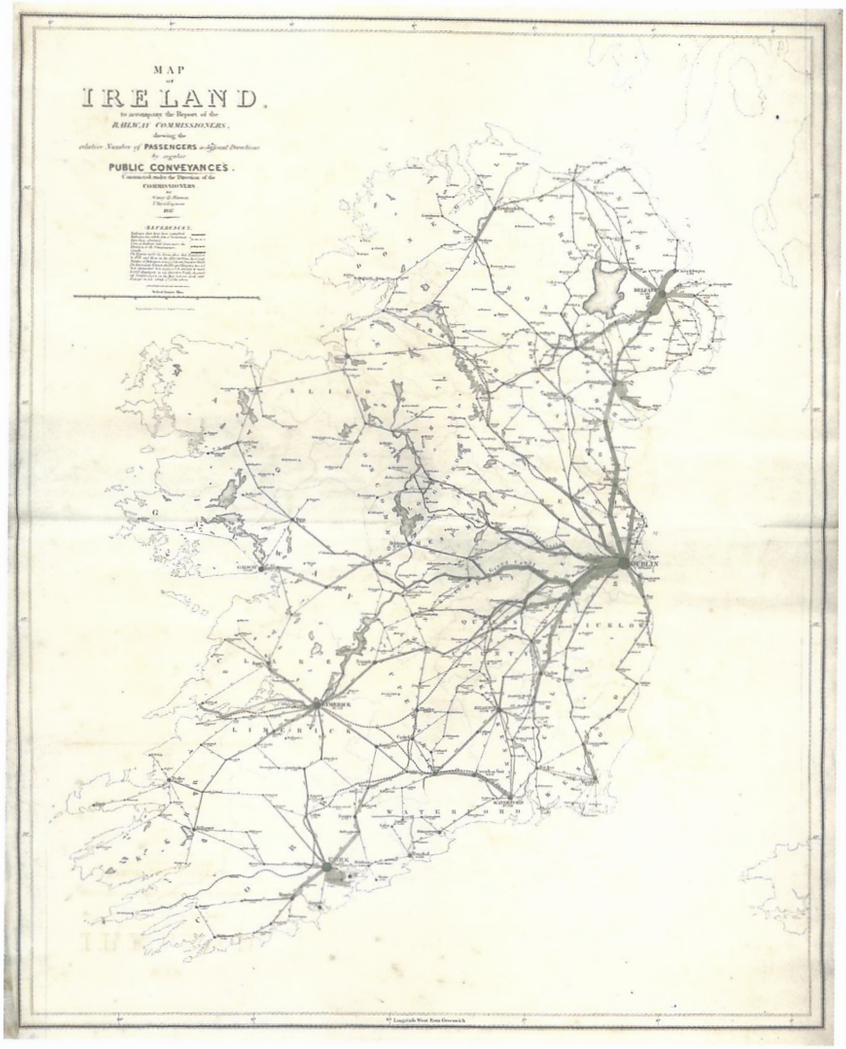
As for my maps, I have heard people say that illustrative maps have been made for a long time. My maps do not just show, they also count, they calculate for the eye; that is the crucial point, the amendment I have introduced through the width of the zones in my figurative maps and through the rectangles in my graphic tableaus.

—CHARLES-JOSEPH MINARD, 1861

The French civil engineer Charles-Joseph Minard, whose long life spanned the final years before the French Revolution through the latter half of the nineteenth century, left behind an impressive body of statistical graphics and maps. Motivated by the intellectual problems he encountered during his professional practice, Minard embarked on a quest to create compelling visualizations to support the analysis of statistical results. He conducted in-depth studies over many decades, and his efforts finally led him to create one of the most famous information graphics ever made: a statistical map of Napoléon's Russian campaign of 1812.

Published in 1869, one year before Minard's death, this graphic eloquently summarizes Napoléon's disastrous military endeavor. On a basemap of what are now Lithuanian, Belarusian, and Russian territories, it visualizes one particularly telling statistical variable: the sharp and steady loss of soldiers that Napoléon's army suffered during the roughly six months covered in the graphic. Though 420,000 men triumphantly invaded Russia in June 1812, the army was already significantly reduced by the time it arrived in Moscow three months later. When Napoléon ordered the troops to retreat from Moscow in the fall, he sent his men to certain death, as they faced an extremely harsh winter in the wide plains of western Russia without any support or infrastructure. The map shows that only some ten thousand soldiers survived [60].

This work has stood out from Minard's extensive oeuvre for a long time and continues to do so today. Its fame has even produced some curious mementos, such as a T-shirt featuring the Napoléon flow (currently available, along with other Minard-related merchandise, in several online shops).[1] With its singular rhetorical power, the graphic is often treated as an isolated effort, which ignores the fact that Minard had originally published it alongside a second campaign map recounting an event from antiquity. Much of this selective fame can be traced back to the enthusiastic praise that the American statistician and political scientist Edward Tufte bestowed on this graphic. He reasoned that "it may well be the best statistical graphic ever drawn," and published a facsimile of it.[2] Tufte, through his groundbreaking books on the principles of designing statistical graphics, can be credited with having brought the work of Minard to the attention of a wider contemporary audience.

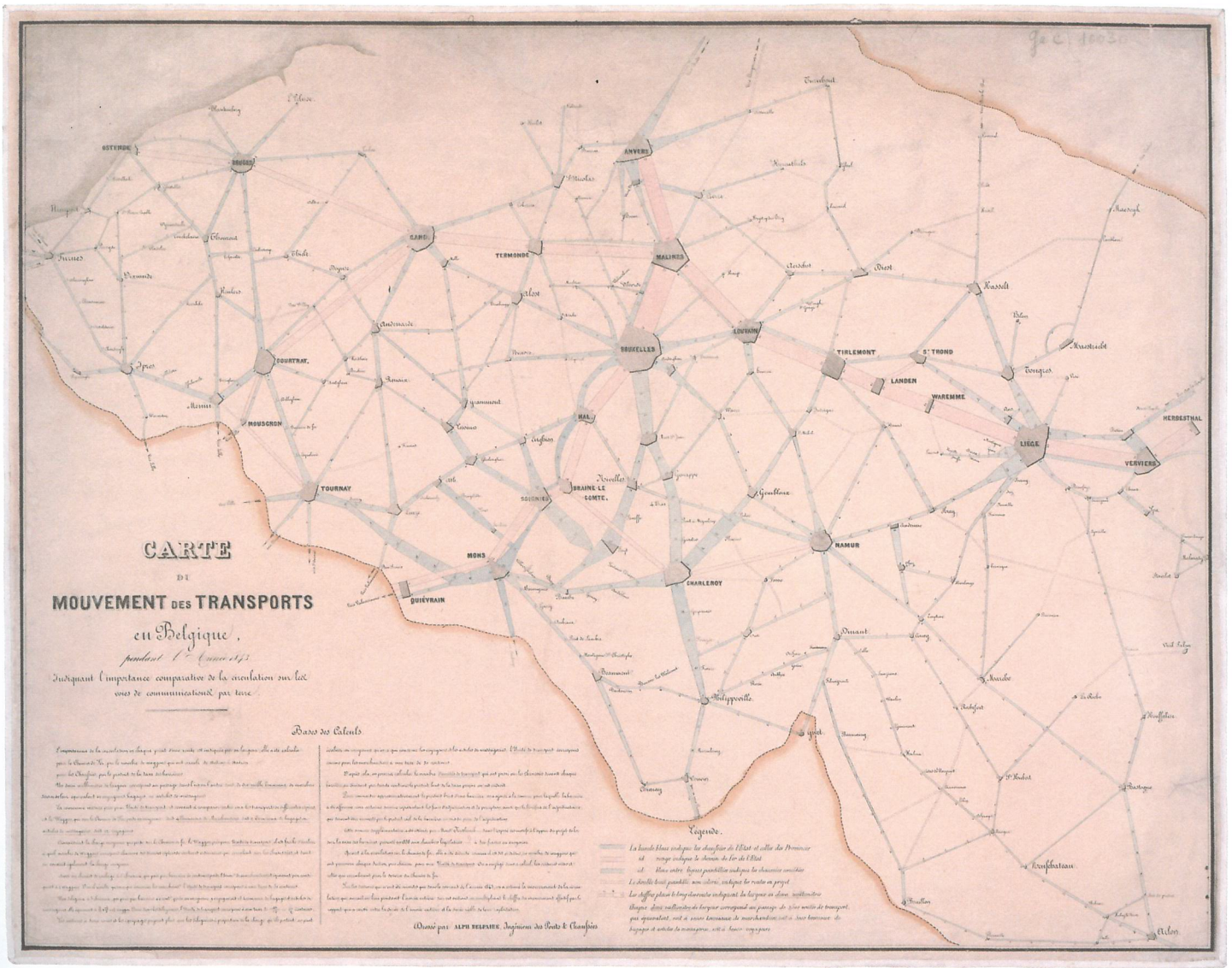


The Royal engineer Lieutenant Henry Drury Harness drew this map in 1837 as part of an atlas to accompany a report by the Irish Railway Commissioners. It is considered to be the first flow map and preceded Minard's work by a few years. However, there is no sign that the latter had any knowledge of this atlas.

Tufte was by no means the first author to ardently praise Minard's work. As early as 1878, the French scientist Étienne-Jules Marey reproduced the Napoléon map in his comprehensive compendium, *La méthode graphique dans les sciences expérimentales et particulièrement en physiologie et en médecine* (The graphic method in the experimental sciences and particularly physiology and medicine). He also recognized the immediate visual power of this work, celebrating it with the much quoted remark about "its brutal eloquence, which seems to defy the pen of the historian."[3] Marey also referred to Minard's larger body of work, labeling his method "the Minard system" and stating that it had inspired numerous imitations and applications.[4] Over the course of the twentieth century, cartography and statistical visualization historians —namely Howard Gray Funkhouser, Arthur Howard Robinson, François de Dainville, Josef W. Konvitz, Gilles Palsky, and Michael Friendly—provided more extensive accounts of Minard's oeuvre of statistical maps.[5] Unfortunately, despite these historians' groundbreaking work, many of Minard's maps have remained unknown to the broader public; all the while, general interest in the history of thematic mapping and statistical graphics has grown exponentially following the surge in information visualization since the 1990s.

It is no coincidence that we should take a renewed interest in Minard's impressive body of work. There are several powerful forces shaping his oeuvre that resonate in our contemporary culture. One of these is an unprecedented abundance of data. The early nineteenth century saw the rise and establishment of the new science of statistics, and Minard, as well as many of his contemporaries, viewed it as a fertile source of information and began to work with this data. Though statistics is now a well-established scientific field, we too are experiencing an unprecedented abundance of structured data, brought about by the rise of digital technology—and it is no coincidence that visualization research has seen a massive rise over the past decades.

Another factor that shaped Minard's oeuvre was the profound change that new communication and transit technologies—such as steam locomotion, the railroad, and the telegraph—brought to the nineteenth century. We also find ourselves in the middle of a technological revolution, which has led to an urgent need to discuss, reflect, and understand the machines that pervade ever more aspects of our lives and create an atmosphere of unprecedented complexity. Minard worked within a sphere of well-educated people who embraced the challenge of grappling with the new developments. He was a pioneer in a movement that aspired to make statistical data useful in the face of monumental cultural changes, and he contributed more works to the emerging field of information visualization than any other single person in the nineteenth century.



Although he worked with various methods, Minard is particularly associated with the development of the flow map.[6] However, he was neither the first nor the only one to attempt an integration of cartography and the "graphical method" in the form of the flux.[7] We know today that at least one man preceded Minard in creating a flow map: the engineer Henry Drury Harness, who created an atlas of six thematic maps relating to railroad traffic in Ireland in 1837.[8] A few years later, and seemingly parallel to Minard's, the Belgian railway engineer Alphonse Belpaire produced a flow map of his own.[9] Regardless of these instances, the flow method can be considered Minard's major theme in and contribution to information visualization, with forty-one such maps in large-format by his hand alone.

This book will explore the following questions: What is the "Minard system"? What prompted Minard to develop this method? What lucky coincidences were involved in creating such a large body of work? What obstacles did he encounter in visualizing data in this manner? And when and why did he resort to other visualization methods? The introductory essay highlights the major influences that shaped Minard's intellectual life and set the stage for his oeuvre of statistical graphics. The catalog presents a complete collection of Minard's statistical graphics as well as detailed documentation of his technical drawings. This book thus creates an integrated view that will allow for a thorough account of Minard's studies in statistical visualization, and that aims to make the conditions and results of his efforts known to a larger public.

Independently and parallel to Minard, the engineer Alphonse Belpaire created a flow map on traffic in Belgium over the year 1843. The map does not bear a date, but it is likely to have been published in 1845. Blue bands refer to roads, rose bands to railroad lines. The flow width shows quantities of transport, such that a half millimeter represents either 10,000 tonnes of goods, 5,000 tonnes of baggage, or 30,000 travelers.

Introduction

The Minard System: A Geography of Flux

Life and Career

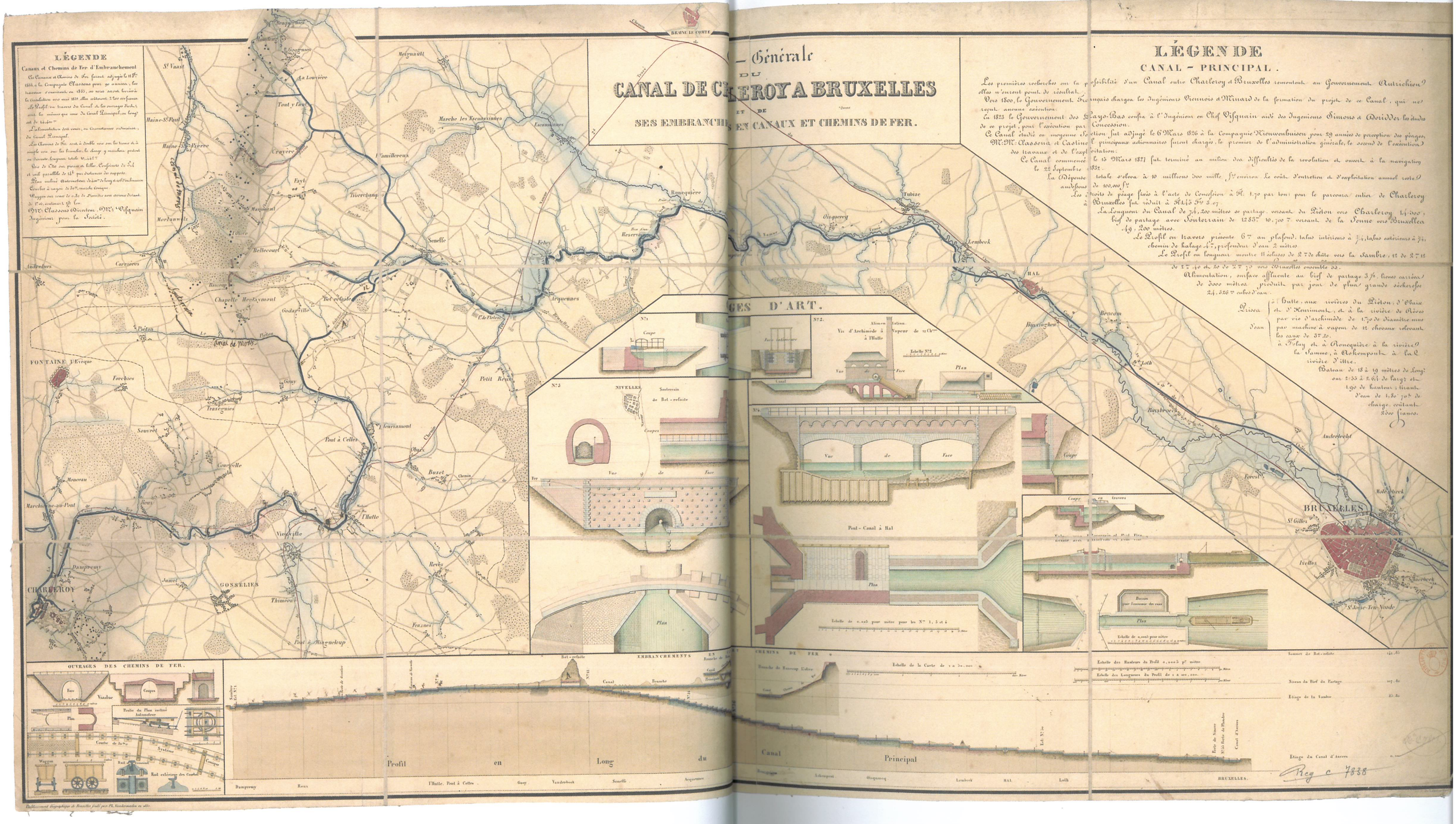
Charles-Joseph Minard was born in 1781 to a middle-class family in Dijon, France, where he was educated at the local college. He showed a preference for mathematics and physical sciences early, and, at the age of fifteen, he entered the recently founded École polytechnique in Paris, where he studied from 1796 to 1800. He was subsequently admitted to the prestigious École des ponts et chaussées in Paris to pursue a degree in civil engineering (ca. 1800–03). To this day, this school is the training center for the renowned state-run Corps des ponts et chaussées (now a part of the Corps des ponts des eaux et des forêts), a national body of expert engineers tasked with overseeing the French traffic infrastructure. All through his professional career, Minard remained closely associated with both the École and the Corps; the École archive continues to maintain the complete collection of Minard's works. After graduating from the École des ponts et chaussées, Minard pursued a long and successful career that took him from civil engineer, to inspector, to member of the Corps. In 1822, at the age of forty-one, he married the daughter of a college friend from Dijon. The couple had two daughters who grew to adulthood; one son was lost in early infancy.

In 1831, at the age of fifty, Minard joined the faculty of the École des ponts et chaussées as professor and inspector while continuing his duty as an engineer of the Corps. The *Almanach royal* lists 29 Rue de l'université, in Paris, as Minard's address from 1839 to 1844, though he may have lived there longer.[1] In 1846, in his mid-sixties, he was given the honor of becoming a permanent member of the Conseil général des ponts et chaussées, a council that directed the work of both the École and the Corps. Minard retired in 1851 at the age of seventy. He then enjoyed almost twenty years of retirement in sufficient health to follow his personal research interests—to read, write, and publish and, most significantly, to create a comprehensive body of statistical maps. In September 1870, at the age of eighty-nine, amid the accelerating events of the collapsing Second Empire and the approach of the Prussian troops, Minard rashly fled to Bordeaux with a part of his family, leaving behind everything except for light baggage and some papers he was working on. He died in Bordeaux from a fever a few weeks later.[2] Curiously, no portrait of him seems to have survived.

Minard's early career was dedicated to engineering services such as inspecting, securing, and building waterways, port installations, and bridges. He was regularly sent on assignment all over France, and in 1839 he was named district inspector to oversee the maintenance and construction of local infrastructure, first in the ninth inspection district, which comprised six departments (administrative districts of France) in the south, and later in the fifteenth inspection district, encompassing several regions in central France.[3]

Traveling and field study were an important part of his work, as was recording his findings and projects in notes, technical drawings, and plans. In 1830, in addition to his duties as a member of the public engineering corps, he was named inspector

OVERLEAF One of Minard's first engineering assignments was the terrain study and construction planning for the extension of the Canal du Charleroi in Belgium (then French territory) between 1802 and 1804. The legend of this 1839 map mentions Minard as one of the engineers sent by the French government to advance the project, even though their designs were not ultimately considered in the execution.



of the École des ponts et chaussées. He taught one course on construction works for canals and riverbeds, and another on fortification works for maritime harbors.[4] As the innovative technology of the railroad steadily gained a foothold in England and was tested throughout the 1820s in early applications in France, Minard found himself tasked with teaching a course about the new technology, though he had little theoretical or practical knowledge about it. However, he devoted himself to the new subject with ardor, seeking to expand his experience by traveling to England at his own expense to learn about the latest developments. He published his findings in a 1834 transcript of his course.[5] In addition to these various endeavors, in 1831 he joined the editorial board of the newly founded *Annales des ponts et chaussées*—the oldest modern professional civil engineering journal—to which he regularly contributed articles on a variety of technical issues.[6]

PREVIOUS The published transcripts of Minard's courses at the École des ponts et chaussées contain extensive diagrams, plans, and large-scale maps. This is plate 9 from his course on harbor construction works. The drawings show Minard's skilled draftsmanship and attention to visual details in his use of different types of lines or intricate hachures.

Out of the various currents shaping Minard's professional career, there are three particularly interesting aspects that set the stage for him to develop a keen interest in charting economic data in diagrams and maps. First, the daily practice of drawing and mapping had always been an integral part of his engineering work; he used visual aids as a tool for both the analysis and the communication of technical and related engineering issues. Second, midway through his career Minard developed an understanding that complex infrastructural projects such as the ones he was working on must be considered not only in terms of technical feasibility but also in regard to their financing, usage, and public utility. Minard was interested in introducing a political economy framework into the more technically oriented discipline of civil engineering. And third, his work in statistical mapping is marked by a general appreciation of a fact-based scientific practice, which tends to value empirical evidence over abstract reasoning and intuition—a tendency that Minard shared with many of his contemporaries and that accompanied the rise of statistics as a science over the course of the nineteenth century. It is along these lines that we will observe the evolution of Minard's oeuvre of statistical maps.

Drawing and Mapping for Engineering

In the rich body of Minard's work, we encounter an engineering practice that utilizes drawing and mapping on a regular basis to record and communicate technical issues as well as to design and project technical constructions. This is not an achievement that can be attributed solely to Minard. Rather, we should see him as having been trained within a European engineering tradition that for centuries had valued drawing and mapping as an indispensable tool to communicate issues of technical construction.[7]

This deeply rooted appreciation for the practice of drawing and mapping was engrained in the training of aspiring engineers from the early days of the École des ponts et chaussées in the Ancien Régime. The institution started in 1747 as the *Bureau des dessinateurs*, which coordinated the work of the Corps des ponts et chaussées. Not only engineering and technical drawing, but also measurement techniques, linear and aerial perspective, and mapping all formed a regular part of the curriculum at the school, which Minard joined in 1800.[8]

We may presume that he acquired sufficient proficiency in technical drawing and mapmaking through his education, a fact that is confirmed by drawings and plans in his early writings. One of his first brochures, published around 1825, contains two plates: one regional project plan and one diagram. The brochure was written and drawn while Minard was engaged in municipal service in Paris and devoting himself to the subject of the city's pavement.[9] The pamphlet first analyzed the history of the ways in which the municipal pavements in Paris had been maintained throughout the previous 188 years, before proposing a new canal—supported by several short, horse-drawn railway lines—to provide Paris with large amounts of high-quality yet affordable cobblestones from the banks of the river Yvette.[10]

The preceding historical analysis is accompanied by Minard's earliest known diagram [1]. Notably, this piece utilizes the abstract representation space of the timeline to follow various key figures throughout a period of 188 years. In Minard's era, the concept of a timeline was less prevalent than it is today. The plotted graphs are hand colored for better legibility and differentiation. For each graph, the legend provides a scale, so that the reader—using a ruler—would be able to measure the precise values on the vertical axis. While this way of deriving exact numbers from the charted graphs is certainly tedious, the diagram also reveals more general temporal patterns.[11]

This early venture in abstract statistical representation was not, however, promptly followed by similar attempts. We don't know exactly what inspired Minard to create this sort of timeline, although it does seem fair to assume he was influenced in part by the work of William Playfair. Playfair's *Commercial and Political Atlas* had appeared in French translation as early as 1789, and Playfair himself experienced a somewhat more favorable reception in Paris than in his native Great Britain. Minard could very well have drawn on this in the early 1820s; however, there is no proof of his familiarity with Playfair until 1861.[12]

Minard does not proceed on the path of statistical representation until the mid-1840s. However, several of his publications in the intervening years testify to his continuing practice of recording and communicating information in technical drawings and plans. In particular, all three of the comprehensive transcripts of his courses (published between 1834 and 1846) contain extensive visual documentation.[13] For instance, the latest of these publications, the *Cours de construction des ouvrages hydrauliques des ports de mer*, contains twenty-five plates of delicately engraved drawings, bound in a separate atlas to accompany the volume of text. These visuals cover natural phenomena, such as wind patterns, recorded in diagrams; sea currents and shifting coastlines in large-scale inset maps; plans of local harbors and the layouts of several existing ones; and construction drawings. All plates are signed "Ch. Jo. Minard del.," clearly demonstrating Minard's authorship.

Even if we attribute some credit for the exquisite execution of these prints to the engraver ("Lemaitre sc."), the plates still testify to the fact that Minard had perfected his draftsmanship and paid attention to the smallest visual detail. For instance, he used an intricate dotting or a delicate hachure to separate the shore from the sea in large-scale maps of estuaries and islands, and he employed several different types of lines to plot the ever-shifting course of a coastline.[14] Also notable are the clean and minimalist aesthetics that these drawings convey. Not only are they refined in every detail of their rendering, including the lines, the dotting, the hachure, and the concise labeling, they also have a very "modern" appeal to them, narrowly focusing on the technical issues at hand and refraining from any graphic decoration. This is a characteristic that we will continue to observe in Minard's later statistical representations.[15]

Given this habitual practice of drawing on visual aids—whether to clarify pre-existing conditions or to draft a new technical structure—it is unsurprising that Minard would employ these skills when facing a very new sort of problem.

Infrastructural Projects and Economic Thinking

Cost estimates and, more generally, the economic evaluation of an infrastructural project had long formed an important part of engineering work. However, as the construction works of both the Corps des ponts et chaussées and the engineers themselves were all paid for by the royal and, later, the national budget, it is plausible that they were not as concerned with economic considerations as private businesses would have been. Furthermore, the evaluation of investments in infrastructure often proved to be intrinsically difficult during the eighteenth century. For instance, the Crown did not impose any nationwide road charges, meaning that the return on investing in good streets did not come back to the state but stayed with streets' users, thus eluding deeper analysis. This changed with the arrival of the railroads in the 1820s and 1830s, which combined investment (in the infrastructure) and operation (of the trains) into one system, which would yield returns by requiring users to pay for their tickets. This enabled the engineers to assess in detail the investments made in a particular railroad line versus the returns that its operation would yield.[16]

In Minard's obituary, Victorin Chevallier, Minard's son-in-law and fellow engineer, wrote that when Minard entered the faculty of the École des ponts et chaussées in 1831, he wanted to establish a new position to teach applied economics to the engineering students.[17] Chevallier further recounts that Minard had pondered economic questions for a long time and had read the works of the most eminent economists. The new teaching position did not come into fruition until 1847; however, the debate

about its creation inspired Minard to write a paper in 1831 that outlined his ideas of what an applied economic science for engineers could look like.[18] This extensive treatise, *Notions élementaires d'économie politique appliquées aux travaux publics* (Basic notions of political economy applied to public works), is a detailed effort to assess the utility of public works. While there was sufficient experience among engineers to figure out the necessary investments for a given construction, it was difficult to assess the expected returns. Minard wrote, "In the current state of our society, public constructions…almost always have as their goal to improve existing conditions; it is this improvement that we should try to express economically, and it is the economies which represent the utility created."[19] In the paper, he tried to develop methods for how exactly the economies of a structure—whether a bridge, canal, or railroad line—could be expressed in a common unit such as money.

It is no coincidence that such considerations would resurface with renewed relevance in the late 1820s, when the railroad gained traction in England and saw its first small-scale applications in France. The new technology confronted the state engineers of the Corps with a whole complex of intricate questions: How can we predict the future usage of the railroads? How can we assess their utility against the investments that will have to be made? Is the relation of investments and utility such that we should envision a national railroad system? As previously mentioned, Minard investigated the new technology and laid out his knowledge on the subject in a publication in 1834. At the time, his economic assessment of the railroad was rather ambiguous: Minard considered its utility to consist mostly in saving time. He acknowledged that faster travel might be helpful for passengers such as businessmen; he felt, however, that saving time was not really necessary in freight traffic. Therefore, he was not certain if steam-powered locomotives were preferable to horse-drawn railroad carriages for the transport of merchandise, given the high investments necessary for the former. It is ironic that Minard—a celebrated innovator in the field of statistical representation—is remembered by some historians of technology as a witness to the inherent inertia of the state-run engineering corps, whose members were not visionary enough to see the full potential of the railroad.[20] His reserve, however, can be understood in the context of his efforts to assess the balance of investments and predicted future usage for traffic infrastructure projects.

When turning to the first group of statistical works that Minard created, beginning in 1844, we can see this rationale at work: he systematically investigated the demand for particular traffic infrastructures. He had formed the belief that new railroad lines would pay off only if they were conceived to serve not just their end points but also the smaller towns along the route, since most passenger and freight traffic was to be gained on short distances between intermediate stations.[21] In order to support his argument, Minard embarked on a quest to assess as precisely as possible the current usage of existing traffic routes, both as an analytic tool and to help predict future demands on specific lines. The first elaborate example to have survived is a sheet of six diagrams dating from May 1844 [3]. The diagrams each represent one particular railroad line in a bar chart, over a horizontal axis subdivided proportionally by the distance between intermediate stations. The vertical axis represents the number of passengers who traveled each section during a given period of time. As the product of distance and passenger trips, the surface area of each rectangle represents the transportation performance for the given part of that railroad line. Minard distinguished between two different types of voyage: the dark hachure refers to passengers traveling the distance from one end point to the other, while the brighter areas represent passengers who traveled only along one or several sections of the route.[22]

In analyzing the traffic flow for existing railroads, Minard sought ways to help predict demand on existing or projected routes. And indeed, these diagrams were very helpful in comparing passenger flux along particular lines. They support Minard's argument that most travel happens between intermediate sections (except for the line between Orléans and Paris in the lower right, where passengers traveling the full distance account for a substantial share of all traffic). Also, general usage patterns of specific routes become easily discernible, like in the three Belgian lines (the top three diagrams); the most passengers travel between Brussels and Mechlin.

Over the next two years, Minard created three more variations of this format, which he termed "graphic tableau" or "figurative tableau." In a brochure published in 1846, he described his rationale for these diagrams: "However, the numbers—of an undisputable statistical utility—are not as easily apprehended by the eye as figures proportional to them. I have thus drawn a figurative tableau of passenger traffic.… This tableau speaks to the eye and renders accessible the results as a whole at one glance."[23] Among these tableaus, one colored piece from December 1845 is particularly worth examining [5]. It introduces no fewer than nine different categories of merchandise that are observed in their travels along the Canal du Centre. Minard did not confine himself to showing the quantities of each type of merchandise in the height of the stacked sections; he also tried to describe the direction of movement by introducing arrows. However, as he executed this rather erratically, it is difficult to read the orientation for select amounts of goods. In the first brochure about his statistical graphics, *Des tableaux graphiques et des cartes figuratives* (1861), he explored the problems of this distinct diagram: "This mode of representation has a little drawback regarding commercial use: sometimes, the journey of a commodity cannot easily be followed with the eye, because the rectangles of the same color representing it are separated by those of another color. If one would like to track the journey of this commodity, it takes a tableau graphique for this one alone."[24] This way of reflecting on his work continually pervades Minard's oeuvre. For instance, when following Minard's statistical maps over the years, we can see that he gradually developed an understanding of the intricacies of integrating many different flows into one coherent representation, and that he continually worked on avoiding clutter in his multiflow representations. This is particularly evident in the Napoléon campaign map, which combines the countless diverse movements of many different parts of the army into one continuous flow.

The First Flow Maps

In considering how he could refine his graphical method, Minard soon made a crucial decision: he switched from diagram to map. When he placed his proportional section bars on a map, he went from working with one spatial dimension in his graphic tableaus (i.e., the horizontal axis of the route) to the two spatial dimensions of longitude and latitude. His first flow map from 1845 shows road traffic in the area between Dijon and Mulhouse and can be understood as another effort to predict demands for a future railroad line in the region, which was projected and debated at the time [4]. As simplistic as this map is from a cartographic point of view, it successfully served its objective. Minard reported to have distributed two hundred copies to members of the Conseil général des ponts et chaussées, deputies of the concerned districts, and fellow engineers. Apparently, the map shaped the debate to the extent that a fake copy was soon made in an attempt to prove another route to be more promising.[25]

Minard's first productive period in statistical mapping stretched from May 1844 to March 1847. During this time, he created variations of the graphic tableaus as well as the first flow maps. The period was capped by a very intricate and lesser known map, in which Minard introduced several novel features that deepened his approach to statistical mapping [9].[26] For the first time, he colored a flow map to distinguish between the various flows. Furthermore, Minard introduced a historical aspect by comparing data from ten years apart. Lastly, Minard added exact numbers along his flows, making it possible to derive precise data from reading the map. Through the experience of seeing his maps used in public discourse, and by

elaborating his graphical methods, Minard developed an ever-stronger impulse to draw from the fertile sources of statistics in order to create meaningful visual analyses for engineers and administration officials. Evidently, this also entailed a strong motivation to adhere to the guidelines and "ethics" of statistics.

After a four-year break between 1847 and 1851, and following his retirement in March 1851, Minard entered into his study of graphic visualization with new fervor. He produced a constant output of statistical maps in large format over the next nearly two decades.[27] The majority of these works were flow maps, and while he occasionally tested other methods of statistical mapping (such as proportional and sectioned pie charts placed on maps), he never really returned to using diagrams until very late in his career. We do not know what shaped his specific preference for the flow map method; however, we should not regard it a mere coincidence but rather acknowledge it as a clear decision on Minard's part. Apparently, he appreciated the flow map for its integration of statistical representation and spatial reasoning, and considered this the most promising path to follow in his visualization studies.[28]

Statistical Thinking and Empirical Evidence

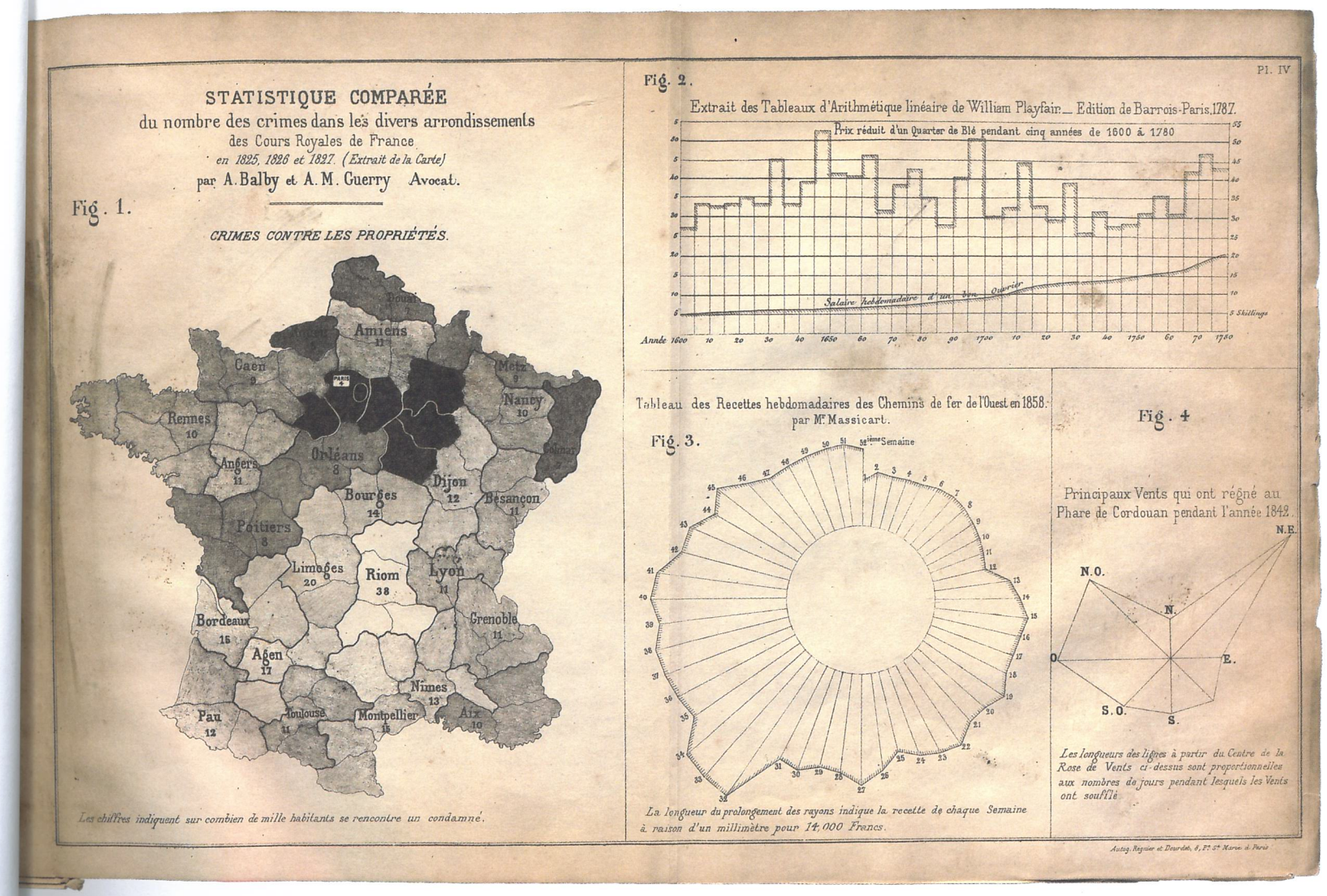
One key factor in understanding Minard's work is the rise of statistics through the early nineteenth century.[29] In a pamphlet titled *La Statistique*, published one year before his death, Minard explored the potential of this new field of study and defended it against contemporary criticism, which dismissed it as not being a proper science:

> *Statistics is the registration of homogenous facts in a systematic, numerical or chronological manner. Memory is the intuitive registration in our brain of ideas or sensations which have left more or less of an impression on us.... In indicating at first the analogy between Statistics and one of the elements most necessary to our understanding, I wanted to relieve it from the state of inferiority in which it has been placed by the scholars, as since memory is indispensable for acquiring our intellectual knowledge, Statistics is the foundation of several sciences at which we wouldn't have arrived without it.*[30]

The treatise also proclaimed a new genre of figurative statistics, which according to Minard was developing rapidly at the time. Minard went on to present successful examples of statistics and statistical graphics across a variety of academic disciplines, including lawmaking, botany, paleontology, and history. While the argument seems a little odd at times, as he mentioned several scientific procedures which are not—in our understanding—actually related to statistics (such as the systematic description of human organs and their functions in physiology), there is one common denominator to be found. In all the examples given, Minard celebrated a singular approach to acquiring knowledge: *the systematic gathering and evaluation of facts*.

Minard showed an appreciation for empirical evidence that was shared by many of his contemporaries throughout the nineteenth century. The role of such evidence in statistics and in the emerging social sciences was expressed by the British statistician William Newmarch in 1861:

> *We have, for example, in Statistics no such body of general laws as are to be found in dynamics, as are to be found in chemistry, or in physiology. But then we claim for Statistics—and it is no small claim to put forward for any branch of knowledge—that it is the application of the Experimental or Baconian method to the several divisions of inquiry which relate to man in society. We say, that where there is no careful application of the Statistical method—in other words, where there is an absence of observation and experiment, so far as observation and experiment can be applied to men in societies—there can be but faint hope of arriving at the truth in any line of research connected with social problems.*[31]



This valuation of experience, empirical research, and exact measurements of social or economic phenomena underlies the intellectual framework of Minard's visualization research. Many details in his maps (particularly in the labeling and text descriptions) testify to Minard's continuing bid for what we might call "data hygiene"—a responsible and transparent handling of the statistical data he processed in his graphics. He continually strove to disclose not just the sources of his numbers but also his methods for aligning and aggregating data or estimating missing figures.[32] Even in his early works, Minard consistently used subheadings or legends to give some explanation of how to read the visualization. In 1847, he began to expand these elements into proper description texts for each map. With very few exceptions, every one of his large-format statistical maps contains one or two texts, which provide information about its topic, sources, and execution, as well as the date of publication and Minard's signature. The maps are designed to be individual works rather than illustrations integrated into a book. From the sources mentioned in the descriptions, as well as from the data portrayed and several brochures accompanying some of the more complex works, we get the sense that each of his maps must have been the result of a personal research project. At the time, statistical information on matters such as population, administration, or transport was not as readily available as it is today. Repeatedly, Minard indicated that he gleaned his data from not only a rich

In his 1861 treatise *Des Tableaux Graphiques et des Cartes Figuratives*, Minard advocated the use of the graphical method to communicate statistical data. He recapped the work of several of his predecessors and reproduced some models of statistical visualization. The table above shows an early choropleth map by Adriano Balbi and André-Michel Guerry (left, with data from 1825–1827), a diagram by William Playfair (ca. 1787, top right), a circular diagram of the weekly receipts of the French Western railroad company by a Mr. Massicart (bottom center, with data from 1858), as well as an unsigned wind diagram from the Cordouan lighthouse (bottom right, with data from 1842).

variety of printed sources but from correspondence with administration officials, fellow engineers, and authorities of commerce or transportation in order to obtain unpublished data for an integrated view of the matter in question.[33]

Two terms Minard frequently used to describe his maps are "figurative" and "approximate." The former appears first in 1851 [**10**] and the latter in 1852 [**12**], after which time they consistently are used together in the majority of Minard's maps.[34] From his 1861 treatise *Des tableaux graphiques et des cartes figuratives*, we can discern what Minard meant when speaking of a figurative map—namely, the transformation of statistical numbers into a visual representation:

> *The great extension which our time has given to statistical research generated the need to record its results in ways which are less dry, more beneficial and more accessible to rapid exploration than the numbers.... In giving statistics a figurative direction, I followed a general impulse toward graphical representations.... In creating a figurative statistics, I satisfied the current need, but have I not just bowed to the taste of our epoch and have I not contributed to enhancing the utility and to shortening the time required for statistical studies?*[35]

This transformation was by no means trivial, and it was also not unanimously supported among statisticians in Minard's time. Even though many statisticians would acknowledge the inherent potential of graphics to render accessible the results of their research, the utility of the graphical method was often considered to be limited. The German-French statistician Maurice Block expressed the reserve of many of his colleagues when he wrote in 1886, "Notwithstanding all the truly remarkable things that have been done, the graphical representations might never achieve the precision of a table of numbers."[36] It is therefore unsurprising that many groundbreaking inventions in the field of information visualization in the nineteenth century were contributed not by statisticians but rather by scientists and professionals such as Minard who had a thorough knowledge of mathematics (thus they were able to process statistical results) and sought to understand phenomena of current interest in their respective fields. For all his passion for creating statistical representations, Minard seems to have been aware of the statisticians' reservations and advocated for his use of figurative maps:

> *The aim of my figurative maps is less to exhibit statistical results, which could be better established by numbers, than to make relationships quickly apparent to the eye, relationships that are instantly grasped where numbers would require the mediation of a mental calculation. The figurative maps are thoroughly in the spirit of the century in which one seeks to save time in all ways possible.*[37]

As for the term "approximate," we may assume that Minard started including it as a way to acknowledge that his graphical representations would always have to compromise some scientific standards of precision. On the one hand, he would try to adhere as much as possible to the notion of statistical precision and gradually adopted several measures to achieve the highest possible standard. Those measures included the disclosure of his sources, his estimates, and the facts on which these estimates were based; the inclusion of raw numbers along his flows or next to his pies; and a clear labeling and description of the graphical elements in the legend. The consistent use of graphic scales for the statistical elements, and the precision expended on the exact transformation of raw data into proportional forms, suggests that Minard designed his maps for both an overview and a "close reading," where the reader would use a ruler to actually measure flow widths or intervals in a diagram.[38]

On the other hand, Minard quite deliberately and continually transgressed every idea of cartographic precision. He ruthlessly revised coastlines and omitted even big islands [**32**], widened the strait of Gibraltar [**41**] and the Bosphorus [**58**], and dispensed with Ireland and Scotland in a map of Europe [**49**]. These are just a few examples, with many more to be discovered throughout his extensive oeuvre. As this rather crude treatment of cartographic principles is such a remarkable and pervasive trait in Minard's maps, it has been much discussed by previous authors. Arthur Howard Robinson, for instance, has written archly of the "tyranny of precise geographical position" from which Minard deliberately escaped.[39] And in his discussion of the distinction between topographic and thematic maps in the nineteenth century, Gilles Palsky explained that this rather liberal approach to mapmaking was considered more than strange by cartographers and was one of the reasons why thematic cartography—such as practiced by Minard—was received rather critically within the circles of geographers and cartographers of the time.[40]

In addition to this "non-Euclidian cartography" (as put by Palsky), it is also interesting to note that Minard's statistical maps are extremely bare.[41] Topographic references are scarce, and landscapes are usually characterized simply by a combination of coastlines and land borders with a few place names positioned loosely on the map. Except for a number of examples where areas are shaded, both land and ocean remain uncolored and are sometimes difficult to distinguish at all. For instance, in the early flow maps of France (prior to 1858), the silhouette of the country is not easily discernable against the dominant flows. Similarly, not all readers immediately understand that the Napoléon campaign graphic [**60**] is in fact a map. The territory on which this drama unfolds is not visually described, except with a few labels for places and rivers.

Minard was clearly quite skilled in drawing and mapmaking. Had it been a priority to him, he would have been very capable of drawing "proper" maps, or at least of creating ones that do not so boldly defy the principles of cartographic representation. It is evident that his "non-Euclidean cartography" is not the result of coincidence, incompetence, or mere negligence. On the contrary, we must consider it a clear decision on Minard's part to treat cartography as an "auxiliary canvas" on which his main story (i.e., the drama of the statistical numbers) unfolds. An indication of this is given in his own description on the map where he first used the term "approximate" in 1852 [**12**]:

> *The aim of this map was to make apprehensible to the eye the relative importance of several movements of traffic. To this consideration I have sacrificed the topographic exactness. Several distances are altered in order to place the zones and in order not to exceed the measures of the largest stones available for the lithographic printing.*[42]

This remark is echoed by many similar comments in the map descriptions, and it points to the fact that his priority was the representation of the statistical data, which was given detailed attention and scrutiny. In his maps, Minard chose a spatial setup for plotting this data. The space, however, is not described in much detail; it is enough that the map references the mental map the reader harbors in her memory. Moreover, the space is not only denied closer attention but must "recede" when it threatens to interfere with the statistical depiction.

Minard—whether consciously or not—systematically worked to carve out a coherent "story" from a given research question. Throughout his oeuvre, we can observe an ever more consequential habit of editing his maps with the aim of shaping a narrative focus. He did so, for instance, by focusing on just one aspect of a given data set, by collecting data from various sources in order to answer a predefined research question, or by juxtaposing maps to compare data sets over time. He thus gradually developed an expertise in composing rich and detailed dataviews while avoiding the clutter and inconsistencies found in some of his earlier maps.

The Reception of Minard's Work

Minard published his maps himself; he was not part of any major scientific society or academy, nor did he publish in any scientific journal other than the *Annales des ponts et chaussées*.[43] The American cartographer Arthur Howard Robinson wondered how exactly Minard circulated his maps, reached a wide audience, and made the impact that he did. Robinson concluded: "He seems to have been a lone worker."[44] This is congruent with Minard's obituary, where he is described as a rather modest person who didn't have much talent for self-display and whose career, considering his merits, advanced rather slowly.[45]

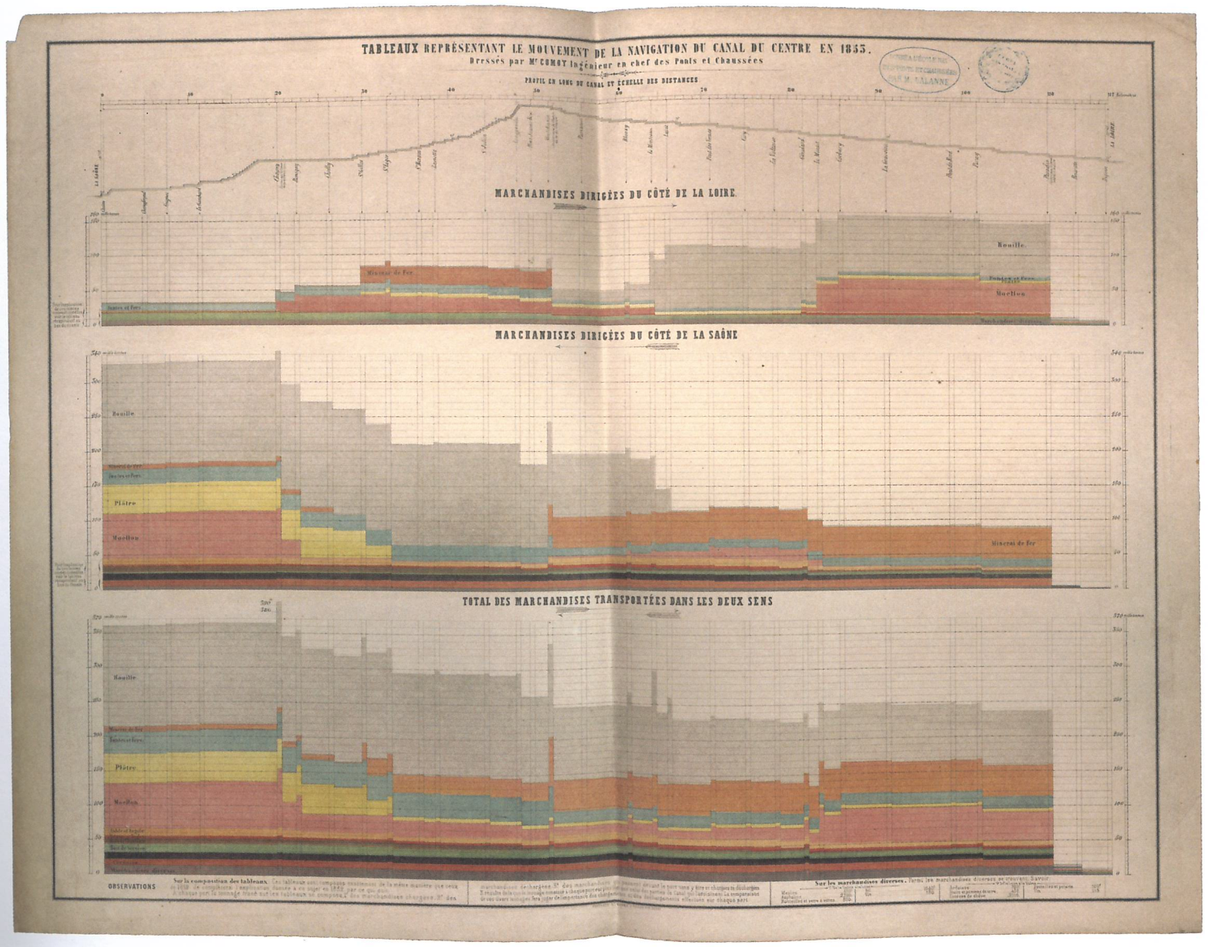
This portrait shows the French statesman Eugène Rouher with a map by Minard draped over the chair. The original painting by Alexandre Cabanel, a famous salon painter in France, was exhibited in Paris at the Salon des Beaux Arts in 1861, and was in possession of Rouher's family until into the twentieth century. This version is a painted copy by Charles Brun. Eugène Rouher gave it to the Musée Mandet in Riom, his home town, where it is kept to this day.

Other than his technical drawings, which were printed as engravings and bound in books or pamphlets, his broadsheet maps were lithographic prints—most of them hand colored, although some maps were printed with color. According to Minard's writings, two of his early maps were printed and distributed in editions of one hundred and two hundred copies, respectively.[46] Lithographic printing generally allowed for print runs of up to ten thousand copies. However, we have no information about Minard's usual print run, and not many copies of his maps seem to have survived.[47] This may be due to a restrained budget on Minard's part; lithographic prints were an expensive investment for a private budget. Also, with the maps targeted to a specific-interest readership, he may have opted for a limited print run of only a few hundred. As for their conservation, broadsheet maps in general (and even more so statistical maps, whose information grew outdated) were considered tools for daily use (as opposed to precious works of art or decoration) and would usually not have been kept for posterity.

While Robinson's characterization of Minard as a "lone worker" seems exaggerated, the questions remain: If Minard had each of his works printed in only a few hundred copies, where did all these maps go? Who were the readers he addressed? And how did word of Minard's work spread? Some of Minard's notes indicate that he would make the effort to send maps to people whom he thought would be interested, such as fellow engineers, deputies, and local politicians. Apart from that, it may be assumed that his printers would have sold a number of copies in their shops.

Apart from these modes of distribution, there seems to have been one fruitful channel for his oeuvre inside the administration of public works. We know Minard to have been a much respected member of the Corps des ponts et chaussées and its influential Conseil général, which coordinated the work of the Corps and thus all national infrastructure projects. The obituary mentions that he received strong encouragement for his statistical maps from several secretaries of public works.[48] While in office, the secretary would also head the Conseil général des ponts et chaussées. Minard was first a temporary and then, from 1846, a permanent member of the Conseil until his retirement in 1851. We can assume that he continued to engage with his peers after his retirement, and would therefore have managed to circulate his maps among high ranks of the administration of public works.

In his 1861 brochure *Des tableaux graphiques et des cartes figuratives*, Minard mentioned that the general director of the Corps des ponts et chaussées, Alfred de Franqueville, had presented his maps to the French statesman Eugène Rouher, who was secretary of agriculture, commerce, and public works at the time. According to Minard, Rouher readily subscribed "to the majority" of his maps, which enabled Minard to publish some ten thousand copies of maps on a variety of subjects.[49] This suggests that the subscription made by the secretary encompassed not only single copies for himself but larger numbers of copies that Rouher may have circulated among his clerks and officers—an assumption which could explain how Minard financed the printing of large editions of his maps and how large numbers of his maps found their way into the administration's offices.



Rouher went on to be one of the most influential politicians in France over the next decade. (He led the government from 1863 to 1869 and served as a close advisor to emperor Napoléon III and his wife.) Minard reported that his maps had been presented to the emperor Napoléon III, who received them favorably.[50] Minard's obituary states that he had the honor of having one of his maps depicted in a life-size, full-figure portrait of Eugène Rouher, painted and presented to the public at the Salon des Beaux-Arts in 1861.[51] It is clearly an indication of a great appreciation that this high-level politician should have included Minard's map in his official portrait and introduced Minard's work to the emperor. It suggests that Rouher valued applied statistics as a means to comprehend some effects of the accelerating industrialization, and that he considered statistical maps such as Minard's highly expedient tools for administration, suitable to mark Rouher as an icon of modern leadership.

The Impact of Minard's Work

Minard observed in *Des tableaux graphiques et des cartes figuratives* that his innovations were almost instantly imitated. He reported, for instance, that he had sent his 1845 colored tableau graphic on the Canal du Centre [5] to Guillaume-Emmanuel Comoy. At the time, Comoy was the inspector in charge of the canal and had provided

Guillaume-Emmanuel Comoy was the engineer in charge of the Canal du Centre, and provided the data for Minard's graphic tableau showing freight traffic on the canal in 1844 [5]. He found this graphic so useful that he subsequently created his own diagrams visualizing traffic on the canal, including this one showing data from 1853. In representing the two directions of traffic in separate diagrams and in using an elaborate grid as a background, he reconciled some of the difficulties of Minard's 1845 original. As an additional feature, he visualized the cargo for each harbor along the canal.

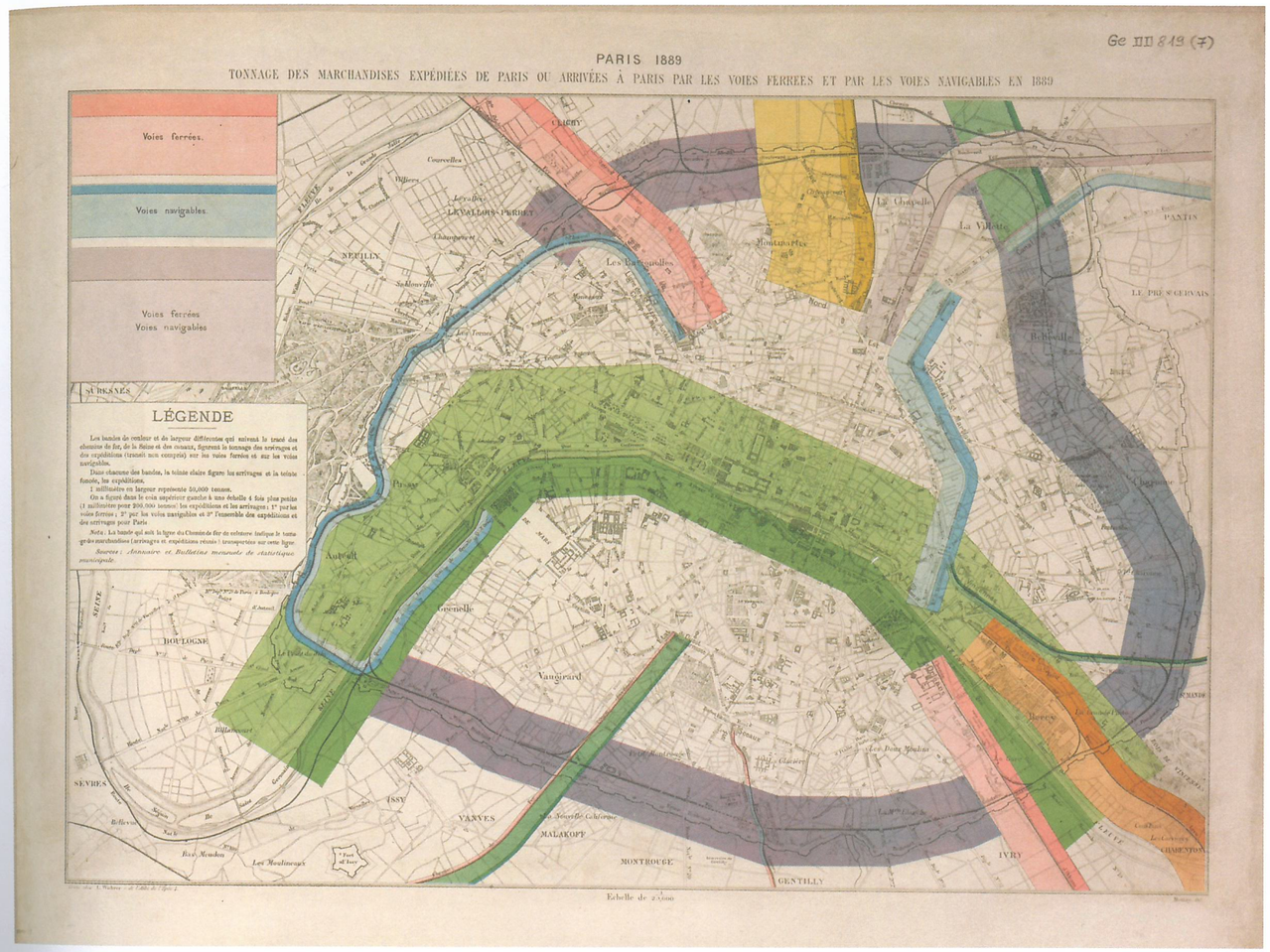
the data for Minard's diagram. Apparently, Comoy found the graphic so useful that he started publishing his own detailed diagrams following Minard's example, visualizing the traffic on the canal every year from 1851 onward.[52] By 1854 Comoy's works had made such an impact that the administration of public works recommended the application of such graphic tableaus to all main waterways (apparently without referencing Minard). Furthermore, Minard recounts that when two of Comoy's diagrams had been exhibited at the Exposition Universelle in 1855, he felt compelled to claim his anteriority, which was given proper credit when the jury mentioned in their printed report that Comoy's works were based on Minard's system.[53]

Minard also mentioned several other direct followers and applications derived from his examples, including a complex mapping project that the administration of Ponts et chaussées published in twelve sheets to document circulation on national roads.[54] Furthermore, through the described channels of circulation, Minard's maps seem to have gained a large audience among administration officials, social and economic researchers, and employees in private businesses concerned with infrastructure projects, such as the railway companies. It was apparently through a combination of a subscription system, commercial sales in the print shops, many informal contacts, the immediate imitation of his methods by colleagues, and word of mouth that his maps and methods became widely known among technical and scientific circles in France during the second part of the nineteenth century. All told, however, we have no indication that Minard exerted any significant influence in administrative matters, such as in the debates regarding the establishment of the French railroad network. His long-lasting influence lies more in his having inspired many fellow engineers and scientists to pursue the visualization research he so impressively established. Gilles Palsky, in his comprehensive overview of statistical mapping in France through the nineteenth century, summarized the impact of Minard's oeuvre by saying: "If his works exerted an immediate influence, it was primarily by initiating a period of enthusiasm for statistical graphics between 1860 and 1900."[55]

Minard's Legacy

Minard's contribution to the growing movement of data visualization using the "graphical method" is outstanding in its range and extent. It was a lucky concurrence of circumstances that allowed him to create his statistical maps. Apart from the influences described above, we also seem to owe this oeuvre to some simpler, external factors. As most of this work was created after Minard's retirement, it seems noteworthy that he (though his health seems to have been unstable for long periods of his life) was well and motivated enough up until a very old age to pursue his personal research interests, and that he had the time to research the data and draw the maps, as well as the money and the connections to have them printed.

Tarbé de Saint-Hardouin, who published a collection of biographies on the engineers of the Corps des ponts et chaussées in 1884, described Minard as a person of independent spirits: "The slowness of his advancement, compared to his contemporaries, was without doubt the result of the independence of his mind, and of the occupations he chose, with the single goal of satisfying his affinity for research and without considering the progress of his administrative career too much."[56] Whether this is a true description of Minard's character we cannot judge. However, his achievements did require a certain independence of spirit. He developed the impulses of several predecessors to establish a new form of scientific communication. He created a very significant aesthetic in his maps; among hundreds of nineteenth-century maps, it will always be easy to identify works by Minard, with their minimalist design, well-defined color schemes, and fine execution. Most of his many works were self-initiated and well researched. It appears that until his death at the age of eighty-nine, he was a spirited man, ready to engage with new topics and experiment with new methods. Among the later works of his oeuvre, several maps



deviate from the usual traffic- and trade-dominated topics, such as a map about global migration [38], the development of ancient languages [56], two double pieces (including the Napoléon map) that cover historical military campaigns [46] [60], and two diagrams on higher education [59] [61]. In addition, one year before his death, Minard published a brochure on ancient construction techniques, featuring several technical drawings. All of these works testify to his wide-ranging interest and curiosity, which kept him at work until his very last days.

The archive of the École nationale des ponts et chaussées in Paris, where Minard had close, lifelong associations, keeps a comprehensive portfolio of his works, bound in a volume, that must have been assembled just months or even weeks before his death. In it, Minard had collected and bequeathed to the archive all maps and diagrams he considered relevant in his oeuvre of statistical visualization, certainly with an aim to preserve it for posterity. It would certainly be fulfilling for him to see new generations of engineers, statisticians, and visualization researchers learning from his example. It is unfortunate that at this point no portrait of him is known to exist in the archive of the École des ponts et chaussées or elsewhere. But then it may be most reverent that we should remember him not by his own likeness, but by the power of his celebrated works.

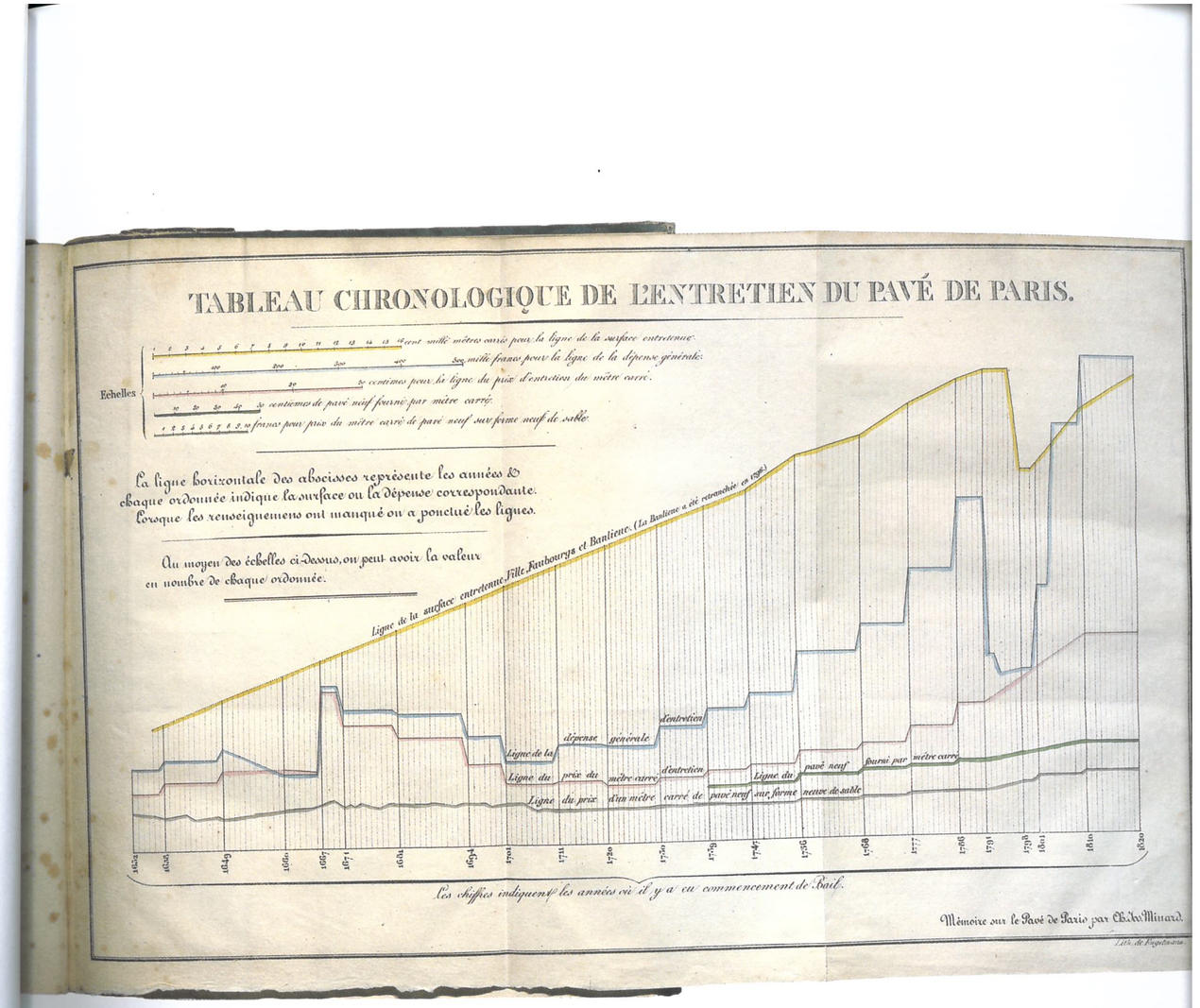
This flow map originates from the *Album de statistique graphique*, by Jacques Bertillon, and shows freight traffic in Paris in 1889. The brighter part of the flow relates to incoming traffic; darker flows show expedient transports. Different modes of communication (waterways, railroads etc.) are distinguished by color. The base map and flows are treated differently than in Minard's works: instead of reducing the base map to the absolute minimum to make room for the flows (as Minard did), the cartographers opted for a transparent flow, which forms a transparent layer over the detailed map.

EDITOR'S NOTE: This is a complete catalog of the known statistical maps and diagrams by Charles-Joseph Minard. Not included are technical drawings and plans (a list of those is provided in the appendix). All works in the catalog are kept in the archive of the École nationale des ponts et chaussées in Paris, except for [34], of which there is known to be only one copy, held at the Bibliothèque nationale de France.

The graphics in this catalog are numbered according to the chronology of their creation date, with several undated works listed according to the probable date of their creation. The catalog follows this chronology, except for three distinct series of works. These maps were updated several times over the course of years and are presented here in three associated groups.

The measures given in the catalog pertain to the specific sheet reproduced here. It is important to keep in mind that the measures for Minard's surviving maps vary from copy to copy, sometimes substantially. This is due to the fact that the maps were printed on sheets larger than the actual graphic, and very often were cropped or cut in pieces and subsequently glued on paper, mounted on linen, or bound in a brochure. Therefore, the measures here only serve to give a general size indication for each map.

The explanatory notes and observations included in most of Minard's statistical graphics provide substantial insight to his visualization studies. Although his original language is at times vague or ambiguous, we have included translations of the original map text for a selection of the most interesting works. Digitized versions of his works can be found online at patrimoine.enpc.fr/collections/show/12.



1

Paris Pavement Maintenance

▲ **"Tableau chronologique de l'entretien du pavé de Paris"**
No date. Lithographic print, hand-colored. 41.5 × 26.0 cm.
Published in: *Tableau des progrès de la dépense du pavé de Paris pendant les deux derniers siècles* (Paris, 1825)

This diagram accompanies a pamphlet about the maintenance of the Paris pavement from 1632 to 1820. Minard described it as a "visual register" that he drew "in order to better grasp all the circumstances of the maintenance."[1] The colored graphs visualize several metrics Minard calculated by drawing from historical contracts. The yellow graph indicates the total pavement surface area in Paris, while the blue one shows the total maintenance expenditures per annum. The vertical axis is not labeled; instead, readers have to make do with horizontal scales provided for each graph in the top left section. Punctuated graphs indicate a lack of data sources. The diagram reveals a pattern break after the Revolution of 1789, when the maintenance budget (blue) nosedived for several years. At the same time, the average maintenance price per square meter (rose) grew because the pavement gradually wore out.

MINARD TRANSLATED

Chronological table of Paris pavement maintenance

The horizontal line of the abscissae represents the years and each ordinate indicates the surface area the corresponding expenditure. Dotted lines were used where information was unavailable. Using th scales above, the reader can find the numerical value of each ordinate.