ALSO BY PETER GALISON

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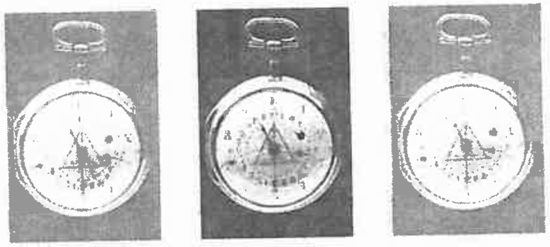
EINSTEIN'S CLOCKS, POINCARÉ'S MAPS

Empires of Time



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Chapter 3

THE ELECTRIC WORLDMAP

Standards of Space and Time

PARIS, HÔTEL DES AFFAIRES étrangères, 20 May 1875, 2:00 P.M. Represented by their decorated plenipotentiaries, seventeen names will be put to a treaty, their resplendent titles marching across the page: "His Majesty, the Emperor of Germany," "His Majesty, the Emperor of Austro-Hungary," "His Excellency, the President of the United States of America," "His Excellency, the President of the French Republic," "His Majesty, the Emperor of All Russia. . . ." We are at the solemn signing of the Convention of the Meter. After years of negotiation, the High Contracting Parties now called into existence an international bureau of weights and measures. The new prototypes of the meter and kilogram it was charged with certifying would supplant the myriad of competing national measures, establish the relation between these gauges and all others, and compare results with the standards used to map the earth.

Here, in the *convention*, diplomacy met science. When Duke Louis Decazes, the French minister of foreign affairs, sent out invitations to other countries back in 1869 for a diplomatic conference on this issue, he invited politicians, but also leading scientists like the German astronomer Wilhelm Förster, who was director both of the German Bureau of Weights and Measures and the Berlin Observatory. By March 1875 the committee had come far enough for Decazes to gently retire the scientific domain, in which the assembled held only a "relative competence," in order to focus on "questions of a political and conventional order (*ordre conventionnel*)," where they had "absolute competence": their conclusions

would form the basis for binding international law. Conventions joining scientific and legal technologies had been concluded before—in 1865, for example, governing telegraphy. Indeed dozens of conventions had aimed to smooth collisions between countries in trade, post, and colonization. Now, in the vital domain of the metric system, even more than the telegraph accord, the delegates had produced an "international contract" as dear to scientists as it was to industrialists and politicians: a legal document that would rule from the spotless precision of the physics laboratory to the smoke and steam of the factory.[1]

If Decazes spoke for diplomacy, Jean Baptiste André Dumas, organic chemist and, since 1868, perpetual secretary of the French Academy of Sciences, spoke for French scientific enthusiasm. As head of the special (scientific) commission on the meter, Dumas had been responsible for the recommendations that now stood before his colleagues. Partially summarizing, partially lobbying, Dumas stood before his fellow delegates to advocate a permanent bureau in Paris vested with the authority to set, maintain, and distribute international standards. Above all, Dumas wanted to justify the universal meter as a standard for industry, for science, for France, for the world. As he saw it, anyone who had set foot in London's 1851 Universal Exposition immediately recognized that "chaos" reigned between national systems. Each country's peculiar system of weights and measures made comparison among them impossible without tedious calculation. At the same time, every subsequent exposition had demonstrated that the reach of the metric system was steadily growing. Everywhere people wanted to throw out discordant measures; they yearned to smash intellectual barriers between peoples. For Dumas, indeed for many senior French scientists, the call for international standards would be heard by all "enlightened men." Having embraced the metric system throughout physics and chemistry laboratories, scientists now taught it widely. Factories, builders, telegraphs, and railroads had seized the meter. Now, Dumas urged, public administration should back the rational meter.

Dumas: Decimals mattered. For both sides, practical and pure science, it was the decimal character of the metric system that mattered. Twelve inches in a foot, three feet in a yard—neither plumber nor physicist could cherish such a hodgepodge. "As for the geodesic origin of the metric system," that pride of the French Revolution, by now "it is absolutely without interest for commerce, for industry and even for science." Upon its adoption in 1799, the meter was supposed to be exactly one ten-millionth of a quarter of the earth's circumference. Dumas assured his listeners that modern proponents of the metric system made no such claim; the assembled knew perfectly well that the earth's size could not be measured with the precision needed for an international standard. For Dumas, the reason for adopting the metric system was because it divided lengths into sensible units of ten. That was what pure scientists wanted and what pragmatic journeymen demanded. To spread this new rational system a center was needed. It should be "neutral, decimal, international." It should be *ça va sans dire*, in Paris.[2]

Dumas reminded his audience that the metric standards had become international precisely because revolutionary France had designed the system to make it so. Long ago, ancient Hebrews had put their measuring prototypes in the Temple. Romans set their standard in the Capitol, Christians sequestered theirs in the Church (which was how Charlemagne's standard kept its original purity). For eighty years, the Archives had performed this task for France, preserving the standard meters since revolutionary times. But now that the high contracting parties had decided to make the meter a truly international standard, they judged the revolutionary meter neither strong enough nor sufficiently invariable to serve as the prototype for the world's measures.

Signing the Convention of the Meter started, rather than ended, the process of distributing the meter. Bureaucrats and scientists lobbied, bullied, and negotiated their countries toward putting the scheme into practice. Some of the great experimenters of Europe and the United States contributed to it: Armand Fizeau, who had measured the "dragging" of the ether by water, as well as the American Albert Michelson, who invented the interferometer, an instrument capable of measuring length to within a fraction of the wavelength of visible light. For fourteen years, French engineers and British metallurgists hammered and smelted their way to a tough, durable iridium-platinum alloy.

While a British firm pounded these hard, pure bars into meter sticks with an inflexible "X" cross section, the French concentrated on producing an enormous "universal comparator" (see figure 3.1), that would, by strict procedure, allow a standard length to be reproduced on another bar to within two ten-thousandths of a millimeter. It was painstaking, nerve-wracking work. When the British metal workers delivered their precious bars to the French, the operator at the conservatoire would set both the standard meter and the blank bar on the bridge of the comparator. Peering through a microscope (M), the operator would line up the one-meter mark on the standard. Then the operator would activate a lever, causing a diamond blade to inscribe a fine line precisely at the one-meter point on the blank. Carving subdivisions was just as difficult. The two microscopes would be set, say, ten centimeters apart. The operators would mark that length. Sliding the bar down, they would etch a second ten-centimeter length into the bar, and so on. To prepare the 30 standard bars that the international delegates would take home with them, the operators repeated this operation 13,000 times. The slightest slip with the diamond point meant starting over again with repolishing of the blank.[3]

Finally, on Saturday, 28 September 1889, two years after Poincaré was elected to the Academy of Sciences, eighteen representatives of the contracting parties gathered in Breteuil for the final sanctioning of the meter. The president of the conference can-

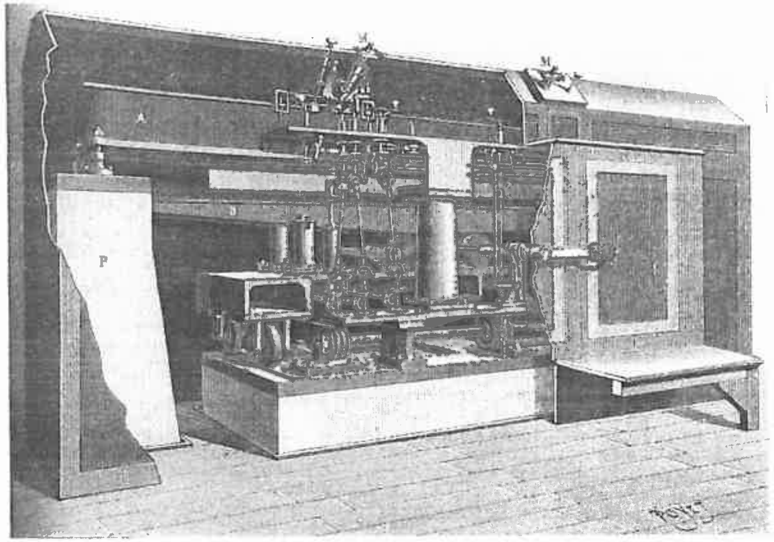

Figure 3.1 Universal Comparator. *This machine served to rule precise lengths for platinum-iridium copies of the standard meter, M. For engineers, physicists, politicians, and philosophers—especially in France—the international success of the standardized unit of length served as a model for what they hoped would be the decimalization and standardization of time.* SOURCE: GUILLAUME, "TRAVAUX DU BUREAU INTERNATIONAL DES POIDS ET MESURES" (1890), P. 21.

vassed their votes—unanimous—and then pronounced: "This prototype of the meter will from now forward represent, at the temperature of melting ice, the metric unit of length," while "this prototype [kilogram] will be considered from now on the unit of mass." All standards stood on display in the meeting room: meters sheathed by protective tubes, kilograms nested in triple glass bell jars. According to plan, each delegate ceremoniously picked a ticket from an urn, the number received assigning his country a meter stick, for which he offered a signed receipt.

Suddenly, these carefully scripted proceedings ground to an abrupt halt. The most important act—the deposit of the meter in its underground safe—was possible only with the three keys needed to open the vault. One of those keys would be in the hands of the director of the French Archives, but he was not there. The president suggested they ask for instructions from the French minister of commerce, but the delegates vigorously objected. Swiss astronomer Adolph Hirsch insisted that the conference was international, not French. The conference would not address an ordinary French minister. Out of the question: Hirsch and his colleagues would deal with France only through its minister of foreign affairs. Diplomacy apparently produced the missing key.

Later that afternoon, at 1:30 to be precise, the commission charged with depositing the international prototypes gathered in the lower basement of the Breteuil Observatory. There the delegates certified that the international prototype **M** would from that moment forward be enclosed in a case covered on the interior with velvet, lodged within a hard cylinder of brass, screwed tight, locked, and placed in the vault. Alongside **M** the standard bearers then prepared two "witnesses" for burial (meter sticks, not delegates). These metallic observers would forever testify, by the very conditions of their bodies, to anything that might befall **M**. In the same ceremonial interment, convention delegates sanctioned the kilogram, **K**, elevating and renaming it as the universal standard of mass. It too found its eternal resting place in the underground iron vault in the company of its witnesses. With two keys, and in full view of the delegates, the director of the International Bureau of Weights and Measures locked the case, secured the inner basement door with a third key, and bolted the exterior door with a fourth and a fifth key. At the conclusion of these solemn events, the president of the conference handed these latter keys in separate, sealed envelopes: one to the director of the International Bureau, one to the general guard of the National Archives, and the last to the president of the International Committee. From that time on, all three basement keys would be needed to enter the sanctum sanctorum.[4]

This was a remarkable moment. **M**, the most precisely forged and measured object in history, the most individually specified humanmade thing, had become, by its burial, the most universal. Here was an object manifestly in France and yet not in France, religiously redolent and yet stridently rational, absolutely material and yet completely abstract. In an age when "family, country, church" had become "family, country, science," **K** and **M** were perfect emblems of the Third Republic: buried in specificity, risen in universality. The symbolic resonance of the meter was lost on no one. Back in 1876, the Republic had even memorialized the new meter by striking a richly iconographic medal in honor of the standard, the scientists who were constructing it, and the glory of the original meter chosen during Germinal of Year III.[5] On the occasion of the sanctioning in 1889, French newspapers recalled with "patriotic satisfaction" how shortly after the "disaster of 1870" foreign scientists, even those who had previously impugned French precision, now acknowledged its triumph.[6]

Before the ink was dry on the Convention of the Meter, delegates were planning new standards that would be built on the model of **M**. Scientific-technical conventions not only garnered symbolic capital for the country or countries that spearheaded them, but they also engendered real benefits for trade exports and smoothed zones of national confrontation. Conventions were also responses to the sudden confrontation of industrial products at the international expositions, the commercial "chaos" to which Dumas had referred. But conventions also mediated the crossing of train lines and schedules, and blame rapidly fell on their absence when trains smashed into one another. For much of the early nineteenth century, regional (even national) systems of communication, production, and exchange had been free to grow in relative isolation. In the last third of the nineteenth century, systems collided at myriad boundaries in the colonies, markets, and fairs. It was this friction that the conventions were designed to ease. They were patches at the ragged fronts at which telegraphic, electric, and railroad networks met.

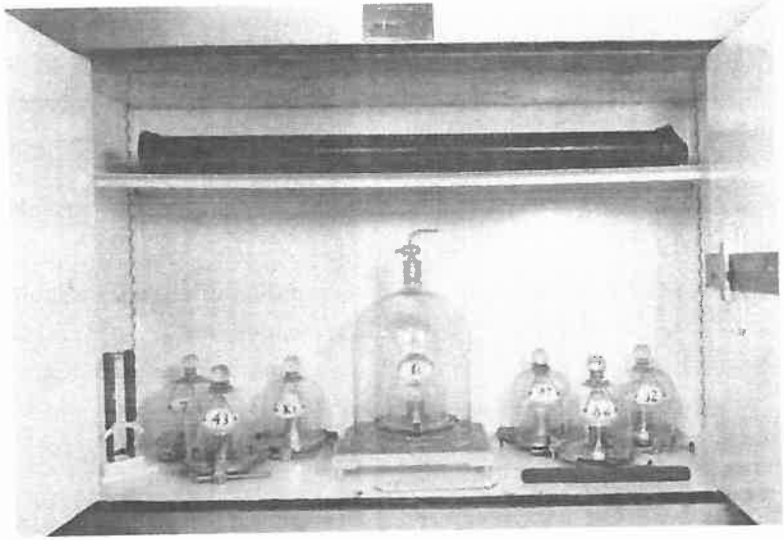

Figure 3.2 ***Burial of the Meter.*** *In the ceremonial 1889 "sanctioning" of the standard meter and kilogram at Breteuil (near Paris) the most painstakingly created physical objects were buried, so they could function externally as universal measures. Here* **M** *lies in its protective metal case on the upper shelf of its triply locked underground vault, while* **K** *presides over its six "witnesses," three standing to each side.* SOURCE: LE BUREAU INTERNATIONAL DES POIDS ET MESURES: 1875–1975, P. 39.

Governments drew up conventions to calm the frantic rustling of incompatible maps as navigators tried to plot routes at the boundary of colonial dominions. They introduced conventions to facilitate the movement of dynamos, gear trains, and steam engines. Regulating these confrontations required hard-fought instruments of accommodation, and their number multiplied: conventions of war; conventions of peace; conventions of electrical power; conventions of temperature, length, and weight. Conventions, as we will see, of time.

The years after Poincaré's January 1887 elevation into the Academy of Sciences came at the height of debate over these new standards. Academicians took an interest down to the detailed metallurgy of the meter bars, and their fascination with the meter led to further conventions, as when one of France's eminent astronomers submitted a paper to the Academy in which the meter served as a model for the decimalization of money. When, just after the sanctioning of the meter, one challenger wrote the Academy to dispute the fidelity of the new bars to the old Archives standard, Berlin astronomer Förster laid down the law: "The international committee of weights and measures [finds it] unacceptable to allow the base of the metric system to depend on uncertain and incessant corrections, now that that base has been materially defined by the international prototype."[7] **M** now ruled alone.

Pushed by the French at every turn (in part out of principle, in part as a countermeasure to the force of imperial Britain), the concept of *convention* widened, condensing into a single word a triple resonance. *Convention* invoked the revolutionary Convention of Year II that introduced the decimal system of space and time; *convention* designated the international treaty, *the* diplomatic instrument that the French, more than any other country, pushed to the fore in the second half of the nineteenth century. More generally, *convention* is a quantity or relation fixed by broad agreement. A convention, fixed by convention, in the tradition of the Convention. When gloved hands lowered the polished standard meter **M** into the vaults of Paris, the French, literally, held the keys to a universal system of weights and measures. Diplomacy and science, nationalism and internationalism, specificity and universality converged in the secular sanctity of that vault.

But if France could lock space and mass in the protected lower basement of Breteuil, time proved more elusive. At the beginning of the 1880s, one French review lamented that clocks were extraordinarily recalcitrant, each one's own "personality" repelling any attempt to regularize it by making corrections based on temperature. Not that French astronomers and physicists had not tried. All

over Europe, neighborhoods, cities, regions, and countries were struggling to standardize and unify their clocks. In Paris and Vienna during the late 1870s, industrial steam plants injected subterranean pipes with compressed air, then modulated that pressure to set clocks pneumatically around the city. Customers could wander through pneumatic shops to select their preferred display of Victorian exactitude.

At first the fifteen-second delay caused by the time it took the pressure pulse to race under the streets of Paris seemed like nothing. Yet time sensitivity had sufficiently mounted by 1881 that even this tiny delay (causing the clocks at different points in the pipework to differ from one another and from the Observatory) became visi-

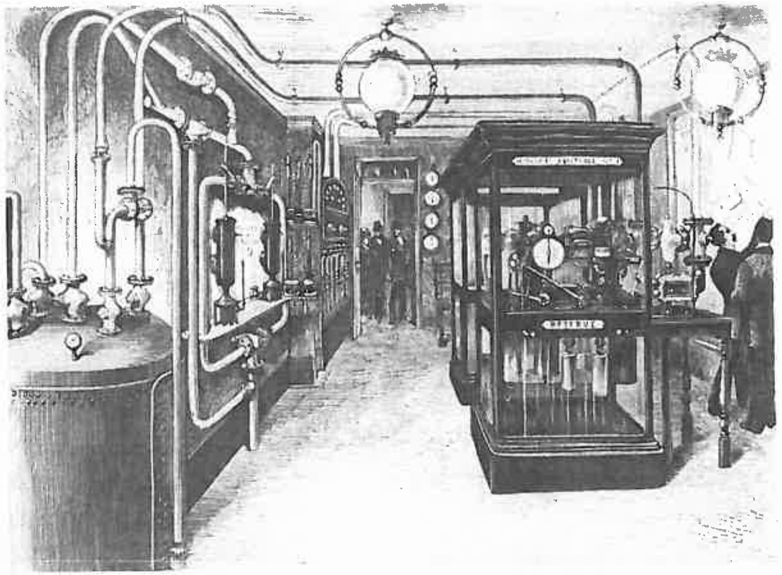

Figure 3.3 ***Pneumatic Unification of Time: The Control Room (circa 1880).*** *From the control room at the Rue du Télégraphe in Paris, the pipelines pumped time under the city streets to synchronize clocks in every quarter of the metropolis.* SOURCE: COMPAGNIE GÉNÉRALE DES HORLOGES PNEUMATIQUES, ARCHIVES DE LA VILLE DE PARIS, VONC 20.

Figure 3.4 Pneumatic Unification of Time: The Display Room (circa 1880). *Here customers—both commercial and private—could purchase clocks that would register the carefully timed bursts of air that they would receive through the pneumatic pipes of Paris.* SOURCE: COMPAGNIE GÉNÉRALE DES HORLOGES PNEUMATIQUES, ARCHIVES DE LA VILLE DE PARIS, VONC 20.

ble. Astronomers caught the problem, so did the engineers of bridges and roads. Soon the public did as well. At first the engineers tried to shrug off the discrepancy: "this small discordance, indisputable in theory, has little practical importance since we are only dealing with clocks that display minutes, and where the minute hands jump in steps and do not permit further divisions, even approximately between that division of time." The clock minders hastened to add that they would offset the Observatory's clock by the fifteen seconds the pulse took to reach the outermost reaches of the network. To be exact, they then mounted retarding counterweights on each pneumatic clock based on its distance from the center. In this way, they reassured their readers, "practically the whole of the discrepancy will be corrected."[8]

Two striking features of time coordination emerge from this little vignette. First, time awareness had become acute. Before the nineteenth century, clocks normally did not even have minute hands.[9] Now a fifteen-second discrepancy could drive engineers to modify public clocks. Second, the transmission time—even of a pressure wave traveling at the speed of sound—looked to professionals and the public like a problem demanding correction. But if the late-nineteenth-century public wanted their seconds adjusted, astronomers had long grown used to far greater precision. Urbain Le Verrier, director of the Paris Observatory and co-discoverer of the planet Neptune, had long since wanted electrical time unification. Synchronizing clocks by pneumatic means would have been absurdly inaccurate in the context of late-nineteenth-century astronomical work. In 1875, no doubt prompted by the Observatory's role in the unification of the system of weights and lengths, Le Verrier proposed standardizing and unifying Parisian time by electricity, as the astronomers had already unified the various rooms of their own observatory. Physicists Cornu and Fizeau, along with the Observatory's astronomers, all endorsed the idea. It was a perfect Polytechnique project. Le Verrier lost no time in pressing the Department of the Seine for support. Le Verrier and his astronomers insisted that their goal was to extend the interior order of the observatory to the whole of the city: "I propose to the City of Paris to give the public clocks a synchronized action and a precision superior to that which we have habitually satisfied ourselves. . . . If the City of Paris agrees . . . it will find here the opportunity to give a new and fertile boost to the art of clockmaking which has made famous the names of French artisans."[10]

Paris agreed, promptly establishing an illustrious commission to guide its clocks. Gustave Tresca would join the time standardization drive; it was he who was supervising the production of the standard meter sticks and weights that would grace the basement at Breteuil. Edmond Becquerel would be there, too, as a major French physicist (he was the father of Henri Becquerel of radioactivity fame). Renowned architect Eugène Viollet-le-Duc served on the commission, no doubt because of his famed restorations (coordinating grand church clocks presented huge architectural and structural issues). Charles Wolf, astronomer at the Paris Observatory, was a commissioner; he had invented much of the observatory's electric time-coordination system. The astronomers and their allies ran a clock-building competition and soon had a working trial system.

By the time the commission reported back to the City in January 1879, Le Verrier had died. But his plan lived. A dozen synchronized clocks would dot Paris, joined by telegraphic cable to the mother clock in the Observatory. Built precisely on the model of coordinated precision they had erected in their own Observatory, each of these secondary clocks had its mechanism set to run fifteen seconds fast each twenty-four hours. A controlling pulse from the Observatory drove an electromagnet in each public clock and that magnet slowed the pendulum, pulling the remote clock into synchrony with the mother clock. Each secondary clock radiated time electrically, resetting other public clocks in city halls, important squares, and churches. From now on, the report proclaimed, the public would have forty public clocks announcing the time correct to the nearest minute—indeed, to the nearest *second* just after it received the reset signal. Still, there were spatial and legal limits past which the Observatory time wires would not go:

> We have not included in the list of clocks to be regulated any belonging to the railroad. It is not that we have misunderstood the enormous interest that the public would have in knowing that these clocks are in agreement among themselves and with those of the City. But . . . it seemed to the Commission that it would be imprudent to engage the City . . . itself in such a complex service, where big interests are in play, and where its responsibility in case of accident arising from the regulation of the clocks could be engaged in an unfortunate way. One can not doubt, however, that the [railroad] Companies, when they see at their doorstep all the clocks of the City regularly indicating the time, and all the same time, will spontaneously put themselves in accord with the time of the Observatory. That day, the unification of time in Paris will be the unification of time in all of France.[11]

Here was an admirable vision: the Observatory would stretch its walls until Le Verrier's system embraced the entirety of Paris. A clock at the country's center of precision would multiply itself until every jeweler, every citizen, would have astronomer's time within a stone's throw. By example, trains and finally all France would follow. Through this series of symbolic reflections—a temporal hall of mirrors—Le Verrier's astronomically set pendulum would set the time of every clock in the country.

The clocks never worked. Ice in the sewer systems promptly cut the wires at numerous points: the current ended up driving the clocks without the intervention of the mother clock. Soon public clocks all over Paris were hawking their own peculiar times. In embarrassment and anger, the commission attacked the chief engineer, precipitating a cascade of mutual recriminations over patents and the patent failure of the public clocks to register anything like the right time. Pleading that the commissioners use his latest inventions, the chief engineer lambasted clocks that were accurate only on receiving their reset signal: "In regarding the clockface at any moment, the observer must have the absolute *certainty* that the clock is correct to within a few seconds at the most, not *to within five minutes*."[12]

During 1882 and 1883, reports streamed back to the authorities that the clocks of one arrondissement after another were not getting proper electrical guidance from the Observatory. By the spring of 1883 not a single public clock tied to the secondary regulators was receiving any current at all.[13] French authors conceded that their country had failed to dominate the time unification of cities. Adding insult to injury, it was London, home of the twelve-inch foot, that led the way toward standardizing time.[14]

After establishing the glorious, rational meter, it was galling to the French scientific establishment that synchronized time had slipped out of their hands. In 1889, the Observatory director pleaded with city authorities that this temporal chaos had to stop: "The Counsel of the Observatory, has been disturbed many times by the manner in which the distribution of time has functioned in Paris. The results obtained up till now are in effect far from being satisfactory, so much so that given the numerous protests, the director of the Observatory had in effect to request the erasure of any mention of 'observatory time'."[15] At the 1900 Universal Exposition, foreigners would see this sorry state of affairs. Couldn't the municipality and the Observatory build a system "more worthy of a city like Paris"? Under these circumstances, it became ever clearer that railroads were far from likely to mimic "spontaneously" the Observatory-City system, as Le Verrier had dreamed.

Times, Trains, and Telegraphs

It was not that the French railroaders did not want coordinated time. They, like the rest of Paris, were transfixed by the coming triumph of the Parisian standard meter as its 1889 sanctification drew near. The industrial *General Review of Railroads* opened its 1888 discussion of time by referring directly to the extraordinary success of metrical reform:

> The metric system, one of the most glorious creations of French genius, has already conquered half of the world, and its complete triumph is no longer doubted by anyone. Its authors have added a new calendar, but they have not concerned themselves with fixing the beginning or middle of the day . . . questions which seem resolved by the advance of the sun. It required the rapidity of communication by rail and telegraph to seed the idea of choosing, more or less arbitrarily, the time of one locality to be imposed on others, and to create in this way normal or national hours. This has given birth to a confusion of a new kind but of the same type as that due to the multiplicity of ancient national weights and measures.[16]

In France, as in many other countries, each train system used the time of the main city served. Bit by bit, as lines from Paris wound deeper into the hinterland, they had chased away local times until, by 1888, Paris fixed the whole country's railroad time. Clock faces in the courtyards and departure lounges indicated the exact mean time of Paris, while platform clocks ran behind the outside clocks by three or sometimes five minutes to give the traveling public a margin of error. So as passengers waited in train stations outside of Paris—in Brest or Nice, for example—they experienced three times: their city's own local time, Paris time (in the waiting room), and an offset time in the track area. (Train time ran in advance of Brest by twenty-seven minutes and behind Nice by twenty.) The *Revue* analyzed other countries' time schemes, examining each one's solution to the time problem. Russia had unified time in January 1888. Sweden had set its clocks one hour later than Greenwich. Germany staggered under multiple *Land*-based times.

"Nowhere else has the question of time been posed in a more pressing manner than in the vast network of railroads of the United States and in the English possessions of North America." Grounded in the North American railroads' April 1883 decision to synchronize all their clocks by zones, the Americans and Canadians had chosen Greenwich as time zero, blocking out huge longitudinal swaths from "Intercolonial time" in the East to "Pacific time" in the West. "Let us add, before leaving America," the French railway journal concluded, "that the [American] charts and color maps offered to the public seem to us, by their clarity and beauty of their printing, noticeably superior to that which we usually see in our countries of ancient civilization." According to the *Revue*, when international scientific delegates gathered in Washington, D.C., in October 1884, it was the railroaders who had been able to remind them that "any change would be useless and inopportune." Now the stakes were clear: could the French—could the world—adopt a "generalized American system"? For the French railroad *Revue*, this was a question that should not be left exclusively in the hands of geographers, geodesists, and astronomers.[17] No doubt with Paris standoffish astronomers in mind, the author wrote: "It is only when the railroads and telegraphs have realized [time] reform that one can hope to see their example followed by other administrations and municipalities. And it is only then, as in North America, that the reform could be complete and could make felt its benefits."[18]

French railroaders, telegraphers, and astronomers looked with a mixture of admiration and anxiety at Britain and the United States when it came to time reform. America stood out for its industrial distribution of time, Britain for its world-dominating network of undersea cables. When Henri Poincaré joined the Bureau of Longitude in 1893, he entered a world quite different from the vast commercial and scientific enterprise administered by the British and the Americans. Clocks ran with stunning precision in the Observatory and appalling inaccuracy in the streets of Paris. The French, especially the Polytechnicians, rued this urban failure, but they were proud of their principled, mathematical, philosophical approach to standardization. They had brought the Enlightenment meter to a triumphant victory and begun extending the universal rationality it announced into the chaotic dominion of time.

On the other side of the Atlantic, North American time reform could boast no leader with the scientific stature of Le Verrier. It simply is not possible to reduce the American time coordination story to the work of an individual, an industry, or a scientist, despite many attempts. Instead, the movement toward synchronization was always critically opalescent, with dozens of town councils, railroad supervisors, telegraphers, scientific-technical societies, diplomats, scientists, and observatories all vying to coordinate clocks in different ways. That effort was so hybrid, so fluctuating in its allegiances and coordinated grids, that astronomers sold time like businessmen and railroaders spoke to the universal order of nature.

French savants found America's most impressive science not mathematical physics, mathematics, or pure astronomy, but rather the work of the ambitious Coast and Geodetic Survey. Teams of cartographers and surveyors were busy laying out the boundaries, rivers, mountains, and natural resources of the rapidly expanding country. Like all their fellow map makers, the Americans struggled with time, because time was inseparable from longitude.

Finding local time on the spot was a matter of watching the sky, then setting a clock by the moment when the sun passed its highest point. Or, more precisely, it meant determining the moment a certain star crossed an imaginary line running vertically up from the northern horizon. If the surveyors also knew what time it was back at a fixed reference point—Washington, D.C., for example—they could then simply reckon the time difference between local and Washington time. If the two times were the same, the surveyors were somewhere on the same longitude line as the Capitol. If the surveyors found their time to be three hours earlier than Washington, then they were an eighth of the way around the globe, to the west.

The map maker's problem was therefore always this same question of distant simultaneity: What time is it right now back in Washington or Paris or Greenwich? So explorers, surveyors, and navigators carried clocks (chronometers) set to the time of their port of departure. All the longitude finder had to do was to compare local time to the chronometer. But getting a precision clock to guard proper time in the unsteady motion of a ship's cabin or on a mule's back was never easy. Add the vagaries of temperature, moisture, and mechanical failings, and the provision of a stable, precise chronometer became one of the most difficult machine problems ever attacked. For John Harrison, the extraordinary eighteenth-century clockmaker, efforts to build an accurate seagoing longitude clock consumed the whole of his life.[19] Gifted though he was, Harrison did not end the search for movable time. The hunt for reliable, transportable clocks continued throughout the nineteenth and twentieth centuries. Astronomers fought long and hard to devise a precise way to use the moon's movement against the fixed stars as a giant clock readable from anywhere. But the moon's position was hard to fix mathematically, and in the field or on a ship it was difficult to measure just where the moon was, except for those rare moments when it actually passed in front of a star or planet.

The single measurement American surveyors most wanted was the longitude difference between the New World and the Old. But the map makers simply could not come to a consensus. One desperate series of attempts—only one among many—began in August 1849, with seven transatlantic voyages in each direction, each bearing twelve accurate chronometers. The hope was that their time cargo would finally show the true difference in time, and therefore longitude, across the Atlantic. In 1851 they stashed on board thirty-seven chronometers, taking advantage of five sailings from Liverpool and two from Cambridge, Massachusetts. After hauling ninety-three chronometers across the seas, the astronomers optimistically claimed a shore-to-shore time difference to within one-twentieth of a second.[20]

Such vaunted precision soon rang hollow. Despite the presence of ever-more-vigilant clock tenders on the ships to protect the ticking freight, the measured time difference from the United States to England was, impossibly, different from that from England to the United States. Something on the high seas was confounding

the clocks. Astronomers suspected that temperature was probably the culprit, with the lower temperatures far offshore slowing the clockworks. This meant that if a lethargic clock set sail at 1:00 P.M. from Cambridge, Massachusetts, it would arrive in Europe showing that Cambridge time was earlier than it really was and induce British map makers, relying on the clocks arriving in England, to put Cambridge, Massachusetts, to the west of its actual location. Conversely, a slow-running seagoing clock set initially in Liverpool would suggest to the Americans that Liverpool time was earlier than it was, so the New World map makers would draw their maps with Liverpool to the west and therefore *closer* to the shores of North America. Testing, calculating, and interpolating did little to help. Crowding the ship with more supervisors, better temperature compensators, and superior clocks just spewed out additional conflicting data. Unable to measure the number that mattered most, the longitude difference between North America and Europe, map makers despaired.

For hundreds of years, cartographers could only dream of being able to send a signal of simultaneity to fix longitude. The telegraph cracked the problem. Over vast distances, an electric current would race a signal through the wires so fast that the reception and transmission seemed practically instantaneous. During the summer of 1848, observatory astronomers from the Harvard Observatory and the Coast Survey tested this new function for the telegraph. One person would tap on the key and the other would listen for a beat at the distant end. Each distant tap would leave a mark on a paper that wound through the receiver's printing device. One evening, one of the mappers, Sears Walker, wondered aloud if they couldn't directly observe and transmit their observation of a star passing through the north. Bond replied: Why not make the escapement of a clock act like a telegraph key so the ticks would be heard anywhere and everywhere along the telegraph line? Then, Why not let that clock-driven signal mark on a smoothly turning cylinder located far from the clock?[21] By comparing the position of marks made by a locally set clock with the position of marks made by signals sent at known times from a distant clock, surveyors could accurately compare distant and local time.

distant 12:00:00→| distant 12:00:01→| distant 12:00:02→|
local 12:00:00→|

For instance, here the local noon occurs about a half-second after the distant noon. Instead of trying to register time by stopping a clock when a star crossed a spider-thread reticle in their telescope, the astronomers could simply measure the distance between lines on their paper. From that simple measurement, the surveyors had longitude.

By the end of 1851, telegraph cables stretched from Cambridge, Massachusetts, to Bangor, Maine; from there the time signal jumped, in a second transmission, from Bangor all the way to Halifax, Nova Scotia. As American scientists began advertizing their electric time transmitters, they found a ready audience in Europe. Bond noted: "It is a gratifying circumstance that this invention is known and spoken of in England only as the 'American method,' and the Astronomer Royal has laid the wires at Greenwich preparatory to introducing it there."[22]

It was not just the astronomers and map makers who cared about the rapid dispersal of simultaneity. Trains had schedules to maintain, and by 1848–49 railroads began forming voluntary associations to fix, by convention, the time on which they ran. For much of New England that meant that all trains on or after 5 November 1849 were to adopt the "true time at Boston as given by William Bond & Son, No. 26 Congress Street."[23] Any railroad not already in this common time system soon was motivated to be so. On 12 August 1853, two trains of the Providence and Worcester line slammed into each other at a blind curve. Fourteen people died, and newspapers blamed the tragedy on a conductor with an itchy finger on the throttle and a slow watch at his side. With another bad-watch disaster just a few days earlier, train lines found themselves under immense pressure to coordinate their clocks. Telegraphically transmitted time became a standard railroad technology.[24]

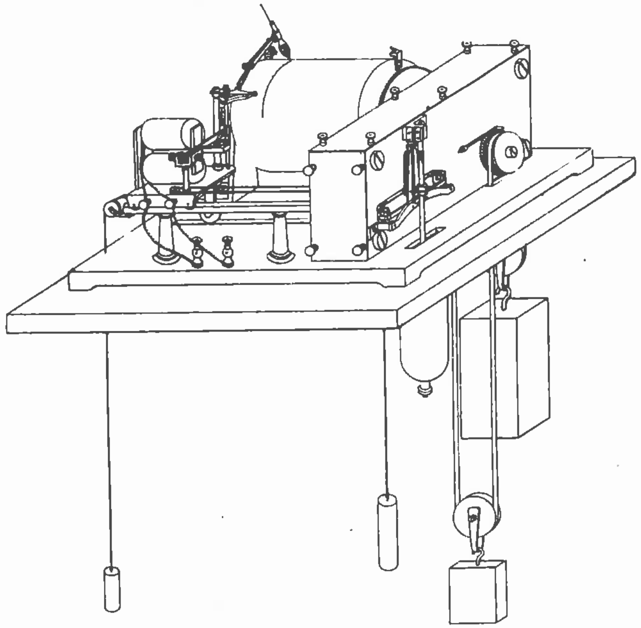

Figure 3.5 **The American Method.** *By recording the arrival of telegraph signals on a precisely rotating drum, the transmission of time could be made vastly more accurate than by earlier, acoustic means. For longer stretches (under the Atlantic, for example) the simultaneity men used the more-sensitive method invented by Lord Kelvin: the incoming electric time signal caused a mirror-mounted magnet to twist ever so slightly, which caused a reflected light beam to shift on a sheet of paper.* Source: Green, Report on Telegraphic Determination (1877), opposite p. 23.

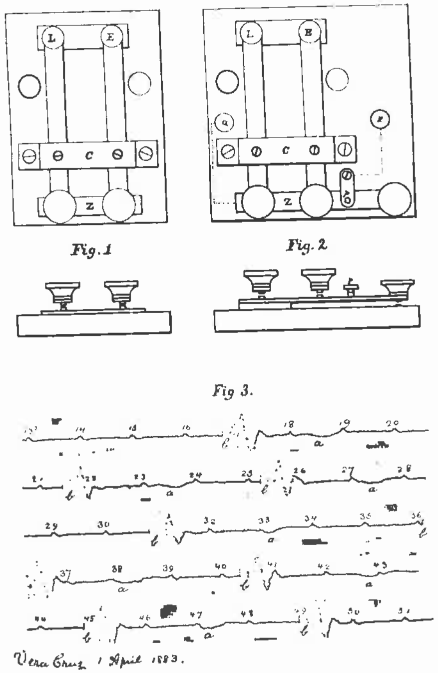

Figure* 3.6 *Traces of Time. *Telegraph keys and the traces of distantly sent time signals recorded by the "American Method" (1883).* SOURCE: CH. HENRY DAVIS ET AL., TELEGRAPHIC LONGITUDE IN MEXICO AND CENTRAL AMERICA (1885), PLATE 1.

Partly pushing the observatories, partly pushed by them, train supervisors, telegraph operators, and watchmakers accelerated the electrical coordination of clocks both in England and in the United States. By 1852, directed by the Astronomer Royal, British clocks were sending electrical signals over telegraph lines both to public clocks and to railways.[25] Soon the Americans were, too. Summing up the status of their time effort, the director of the Harvard College Observatory boasted in late 1853 that the "beats of our clock can, in effect, be instantly made audible at any telegraph station within several hundred miles of this Observatory."[26] During the 1860s and 1870s, coordinated time reached deeper into the cities and train system. Hailed in the press, visible in the streets, studied in observatories and laboratories, the synchronized clock was anything but rarified science. Its capillary extension into train stations, neighborhoods, and churches meant that synchronized time intervened in peoples' lives the way electric power, sewage, or gas did: as a circulating fluid of modern urban life. Unlike other public services, time synchronization depended directly on scientists. By the end of the 1870s, the Harvard College Observatory was but one site sending time, though for a few years its service was one of the largest. Idiosyncratic developments in Pittsburgh, Cincinnati, Greenwich, Paris, or Berlin set each apart.[27]

Marketing Time

Shortly after those first experiments on electrical time, Harvard Observatory hired a telegraph line to distribute to Boston the time its astronomers had determined by the measurement of the stars. By 1871, the observatory director was charging for the service, hoping to install a prominent clock "so that the public can see and learn to appreciate the method of communicating time."[28] Returns were good: in 1875, the service netted $2,400, a yield sufficiently large that the observatory hired a proprietor for its time business.[29] Astronomer Leonard Waldo came to Harvard in February 1877 from Yale, where he had run a similar service. By then the Cantabrigians had invested over $8,000 in instruments, clocks, and telegraph lines. Now they needed customers. Using their telegraph to trigger its noon start, Waldo planned to drop a large copper time ball down a mast on top of one of Boston's higher buildings. He hoped that this public display, visible both to landlubbers and navigators, would dramatically boost the observatory's recognition. So would a major recruitment of railways. Jewelers and clockmakers too were needed as time clients, not to speak of private individuals who clamored (or ought to, according to Waldo) for precision time.

Chapter 4

POINCARÉ'S MAPS

Time, Reason, Nation

AFTER THE 1884 World Time Conference set the prime meridian in Greenwich, resistance in France hardened. Janssen returned to Paris, still fuming from the rout. Appearing before the French Academy of Sciences on 9 March 1885, he recounted, blow by blow, the battles of the previous year, starting with the political: the Americans had loaded the meeting with small states that were allied to the U.S. Happily enough, there were some victories, he assured his colleagues, reprinting a long speech by the French delegation. One after the other, Janssen recalled, the Americans and British had taken the floor to fight the French, each Anglophone in his special domain of competence. "It is perhaps permitted to say, despite the authority, the talent, and the number of scientists who combated the principle of the neutrality of the meridian, that principle resisted these shocks without being disturbed and without any scientific breach. The meridian proposed by France remains still the impartial, scientific, and definitive solution to the question. We believe that there was honor to our country to have defended that cause."[1] On the Continent, Janssen was not alone in his discontent. The Abbe Tondine de Quarenghi campaigned in 1889–90 in the name of the Bologna Academy of Science for the prime meridian to be moved to Jerusalem, the Universal City "par excellence," center of the three continents of the ancient world and the common sanctuary of three world religions.[2]

Unlike France, Germany was not troubled by the Greenwich prime meridian. The Germans were preoccupied with their long

history of the quasi-autonomous states that had left the country struggling with a hodgepodge of mechanical and electrical time systems. It was this time *dis*unity that brought the aging General Fieldmarshal Count Helmuth Carl Bernhard von Moltke to speak, on 16 March 1891, to the Imperial German Parliament. Railroads had been key to von Moltke's celebrated triumph against France. For almost a half-century he had impressed upon his countrymen the vital role of trains in the rapid deployment of military assets. Already in 1843 he had insisted, "Every new development of railways is a military advantage; and for the national defence a few million on the completion of our railways is far more profitably employed than on our new fortresses." Von Moltke drove these plans to completion, grounding his military strategy in the power of new railway lines. By the fall of 1867 he claimed that with the south German states he could have 360,000 men massed in three weeks and 430,000 in four.[3]

Such planning paid. Not only the Germans but also their French adversaries recognized after the Franco-Prussian war of 1870–71 that von Moltke's dextrous use of precision-synchronized trains had destroyed the Second Empire, fundamentally changing the balance of European power. For the twenty years following his triumph over France, von Moltke's (and later Schlieffen's) Great General Staff oversaw a massive expansion of the military as it grew into the force of a unified Reich. Patiently, obsessively, the generals ran an endless series of technical war games as they practiced the choreographed marshaling of 3 million soldiers using a hundred thousand train cars. In 1889 the military pleaded with the Reichstag to adopt standard time to simplify their train scheduling. The politicians refused.[4]

Von Moltke of March 1891 was an unequaled hero in Prussia. When he entered a public place, men stood in silence until he took his seat. So when the general appeared before a plenary session of the Parliament on the subject of time and railroads, it was a major event.[5] In his scratchy voice (he died just over a month later), von Moltke intoned:

> That unity of time (*Einheitszeit*) is indispensable for the satisfactory operating of railways is universally recognized, and is not disputed. But, meine Herren, we have in Germany five different units of time. In north Germany, including Saxony, we reckon by Berlin time; in Bavaria, by that of Munich; in Wurtemburg, by that of Stuttgart; in Baden, by that of Carlsruhe, and on the Rhine Palatinate by that of Ludwigshafen. We have thus in Germany five zones, with all the drawbacks and disadvantages which result. These we have in our own fatherland, besides those we dread to meet at the French and Russian boundaries. This is, I may say, a ruin which has remained standing out of the once splintered condition of Germany, but which, since we have become an empire, it is proper should be done away with.

From the audience rang out: "sehr wahr" (very true). Von Moltke went on to say that while the current piecemeal ruin of time might only be an inconvenience for the traveler, it was an "actual difficulty of vital importance" for the railway business and, even worse, for the military. What, he asked, would happen in case of troop mobilization? There had to be a standard, one that would fall along the fifteenth meridian (about fifty miles east of the Brandenburg Gate), that would be the reference point; local times within Germany would differ but would require an offset by a mere half-hour or so on either extreme of the empire. "*Meine Herren*, unity of time merely for the railway does not set aside all the disadvantages which I have briefly mentioned; that will only be possible when we reach a unity of time reckoning for the whole of Germany, that is to say, when all local time is swept away."[6] Empire demanded it.

Von Moltke conceded that the public might dissent. But after some "careful consideration," scientific men of the observatories

would set things right, and lend "their authority against this spirit of opposition." "Meine Herren, science desires much more than we do. She is not content with a German unity of time, or with that of middle Europe, but she is desirous of obtaining a world time, based upon the meridian of Greenwich, and certainly with full right from her standpoint, and with the end she has in view." Farms and factory workers could shift their clock starting times as they wished. If a manufacturer wanted his workers to start at the crack of dawn, then let him open the gates at 6:29 in March. Let the farmers follow the sun, let the schools and courts make due with their always loose schedules. Von Moltke wanted a nationally coordinated clock based on Greenwich. What mattered to the General Staff was that the railroads and armies should answer to a coordinated single time, one linked to the emerging electric worldmap. Much of Europe followed.[7]

But not all Europeans. Perhaps the best known action against Greenwich is also one of the murkiest. On Thursday 15 February 1894, a young French anarchist, Martial Bourdin, bought a ticket from Westminster Bridge to Greenwich. According to one of two observatory assistants, when chatting in the lower computing room, the pair "were suddenly startled by a loud explosion, the detonation of which was sharp and clear. . . . I immediately remarked to Mr. Hollis, 'That is dynamite! Spot the time'." Trained to observe by the clock, they duly recorded the detonation at 4:51. When a policeman arrived at the detonation scene in the park below the observatory, he found Bourdin dying. The anarchist had lost his hand and received a massive blow of explosive and bomb fragments. For years, doubt lingered about Bourdin's motives; anarchists suspected a police setup; others saw in it one more in the long series of French anarchist strikes, including one on the Chamber of Deputies in Paris (December 1893) and another in a Paris café just three days before Bourdin's demise. Joseph Conrad's version of the events in his 1907 work *The Secret Agent* remains the canvas on which these events have been seen: a dark sketch of dupes, manipulators, and careerists from which no one emerges unsullied. In Conrad's world the conniving First Secretary of a Foreign Power insisted on an attack that would frighten the class enemies beyond murder: "The demonstration must be against learning—science. The attack must have all the shocking senselessness of gratuitous blasphemy." It must strike at the mysterious scientific heart of material prosperity. "'Yes,' he continued with a contemptuous smile. 'The blowing up of the first meridian is bound to raise a howl of execration.'"[8]

Without a doubt the first meridian stood as a powerful if highly contested symbol. But even in France, where Janssen and others recoiled at Britain's arrogation of world power, there were those who were entirely supportive of setting French time to the master clock of the great Christopher Wren observatory.

Charles Lallemand, a member of the French Bureau of Longitude and an ally of Poincaré, made his support of Greenwich time crystal clear. Of course universal time (a single time for the whole world) would be an unmitigated disaster: the Japanese man in the street would surely refuse to live and work by the time it happened to be in Greenwich at that moment.[9] Lallemand insisted that time reform would have remained mired in chaos if the North Americans, "with their admirable practical sense of *Business'men*, hadn't imagined an ingenious compromise, uniting, or approximately so, all the advantages of the universal hour with that of local time": time zones.[10]

Writing in 1897, Lallemand insisted that it was an unparalleled victory in the domain of human reform that only ten years had sufficed for a simple, practical system of time zones to have conquered almost the totality of the civilized world. All of Europe now adhered to the system with the exception of France, Spain, and Portugal. What was needed for the French to join in this reform was so little: a delay of a mere 9 minutes and 21 seconds would set things right. Not only was the present system foolishly complicated, it meant, as Lallemand sadly noted, that on the other side of the earth, there was an equatorial zone spanning 250 miles between the antimeridian lines of Paris and Greenwich in which the very date was ambiguous. Standing (or floating) in that purgatorial time zone, you could class yourself as witnessing 31 December 1899 or 1 January 1900, depending on which set of maps lay before you.[11]

For Lallemand, such ambiguity was intolerable. Objections flew fast and furious in this campaign of articles and broadsheets. Some claimed that the zones weren't "neutral," following the line taken at the contentious Washington meeting. False, Lallemand declared: Not only did the new zone system follow the standard, neutral twenty-four-hour clock, but the "vertiginous speed" of acceptance in both the new and old worlds had showed just how neutral it was. It is quite true, he conceded, that one meridial line ran through Greenwich. But that reference point was already familiar to nine-tenths of the world's sailors. Can one really say that exchanging a longitude of zero for 9 minutes and 21 seconds would cause us to lose our French originality and scientific personality? Nonsense, he fulminated. Paris had long taken the position "20 degrees east," using a first meridian on the island of Ferro. Even the much-vaunted neutrality of the revolutionary Convention that established the meter is not exact: what began in revolutionary France as a neutral measure (1 meter = 1/10,000,000 of a quarter of the circumference of the globe) rapidly deviated from that ideal as foreign nations copied a reference bar set in Paris. How, then, he demanded, could France possibly consider it a humiliation to modify its prime meridian? Some said it would render obsolete all French maps. No, Lallemand riposted, we could even overstrike the new longitude lines in a different color. He concluded that he and his countrymen would not be sacrificing their national meridian for the British. They would merely be offsetting their clocks by 9 minutes and 21 seconds for the benefit of telegraphy, navigation, and train travel. All "men of progress," he concluded, should back the reformation of time.[12]