Creating Historical Transportation Shapefiles of Navigable Rivers, Canals and Railroads for the United States Before World War I

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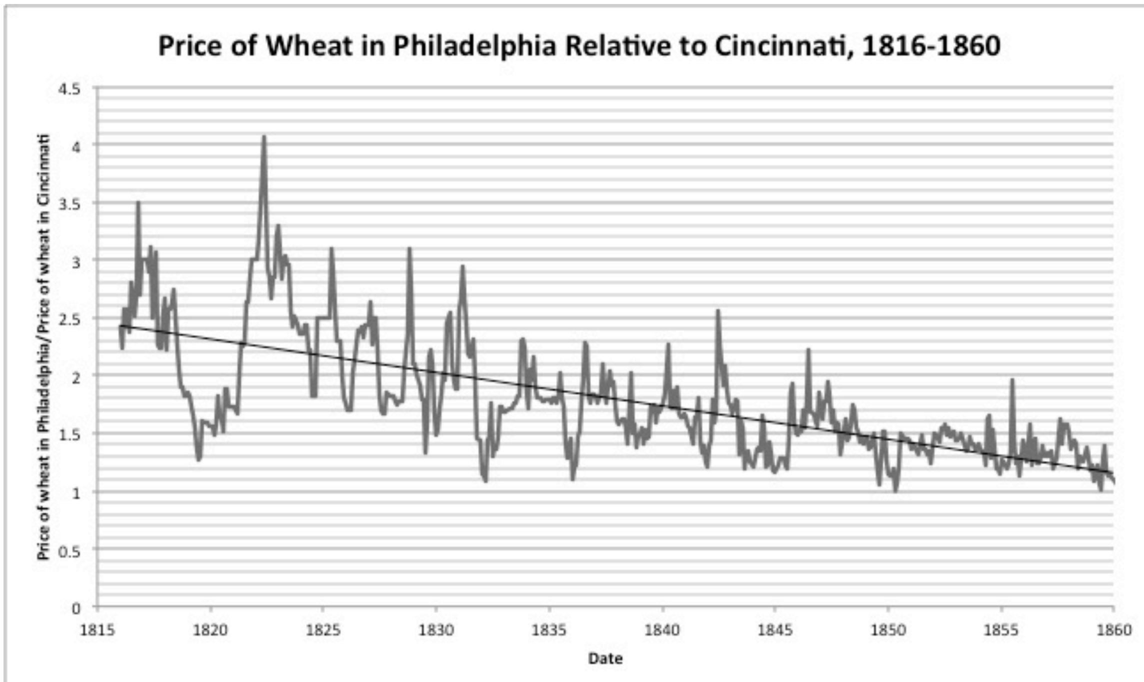
At the beginning of the nineteenth century, it cost between 15 and 30 cents to transport a ton of goods one mile by road (Rothenberg 1981, Taylor 1951). A hundred years later, contemporary estimates indicate that the cost had not really changed: 25 cents per ton-mile (U. S. Congress. Senate. 1904). Indeed, some of those campaigning for better roads at the end of the nineteenth century suggested that the costs might be much higher.[1] This sad state of affairs reflected the very limited adoption of any of the improvements that had been made in the technology, especially road construction such as the use of macadam paving or even crushed and compacted gravel that might have cut costs by half (U. S. Congress. Senate. 1904). Over that same period, however, shipping costs by other transportation modes had fallen dramatically, often to a small fraction of what they had been earlier and an even smaller fraction of the rate by road. Moreover, the quality of their service was typically much improved in terms of speed, certainty of delivery, etc.. Those reductions in cost and improvements in service constitute what

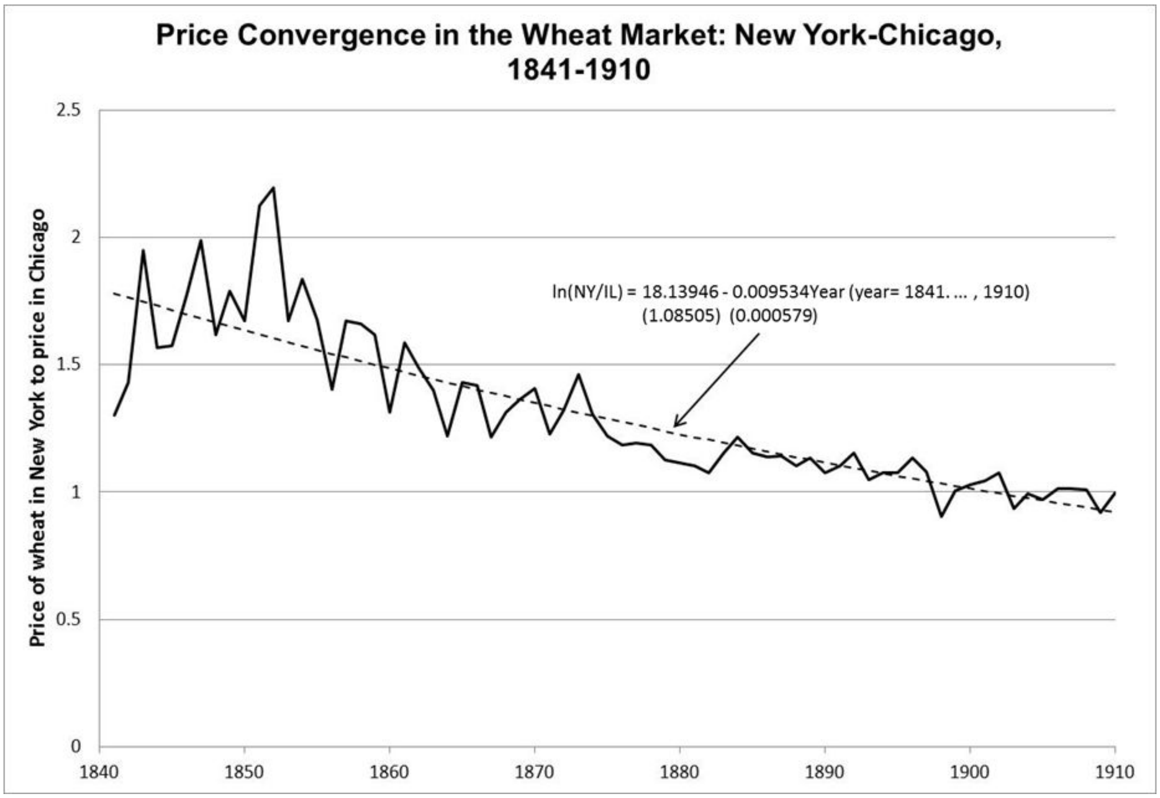
[1] For example, one of the pamphlets put out by the Good Roads Movement suggested that cost around 1890 might have been as high as 50 cents per ton-mile and many times that if the weather was bad: "Within a few miles of the "city of brotherly love," a contractor agreed to haul a boat load of salt hay weighing thirty-five tons for a distance of seven miles, four or five of which were over the earth roads of the city. It was expected that this hauling could have been done in three days at a cost of fifty dollars; but the roads being hub-deep in mud it was found that it required two weeks and cost two hundred dollars, while the horses were nearly "used up" (Potter et al. 1891).

George Rogers Taylor called "The Transportation Revolution." They would have a profound effect upon the location of people and economic activity in this country. For example, the price differentials for most products between cities shrank dramatically. For example, in July 1816 wheat in Philadelphia sold for 2.8 times the price being charged in Cincinnati (Cole 1938b, a). Midwestern farmers would have loved to sell their produce



(Source: Data from Cole as tabulated by Mario Crucini. See http://www.vanderbilt.edu/econ/cipr/cole-historical-data.html)

in Philadelphia and Philadelphia consumers would have loved to buy in Cincinnati but 500 airlines miles stood between the two – and no airlines. Instead, there was an arduous and roundabout trip of several weeks by one of several possible routes that risked life and property. Over the next four plus decades, that price differential narrowed dramatically—not always consistently, for there were random local supply and demand fluctuations that occurred—but slowly and steadily. The same was true of wheat prices between Chicago and New York. This city pair of prices converged at an average annual rate of about 1% per year from 1841 onwards to approximate equality by the end of the century. Multiple prices are indicative of multiple markets; a single price is consistent with the existence of a single market. The major factor bringing those markets together into just one large market was the declining cost of transportation associated with the innovation and expansion of new, improved and improving modes of transportation.



(Source: Illinois, Boyle (1922); New York, Ronk (1936))

These transportation improvements were especially critical in a country of continental proportions like the United States, as many politicans recognized. Jefferson's Secretary of the Treasury, Albert Gallatin, for example, argued to Congress that "good roads and canals will shorten distances, facilitate commercial and personal intercourse, and unite, by a still more intimate community of interests, the most remote quarters of the United States" and advocated for direct government intervention to prtomote and accelerate their construction (U. S. Congress. Senate 1808). Obviously, he failed with regard to roads since nothing much happened with that medium until the twentieth century. His arguments, however, were prescient. Steam navigation on eastern rivers had barely begun at the time of Gallatin's report and was unknown on the rivers and lakes in the interior. The canal building boom had yet to begin and, most significantly, he anticipated the railroad by two decades, attaching an annex to his report by famed Philadelphia engineer, Benjamin Latrobe, extolling their virtues.

Canals, steamboat navigation and railroads formed the core of the nineteenth century transportation revolution and spread across this continent. In 1800, the territory west of the Mississippi River was not even a part of the United States and Chicago was at least a 5-week trip away from New York. By 1857, the trip could be made in two days; by 1930 trains made the trip in a day (Paullin et al. 1932). Moreover, after 1869, it was possible to take a train (although not without multiple changes of train and between train stations) across the entire country from East Coast to West.

In this essay, I describe the various procedures that I have used to create my historical geographic information systems (GIS) shapefiles (hereafter SHP) of railroads, rivers and canals for the lower 48 states of the United States covering the period from the founding of the nation through 1911. These document and detail the spread of the improved means of transportation within the United States over that period. The files themselves may be downloaded from https://my.vanderbilt.edu/jeremyatack/data-downloads/. In creating those files, however, numerous issues arose that shade and shape their interpretation and use. This essay is designed to encourage use of this new resource but also alert the user to these issues. It also likely contains some useful hints for others undertaking similar projects.

I am not the first person to try to map such key aspects of American development. In particular, in the mid-1970s, Christopher Baer and colleagues at the Eleutherian Mills-Hagley Foundation library began to map the location and document the extent of water and rail transportation prior to the Civil War in the Middle Atlantic states. This important study escaped my attention until recently. I have belatedly used it to revise my railroad SHP files in the four Middle Atlantic cities for which they provide large-scale maps for 1860: Baltimore, Philadelphia, New York city and Washington DC (Baer et al. 1981).

When Baer et al. conducted their study, GIS was still highly specialized and in its infancy so the results of their historical investigation were published as a series of large scale maps depicting the state of affairs at fifteen year intervals from 1800 to 1860. Like me, the authors also grappled with the slippery concept of navigability and mark on their map for 1800 the "limit—ascending navigation" and "absolute limit" as well as classifying rivers and streams into those that were "fully boatable" or "marginally boatable or timber streams." Thereafter, their mapping of water transportation is limited to canals and improvements (Baer et al. 1981). (added December 2015)

I created my SHP files without any outside or institutional financial support, doing the work myself (except where explicitly noted). It has taken several years. I used ESRI's GIS software, initially ArcGIS v.9.3-10.3 and, more recently, ArcGIS Pro. The work was done on an Apple MacBook Pro and a 27" iMac desktop using Parallels under OS X (rather than Bootcamp) to run Windows 7. In editing large, complex SHP files, the 64-bit architecture of ArcGIS Pro and lots of memory added a welcome speed and immediacy to the action but ArcGIS Pro only became available late in the process.

I use the 1983 North American geographic coordinate system with a contiguous USA Albers equal area conic projection for my SHP files. All of my GIS SHP files reference properly against other GIS sources such as U.S.G.S. topographical maps and the various NHGIS boundary files.

Since GIS itself is relatively new, tracing back to the work of Tomlinson in the late 1960s but only becoming widely used at the end of the twentieth century, most of the available GIS data is of similarly recent vintage. Some of those data, like a mapping of physical features such as the coastline or terrain, are relatively permanent, but are still susceptible to change. For example, strip-mining operations have leveled many mountain tops and filled valleys.[2] Coastal erosion and river delta accretions have changed coastlines.[3] Large manmade lakes how occupy many river valleys such as lakes Mead and Powell along the Colorado River and Fort Peck Lake on the upper Missouri River and obscure many natural and man-made features. Towns and cities have been established and many of these have grown—some enormously. Others, however, have withered and all but disappeared—sometimes within the span of a few years.[4] The more current the GIS data, the easier it is to understand, interpret and relate GPS information.

Historical data, however, while perhaps of more limited use, can still be of great

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[2] See, for example, http://appvoices.org/end-mountaintop-removal/mtr101/ (visited 7/27/2015) where a map of eastern Kentucky and Tennessee and southern West Virginia for 2009 suggests that the terrain across 1.2 million acres –an area approximately equal to the state of Delaware, has been reshaped by this (MTR=mountain top removal) mining method.

[3] See, for example, http://pubs.usgs.gov/fs/barrier-islands/ and http://www.nbcnews.com/science/hurricane-sandy-swept-away-half-barrier-islands-sand-8C11018882 regarding erosion. See http://www.nytimes.com/2015/08/11/science/elwha-river-dam-removal-project-washington.html?_r=0 for a recent case of accretion .

[4] Ghost towns are to be found in every state. See http://www.ghosttowns.com/

value both in understanding historical outcomes (see, for example, Knowles 2002) as well as contemporary issues (Bleakley and Lin 2015, 2012). Transportation infrastructure in particular has had an important impact upon the location and development of economic activity (Donaldson and Hornbeck 2015, Donaldson 2010). Moreover, that infrastructure has evolved over time through successive waves of invention and innovation. Sometimes, those new modes displaced the old; sometimes they remained complementary. Where and when they were substitutes, the older technology faded and was sometimes reabsorbed. As a result, much of the earlier transportation infrastructure and the timing of its evolution have all but disappeared (or its presence obscured), even though its influence on current economic activity might remain (Bleakley and Lin 2012). Indeed, of course, transportation is at the heart of much of the contemporary use of GPS. Historically too, transportation was often an important feature on contemporary maps and a time-ordered sequence of those maps can reveal something about its historical evolution.

Unfortunately, however, those historical maps are not only spatially inaccurate (and generally increasingly inaccurate the further back in time one goes) but may also contain what Mark Ovenden has called “cartografibs” (Ovenden 2011)—inaccuracies. Some of those inaccuracies were willful to hide activities such as Los Alamos and Oak Ridge during the Second World War or to provide evidence of unauthorized copying. Some, however, simply reflect over-optimism regarding anticipated changes. This is especially likely to be true of man-made works that were in progress or projected while the map plates were being prepared. Mapmakers, not surprisingly, wanted their maps to contain most up-to-date information possible and have the longest possible useful life expectancies. Inevitably, they would sometime misguess or simply be misled by overly optimistic plans.

Elsewhere, I (Atack 2013) have written regarding the creation of my earlier series of historical GIS shapefiles for canals, navigable rivers and railroads. The new files are their successors. They build upon my earlier experiences but began from a *tabula rasa*. They have been at least three years in the making. The manner by which these have been constructed is described below along with a necessary discussion of the philosophy that guided it. Although railroads have attracted the most attention (see, for example, Atack, Jaremski, and Rousseau 2014, Atack and Margo 2011, Atack and Margo 2012, Chandler 1965, Donaldson and Hornbeck 2015, Fishlow 1965, Fogel 1962), they were the last of the nineteenth century transportation improvements to be innovated and their spread was impacted by earlier transportation improvements. For that reason, railroads are discussed last and I begin with a discussion of water transportation.

Historical maps inform my SHP files but my SHP files are <u>not</u>, themselves, tracings of transportation modes shown on those maps. The specific geographic locations of transportation infrastructure, as I describe below, were determined from USGS topographic maps of various vintages and by satellite imagery. Their locations were then approximated as closely as possible by creating polylines and snapping ends to edges and vertices where necessary. Where and when a particular feature also once formed a political boundary, I used that boundary (or a somewhat simplified version thereof) in the historical NHGIS boundary files to determine its geographic location.[5] My goal was to

[5] It is also worth emphasizing that GIS makes use of the rules of Euclidean geometry in that lines have length but no breadth and points exist but have neither length nor

be accurate on the ground to within feet (as opposed to hundreds of yards or miles) of the true location.

The existence of a particular means of transportation at a specific date, however, was based upon its being shown on a map from that time. To generate these SHP files, historical map images showing various transportation improvements at specific dates were georeferenced (using ArcGIS tools) against NHGIS 2008 TIGER-based historical state and county boundary files and the U.S. National Atlas database of cities and towns using the ESRI's spline function.

In general, I began with points distributed as evenly as possible around the borders of the historical map images. I added points in the interior of the map images when the initial georeferencing was felt to be unsatisfactory (i.e. seemed to have large errors as one moved away from the reference points) but I used no hard-and-fast standard regarding fit as the historical map images were used only to inform the "existence," not the specific location, of the transportation infrastructure.

My goal in creating these SHP files was to capture the destinations served by different transportation media in the nineteenth century and the geographic area with "access" (however that might be defined by the user) to a specific transportation medium, or served by it, during the period.[6] Underlying this research is my belief that George Rogers Taylor (Taylor 1951) was not exaggerating when he argued that there was a "transportation revolution" in the nineteenth

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breadth, whereas the features that these represent, especially major rivers, have breadth.

[6] See, for example, Donaldson and Hornbeck (2015). Similarly, the network analysis tool in ArcGIS allows the user to define a geographic area that meets specific conditions such as transport costs less than or equal to some threshold.

century, although Fogel's (1964) work on the railroad seemed to greatly diminish the railroad's importance. The advent of GIS, however, has provided the profession with an important new tool with which to re-examine the contribution of improved means of transportation.[7]

Water-borne Transportation

Water provided, from earliest times, the most efficient—and thus cheapest—means of transportation. It remains so today. It was used in America from earliest times by the indigenous peoples as well as by European explorers and settlers. Indeed, shipping by water was so important to commerce that English jurisprudence developed a distinct set of rules and customs — Admiralty law —governing its conduct.[8] Moreover, the lineage of these laws stretches back to ancient Roman times and includes the more recent evolution of international agreements regarding the freedom of the seas. The rules include denying monopoly rights over critical waterways like the Straits of Gibraltar, Hormuz and Malacca or the English Channel.

These laws and principles in English law were extended to America through English colonization and carried over into American jurisprudence via Article III, Section 2 of the U.S. Constitution (United States 1789) which designates Admiralty law as the exclusive

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[7] Such as its impact upon urbanization and population growth (Atack, Haines, and Margo 2010), agricultural expansion (Atack and Margo 2011), the expansion of banking before the Civil War (Atack, Jaremski, and Rousseau 2014) or bank balance sheets (Atack, Jaremski, and Rousseau 2015).

[8] Among the differences from the customary Anglo-American law, for example, there is no right to trial by jury under Admiralty.

domain of the Federal government.[9] Parts also carried over into states' laws. Central to Admiralty is the principle of navigation by which those waters deemed to be navigable became imbued with the character of a public highway and to which the public thereby has the right of access and passage.

Rivers: As originally conceived in English jurisprudence, navigability applied to waters subject to "the ebb and flow of the seas" (Story 1833)– that is to the oceans and the tidal reaches of rivers. This is sometimes referred to as the "salt water test" of navigability. However, while this criterion worked well in a small island like England, it proved less suitable in a country of continental proportions like the United States. As Chief Justice Field would later remark:

> "There [in England], no waters are navigable in fact, or at least to any considerable extent, which are not subject to the tide, and from this circumstance tidewater and navigable water there signify substantially the same thing. But in this country, the case is widely different. Some of our rivers are as navigable for many hundreds of miles above as they are below the limits of tidewater, and some of them are navigable for great distances by large vessels which are not even affected by the tide at any point during their entire length." (United States 1870)

Indeed, even before the U.S. Constitution was adopted, new rules were applied to the interior of this country. Specifically, the Northwest Ordinance of 1787 decreed that "the navigable waters leading into the Mississippi and St. Lawrence, and the carrying

[9] Specifically, "The judicial power shall extend … to all cases of admiralty and maritime jurisdiction…"
https://www.law.cornell.edu/constitution/articleiii#section2

places between the same, shall be common highways and forever free, as well to the inhabitants of the state as to the citizens of the United States, without any tax imposed or duties therefor" (United States. Continental Congress. 1787. Article IV). Rights to these waters and the streambed over which the water flowed passed to the various states upon their admission to Union.

However, the federal government retained (and still retains) an easement over those waters for the purposes of transportation although the individual states were free to reallocate the underlying streambed as best suited their purposes. Some states, such as Kentucky, Michigan and Ohio conveyed most of their streambeds to the riparian owners (except for the bed of the Ohio River which remains the property of the Commonwealth of Kentucky, while Michigan and Ohio retained the lands under the Great Lakes within their borders). In Arkansas, Tennessee, Wisconsin and many other states, by contrast, the bed of a navigable waterway is still held in trust by the state for the people.[10]

There is no specific definition of what constitutes or constituted navigability although the term appears repeatedly in federal and state legislation. Consequently, it has been, and remains, the subject of frequent litigation.[11] In response, the courts have accepted various tests. These differ between the various states and have also

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[10] See, for example, State v. Muncie Pulp Co. (Tennessee 1907). Wisconsin, in particular, decided in 1911 that streams and lakes in the state were navigable if they are "navigable in fact for any purpose," including recreational use, a principle that it maintains to this day under Wis. Stat. § 30.10 (Wisconsin 2015), even if the stream or lake is useable for only part of the year—see also http://learningstore.uwex.edu/assets/pdfs/g3622.pdf.

[11] And it is still being litigated. See, for example, *PPL Montana, LLC v. Montana* (United States 2012). Also *New York Times* "Supreme Court Wades Into Raging Dispute Over Riverbed Ownership"(New York Times. 2011).

evolved at the federal level.

The first test is whether or not United States government surveyors pursuant to the Land Act of 1785 and its successor legislation had "meandered" a waterway and declared it to be navigable.[12] Another test arises from past legal decisions (i.e. *stari decisis*) since a prior declaration that a waterway was navigable conveyed an easement for public passage thereby impairing private property rights. In particular, in the *Daniel Ball* case (United States 1870) the Court ruled that waterways that were "navigable in fact" were "navigable-in-law"—at least for the purposes of travel and transportation.[13] Indeed, in *The Montello*, the court would

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[12] Similar survey instructions are used to this day (including use of the Gunter chain as the measure = 66 feet) as in the Bureau of Land Management Manual:

> "3-120. Facing downstream, the bank on the left hand is termed the left bank and that on the right hand the right bank. These terms will be universally used to distinguish the two banks of a river or stream.
>
> Navigable rivers and bayous, as well as all rivers not navigable, the right-angle width of which is 3 chains and upwards, are meandered on both banks, at the ordinary mean high-water mark, by taking the general courses and distances of their sinuosities. Rivers not classed as navigable are not meandered above the point where the average right-angle width is less than 3 chains, except when duly authorized.
>
> Shallow streams and intermittent streams without well-defined channel or banks are not meandered, even when more than 3 chains wide. Tidewater streams are meandered at ordinary mean high tide as far as navigable, even when less than 3 chains wide. Tidewater inlets and bayous are recorded, and are meandered if more than 3 chains in width, but when non-navigable are not meandered when less than 3 chains wide."

See http://www.blm.gov/cadastral/Manual/73man/id156_m.htm

[13] The operator of the steamship, *The Daniel Ball*, on the Grand River in Michigan was convicted of operating without a license. He appealed on the grounds that the Grand River was not navigable but lost. The ruling declared "rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or are susceptible of being used, in their ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water."

subsequently hold that evidence of early fur traders using canoes on the Fox River was sufficient to make that waterway "navigable in law" (United States 1874). The immediate consequence of this decision was that the U.S. Corp of Engineers took over completion of the Portage Canal connecting the Fox and Wisconsin Rivers.

These various federal guidelines regarding navigability were subsequently codified in 33 USC "Navigation and Navigable Waters" after the Rivers and Harbor Appropriations Act of 1899. In particular, the law decrees that the "[N]avigable waters of the United States are those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible for use to transport interstate or foreign commerce" (33 USC § 329.4) *at the time of statehood.*

Under the federal constitution, however, individual states are free to adopt their own rules provided that these do not contradict the Constitution. As a result, as one legal scholar would remark, there are almost as many state definitions as

> "there are common law states. These vary from the rule in Texas which provides that a stream so far as it retains an average width of 30 feet is navigable, and the Mississippi rule which declares that ant stream or bayou 25 miles long and deep enough for any 30 consecutive days to float a steamboat with a capacity of 200 bales of

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The qualification regarding travel and transportation has provided courts with wiggle room and led to the decision in *Douglaston Manor v. Bahrakis* (New York 1997) which denied the public's right to fish the waters of the Salmon River in Oswego County, NY, along a section of river where Douglaston Manor owned land on both banks of the river whether from a boat or by wading (i.e. without riparian trespass).

> cotton to be navigable to the North Carolina rule which holds that a stream to be navigable must have the capacity of supporting sea-going vessels" (Kanneberg 1946).

Some states, like Michigan and Wisconsin, had even looser standards for navigability. In them, any stream capable of floating a saw log was navigable.

Moreover, determinations regarding navigability have continued to evolve. For example, the Arkansas Supreme Court in *State v. McIlroy* (Arkansas 1980) extended its traditional understanding of navigability to include recreational use.[14] Furthermore, some waterways that had once been navigable could have that definition rescinded by the state provided the federal government did not object since navigability conveyed a public right of access and unrestricted passage.[15]

Waterways have always been barriers to overland transportation. Where they could not be forded, goods and people had to detour, be ferried across, or the waterway had to be bridged. Each option was costly. However, where the

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[14] "Arkansas, as most states in their infancy, was mostly concerned with river traffic by steamboats or barges when cases like *Lutesville, supra*, were decided. We have had no case regarding recreational use of waters such as the Mulberry. It may be that our decisions did or did not anticipate such use of streams which are suitable, as the Mulberry is, for recreational use. Such use would include flat-bottomed boats for fishing and canoes for floating — or both. There is no doubt that the segment of the Mulberry River that is involved in this lawsuit can be used for a substantial portion of the year for recreational purposes. Consequently, we hold that it is navigable at that place with all the incidental rights of that determination." (Arkansas 1980).

[15] For example, the Kansas legislature (Kansas 1864) declared "that the Kansas, Republican, Smoky Hill, Solomon, and Big Blue rivers within the limits of the state of Kansas are hereby declared not navigable rivers or streams" and allowed railroad and bridge companies chartered by the state to bridge or dam them as if those waterways had never been declared navigable streams. See *Kaw Valley Drainage District of Wyandotte County v Missouri Pacific Railway Company* (Kansas 1916).

waterway happened to be a navigable river, bridges posed special challenges. Navigability conveyed the right of unrestricted passage along the waterway, yet a bridge created an artificial barrier in terms of headroom above the surface of the water. Moreover, a particular river's characteristics may have required the construction of support structures in the streambed that posed a hazard to navigation and artificially constrained the river's channel. Either could be viewed as impeding passage. Bridges thus led to litigation and, ultimately, landmark court decisions that ultimately favored the interests of those wishing to cross the waterways over those intent upon using them for transportation.

In the *Wheeling Bridge Case*, steamboat interests in the Pittsburgh area (=the state of Pennsylvania in the suit) sued the Virginia-chartered company responsible for construction of the bridge alleging that the bridge had been built closer to the surface of the water than specified in the charter and lower than required for safe passage by the latest and largest steamboats whose smokestacks were being built ever-taller to improve boiler performance and lower operating costs.[16] Their fear was that Wheeling, not Pittsburgh, might become the northern terminus of river trade on the Ohio if those more efficient and thus lower cost steamboats could not reach Pittsburgh. These fears were reinforced by the Baltimore and Ohio railroad's decision to build its rail terminus at Wheeling.

An initial majority finding in favor of the plaintiffs (United States 1851) was rendered moot by Congressional action on August 31, 1852 that declared the bridge

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[16] One implication of Pittsburgh's argument is that there existed scale economies in western river steamboating—a source of modern scholarly debate between Atack (Atack 1978) and Haites and Mak (1978, 1976).

to be a lawful as built and requiring that steamboats adjust their operation to these new circumstances. Nature, however, would intervene when the bridge was blown down by a violent storm in May of 1854.

Upon hearing of plans to rebuild the bridge, the state of Pennsylvania sought an injunction against the new construction. This was granted by Chief Justice Robert Grier (a Pennsylvanian) as the Court was not then in session but the injunction was ignored by the company. After a full hearing before the Court in December 1854, a majority of the court decided that Congress had acted within its authority under the commerce clause and dissolved the injunction (United States 1855). The rebuilt bridge reopened in 1859.[17]

Despite the "win" from the Wheeling Bridge case for those favoring bridging the Ohio River, the fight was so bruising that no railroad bridge crossed the river until 1870 when the 14th Street Bridge in Louisville was opened (Kleber 2001).

Indeed, railroads crossed the mighty Mississippi River before they crossed the Ohio but, as with the road bridge at Wheeling, the litigation surrounding that successful bridging was protracted and expensive. The Mississippi River was a much more formidable technical challenge than the Ohio. Moreover, its north to south path from the northern United States to the Gulf of Mexico meant that it could not easily be outflanked like the Ohio. A general railroad law in Illinois in 1849 had given blanket authorization for railroads to bridge any watercourse in the state provided that navigation was unimpaired. But, as with any state law, its reach

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[17] For an extended history of the case see Monroe (1947). Also http://web.mit.edu/1.011/www/finalppr/areyes-Wheeling_Bridge_Report_final.pdf

extended only to the state border and between Illinois and Iowa this lay in the middle of the Mississippi River.[18] Therefore, in 1853, Illinois chartered the Railroad Bridge Company to "build, maintain, and use a railroad bridge over the Mississippi River … in such a manner as shall not materially obstruct or interfere with the free navigation of said river" (i.e. compliant with federal standards regarding navigability) at Rock Island.

Construction on the bridge began shortly thereafter and it opened to traffic April 22, 1856 amidst opposition from steamboat interests, the city of St. Louis which feared loss of its position as a port, and even the federal government (since Rock Island was federal property). Again, as with the Wheeling Bridge, fate intervened. After just 15 days of operation, a steamboat, the *Effie Afton*, headed upsteam, lost power after passing the bridge draw, drifted back downstream where it collided with a bridge span. Fire broke out and the boat and a bridge span were destroyed. The captain of the vessel subsequently filed suit in U.S. District Court in Chicago for loss of his vessel and its cargo (United States. District Court for Northern Illinois. 1857).[19] Abraham Lincoln appeared as lead counsel for the defense and managed to win a hung jury in part by his assertion that persons wishing to cross the river had as great a right as anyone wishing to go up or down the river, although

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[18] This is the normal rule where a body of water marks a boundary. The exception is the Ohio River as the Northwest Ordinances defined the territory as beginning on the northern shores of the river. Thus Kentucky (and Virginia) and not Ohio, Indiana or Illinois controls the entire waterway for purposes such as fishing—and bridging.
[19] See http://www.archives.gov/publications/prologue/2004/summer/bridge.html and http://castle.eiu.edu/~wow/classes/sp07/lawdocument.pdf.

his exact words have been lost.[20]

The damaged span was replaced and the bridge reopened four months later. However, in 1858 the House Committee on Commerce conducted an investigation and concluded that the bridge was a serious obstruction to navigation of the river (United States. Congress. House. Committee on Commerce. 1858). However, the Committee recommended that the matter should be settled in the courts rather than by legislation.

Shortly thereafter, a suit was filed in the U.S. District Court seeking to have the bridge declared a nuisance and removed (United States. District Court for Southern Iowa 1859). That court found in favor of the plaintiff and ordered the Iowa half of the bridge removed. No action, however, was taken as the railroad appealed and the case, *Mississippi and Missouri Railroad Company v Ward*, came before Supreme Court in December 1862. By the end of January 1863, the court had rendered its majority opinion, overruling the District Court order and finding for the defense on the ground that if the original decision were upheld then, according to Justice John Catron, “no lawful bridge could be built across the Mississippi anywhere; nor could the great facilities to commerce, accomplished by the invention of railroads, be made available where great rivers had to be crossed" (United States. 1862). This opinion was subsequently reaffirmed in *The Galena, Dubuque, Dunleith, and*

[20] The Court records for the U.S. District Court for Northern Illinois were all destroyed in the Chicago Fire of 1871 including the transcript of the trial has been lost. See http://www.archives.gov/publications/prologue/2004/summer/bridge.html.

Minnesota Packet Co. v. *The Rock Island Bridge* (United States. 1867).[21]

Given this profusion of different standards at the state and federal level regarding navigability, I have adopted a uniform pragmatic standard for my river SHP files: I call those stretches of a river "navigable" where steamboats regularly operated for some time during the nineteenth century. This determination was made based works such as Hunter's (1949) history of western river steamboating and Chittenden (1903) as well as from discussions regarding the navigability of individual rivers in the annual reports to Congress made by the Corp of Engineers. These reports are now searchable on-line.

Thanks to their engine, steamboats could go against the river current almost as easily as with it, thereby making bilateral trade a real possibility. Their principal competitor, the flatboat or raft, on the other hand, could only make a single one-way trip downstream (Haites, Mak, and Walton 1975). Canals and railroads also enjoyed the same advantage of being largely indifferent to the direction of trade.

The rivers that we see today, however, differ from those at earlier times as a result of the actions of man and nature. Floods have suddenly created new watercourses.[22] Silt, gravel and other waterborne debris have also gradually shifted a river's flow and course—for example, along the Red River in Texas and Louisiana.

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[21] See also http://www.archives.gov/publications/prologue/2004/summer/bridge.html

[22] A process known in legal parlance as avulsion. Probably the most dramatic change wrought by nature took place in April 1881 when the Mississippi River in flood broke through an oxbow to the north of its confluence with the Kaskaskia River and took over the lower 10 miles of the Kaskaskia river for its new channel. As a result, the city of Kaskaskia found itself on the west side of the river and cut off from the rest of Illinois, although it remains a part of the state to this day.

Different legal rules apply to these situations. Accretion and erosion through the normal action of water leaves boundaries unchanged—generally in the middle of the stream regardless of wherever that might be at any moment. On the other hand, sudden changes resulting from flooding, landslips and the like, leave the boundary fixed in its original location—in the middle of the old watercourse even if that no longer contains water. Moreover, man, in an effort to improve upon nature and render rivers more useful, has straightened and dammed them (Paskoff 2007).[23] These human activities and the effects of floods have generally shortened point-to-point distances and reduced travel times.[24]

Consequently, SHP files of currently navigable rivers such as those of the U.S. Army Corp of Engineers "National Waterway Network" (http://www.navigationdatacenter.us/data/datanwn.htm) that are a part of the modern national transportation database (http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/2014/polyline) are of limited usefulness in reconstructing accurate courses for nineteenth century rivers.

In many cases, a river's earlier course can be recovered from political boundaries, most of which were determined during the nineteenth century and

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[23] The Missouri in particular is dotted with large dams for flood control and to improve navigation on its upper reaches.
The Sangamon River (among many others) has also been straightened. As a result it now enters the Illinois River some ten miles southwest of its original confluence and is much shorter than it was in its natural state.

[24] The Mississippi River today is perhaps 10% shorter than it was in the 19th century.

many of which were influenced by the natural barriers created by waterways.[25] Unbridged waterways made delivering locally-supplied services such as police protection or schooling across those barriers inconvenient at best and dangerous or impossible at worst, making the waterways a natural break between political and economic jurisdictions. Moreover, court decisions held that changes in water courses left political boundaries, including those between states, unchanged regardless of what might happen to the private property rights from erosion or accretion one one-time riparian owners. Consequently, reaches of many steamboat-navigated rivers diverge from their courses they have on today's maps and I have approximated these earlier paths using political boundaries from the NHGIS boundary files.

Some rivers have also been "improved" to enhance their carrying capacity and regulate their flow by means of a system of locks and dams. Historically, these were identified by the suffix "Navigation" as in the Muskingum, the Monongahela, and the Youghiogheny Navigations. Indeed, nowadays, both the Ohio River and the Mississippi River above St. Louis would also qualify for this designation. As a general rule, I have treated Navigations as rivers rather than as canals (i.e. they are included in my rivers SHP file rather than in the canals SHP file). My working definition of a navigation is more restrictive than that given by, say Wikipedia, which defines it as a navigable waterway that "parallels a river and shares its

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[25] The various county boundary changes are detailed in the Newberry Library's "Atlas of Historical County Boundaries" at http://publications.newberry.org/ahcbp/index.html. A listing of river borders for U.S. states appears at http://en.wikipedia.org/wiki/List_of_river_borders_of_U.S._states.

drainage basin." Specifically, I interpret "parallel" as meaning coincident with the natural watercourse (which may be sunken beneath the surface of the Navigation). Thus, the Muskingum, the Monongahela, and the Youghiogheny navigations are in my river SHP file but the Susquehanna and the Juanita Divisions of the Pennsylvania Mainline canal (see below) which parallel their respective rivers, each is treated as a canal since barges operating along them paralleled the natural watercourse but spent very little time in the actual natural watercourse even when switching river banks.

Some rivers, like the Connecticut River, were not dammed but required short canals around particularly troublesome spots like at Windsor Locks (Harte 1938). So too did the Ohio River at Louisville where the Louisville-Portland Canal diverted traffic around the Falls of the Ohio (Trescott 1958). These are treated as short breaks in the river since they (generally) forced traffic out of the natural watercourse and into a man-made one. They did not, however, require any transshipment of cargo or passengers provided that the vessel could fit in the lock chambers.

My mapping <u>excludes</u> those waterways that <u>could have been</u> made navigable (see, for example, (United States. Census Office. and Gannett 1898, plate 370) but were not before the second decade of the twentieth century. My mapping of navigable waterways thus differs from that used by Fogel (1964) for his railroad counterfactual.

Some of the discrepancies between sources such as Fogel (1964) and my mapping, however, may simply reflect my inability to document that steamboats regularly operated on specific waters. For example, the Conecuh River is not included in my SHP file of navigable rivers because, although the historical evidence indicates that flatboats were regularly used on the river, only one steamboat, the "Shaw," ever made it up the river from Pensacola. It was sunk by a snag shortly after reloading with a cargo of cotton at Brooklyn Landing in 1845, bringing a premature end to experiments with steam navigation on that river (Riley 1881, 125). Fogel, however, treats the Conecuh River as a navigable.

On rivers that were navigable, I have placed the head of navigation at the point where the historical record indicates steamboats would often travel for at least a part of most years rather than at the highest point ever reached. Thus, for example, Louis Hunter in his (generally) authoritative *Steamboats on the Western Rivers* (Hunter 1949) lists Fulton, Arkansas as the head of navigation on the Red River. However, I give Fort Towson, OK as the head of steamboat navigation on the Red River during the nineteenth century based upon contemporary local newspaper advertisements and reports summarized by Wright (1930, 83-5) indicating regular packet service to that point by the early 1840s with more than a dozen steamboat landings above the Oklahoma line by 1854.

Given this lack of certainty about any specific head of steamboat navigation, I have given a beginning date and source for the use of each river or stretch of water by steamboats in the SHP file. When I also found a definitive date by which navigation had ceased, that too has been recorded. If no specific ending date was cited in the literature, I have used "2100" which should be interpreted as indicating that navigation of the river continues (although the age of steamboat navigation *per* *se* ended decades ago).

While various sources did not always agree, I was usually able to determine the head of navigation on each river. The downstream limit of navigation, however, is less easily specified. At some point, rivers flowing into the Atlantic (including the Gulf of Mexico) and the Pacific oceans become subject to the ebb and flow of the tides and are thus navigable *per se* under the English Common Law definition. However, this is not the same as the point where rivers (and river navigation) end and the seas (and ocean or coastal navigation) begin. According to the National Oceanographic and Atmospheric Administration, there is no legal definition of what constitutes the coastline or shoreline (see, for example, http://shoreline.noaa.gov/). Consequently, I generated coastlines for the West Coast, the East Coast and Gulf and the Great Lakes by converting the NHGIS TIGER-based polygon state boundary SHP files to lines and dissolving the vectors fronting the ocean or Great Lakes. This procedure generates coastlines that are coincident with the NHGIS TIGER-based historical county boundary used as reference points in all our work.[26]

My navigable river features (but not the steamboat-navigated SHP file that I have made available to researchers) terminate at the coastline. There, presumably, cargo could be transferred to and from seagoing vessels that were more efficient means of transportation (generally being larger). One consequence of this seemingly rational decision, however, is that neither the Delaware nor the Potomac rivers would have appeared as a navigable river in my SHP file since the entire lower

[26] But those SHP files sometimes contained (seemingly random) extraneous polylines interior to the coast. These have been deleted from the coastline SHP files.

reaches of these rivers appear on the ocean side of what I (and NHGIS) have called the coastline.[27] Similarly, the Hudson River beginning a few miles below the northern border of Westchester County lies on the ocean side of the coastline.

To deal with this problem, I have generated a second river SHP file: "Tidal Reaches." This connects to the navigable portions of rivers and to those canals that terminated at the coastline and traces out the river channels of those navigable rivers as shown on USGS topographical maps. It has been merged with the "Navigable Rivers" SHP file to create the "Steamboat Navigated River" SHP file. Those stretches of each navigable river that lay beyond the coastline are identified in this SHP file's database by the field "Tidal" which has been assigned a value of 1 (zero otherwise) for tidal reaches. The extent of these tidal reaches on the USGS topographical maps, however, appears to be somewhat arbitrary. Moreover, the question of whether or not broad river estuaries and tidal inlets could be used by river steamboats depended upon steamboat design. As a general rule, those steamboats that were built to operate on the eastern rivers like the Delaware, the Potomac, the Connecticut and the Hudson could and did also operate in coastal waters. However, those boats designed for the Mississippi and Ohio rivers were structurally incapable of being used on open waters (Hunter 1949) as they were at risk of breaking it two even on broad reaches of those rivers if their shallow hulls lost the support of the water at any point below the waterline.

[27] For example, the Delaware River estuary is only closed in the coastline shapefile above Trenton. The same is true of the Columbia River in the Pacific Northwest which appears as an estuary below Crima Island, approximately 50 miles from the mouth of the river on the Oregon-Washington coast.

Canals: Canals—man-made waterways—were key components in Treasury Secretary Albert Gallatin's bold plan for the early nation's transportation infrastructure (U. S. Congress. Senate 1808). The federal government failed to act on most of Gallatin's plan but the great commercial success of the Erie Canal sparked a series of canal booms in America (especially Goodrich 1961, Segal 1961). Some canals were very short and served to move traffic around specific obstacles such as the Louisville and Portland Canal (bypassing the Falls of the Ohio near Louisville, Kentucky) and the Soo Locks (which bypass the rapids on the St. Mary River between Lake Superior and the lower Great Lakes). Others were much longer and crossed multiple natural watersheds and drainage basins such as the Erie Canal linking Lake Erie to the Hudson River and the Wabash and Erie Canal, linking Lake Erie at Toledo through the Wabash River to the Ohio River at Evansville, Indiana.

Unfortunately, virtually all of the earliest canals in America have now been lost.[28] Their prisms (canals' cross-sections) have silted up and have become overgrown (see, for example, the satellite image in the right panel of Figure 1), although some features like lock chambers and towpaths may remain. Moreover, several canals have been repurposed in ways that have obliterated much of the archaeological evidence. Railroads

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[28] At least two canals were built in the United States during the twentieth century and are still in operation (as are other, older canals that are still in service but which have been updated and improved like the Soo Locks): The New York Barge Canal, completed in 1918, took over sections of the original Erie Canal and bypassed others and the Tennessee-Tombigbee waterway which opened in 1984. In addition, there is the intercoastal waterway that was begun in the early nineteenth century but on which most work was done in the twentieth century. Neither the intercoastal waterway (as a single entity) nor the Tenn-Tom are included in my SHP file, though some early bits of what becomes the intercoastal waterway, like the Albemarle and Chesapeake canal, are (see, for example, http://www.carolana.com/NC/Transportation/albemarle_and_chesapeake_canal.html).

that came along later were built along the rights-of-way of many canals, including the Pennsylvania Mainline, the Whitewater and the Framingham canals, beginning in the middle of the nineteenth century. Many railroad rights of way have subsequently met similar fates as highways have been built atop them. For example, a part of Interstate 10 in Houston now occupies the old Pacific Railroad right-of-way.[29]

Two water routes that have the term "Navigation" as a part of their names are included among the canals rather than being treated as rivers on the grounds that they had much more in common with canals than with rivers. Sixty-two miles of the 108 mile Schuylkill Navigation between Philadelphia and Port Carbon was covered by separate canals built along the Schuylkill River bank rather than via the rivers itself although today, only brief stretches of these canals remain in water such as around Mont Clare, PA (Google Earth, below Lock 60 at 40°08′42″N 75°30′28″W). I have also included the Bald Eagle and Spring Creek Navigation among the canals since it required an extensive canal cut to complete the link between Lock Haven and Bellefonte, PA.

Construction of my SHP file for canals began with various, relatively inaccurately drawn maps of canal routes. Some of these, such as Poor (1860) and maps in the David Rumsey collection (www.davidrumsey.com, for example, (Tanner 1840)), were more or

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29 The portion of Southern Pacific railroad right of way between Katy, TX and Tower 13 [in northwest Houston] was abandoned in 1997, after the Union Pacific Railroad merged with the Southern Pacific Railroad (then owner of the Missouri-Kansas-Texas Railroad which built the track in 1893). The Katy Freeway (Interstate 10) has since been widened onto the adjacent right-of-way for most of its length, completely obliterating any traces of it. See http://www.abandonedrails.com/Houston_to_Katy.
Even the original Erie Canal could not escape despite its historical significance and status as a cultural icon as a stretch near Port Byron is now a part of the New York Thruway.

less contemporaneous. Others, such as Goodrich (1961), are retrospective. These sources have been used to provide evidence of the existence of a canal and to indicate its general location.

The actual mapping of the canal's location (so far as possible), however, was made by hand-digitizing points using ArcGIS and 7.5 minute U.S.G.S topographical maps made in the mid- to late-twentieth century. These maps often mark vestiges of features like the trace of "Wabash and Erie Canal" shown on the Elberfeld (Indiana) Quadrangle 7.5 minute series map from the USGS that was first issued in 1961 (left panel of Figure 1).[30] This and similar topographical maps are available as basemaps within ArcGIS via ArcGIS Online. They are thus relatively easy to use although downloading and rendering can be slow and tedious depending upon the extent of any zoom. Unfortunately, the far superior ESRI ArcGIS Pro program has not yet implemented these earlier USGS topo maps as basemaps. Instead, ArcGIS Pro uses the more recent 2009 7.5 minute maps (see, for example, http://nationalmap.gov /ustopo/quickstart.pdf). However, while these maps are based on images of the earlier topo maps, they lack much of the detail—including showing and identifying features like abandoned canals (see, for example, Appendix A which shows the same area as Figure 1).

[30] Available from http://ims.er.usgs.gov as gda_5285424.zip.

FIGURE 1
The Location of Part of the Wabash and Erie Canal as Shown on a Mid-Twentieth Century U.S.G.S Topographical Map and the Same Area from Satellite Imagery

The mid-twentieth century USGS topographical maps have been supplemented by much earlier historical topographical maps from the late nineteenth and early twentieth centuries that the USGS has made available as overlays through http://historicalmaps.arcgis.com/usgs/.

I also relied upon histories of the various canals such as Whitford's history of the Erie Canal (Whitford 1922) and Poor (1860) who describe the routes taken by canals and when various sections opened to traffic. In a few instances, gaps in the tracing of abandoned canals shown intermittently on the topographical maps were approximated by looking at satellite imagery for vegetation differences or by using the elevation data encoded in the topographical maps. At worst, clearly identified points along a canal within a mile or less were connected by a straight line or a line that maintained a fixed relationship to other features on the topographical map. In urban areas, where urban renewal and road construction have eliminated many of the remnants of early canals, their prior existence lives on in street names like “Canal” and “Basin” street that were associated with canals and which are recorded in Street Views and similar urban maps.

Railroads

Railroads present none of the identification issues associated with canals and rivers. The technology is specific and quite easily defined: A railroad is a technology involving the use of flanged wheels affixed to an axle and running on a track. The distance between the flanges on the inside of the wheels sets the track gauge. The earliest tracks were wood, subsequently reinforced by an iron strap for wear and as a bearing surface. Eventually these straps evolved into the familiar “T” rail. In time, steel was substituted for iron providing longer life and offering a significantly higher carrying capacity (Atack and Brueckner 1982).

This definition of a railroad is sufficiently general to include gravity railways and the use of inclined planes where power was provided by stationary engines (such as with the Alleghany Portage railroad between Holidaysburg and Johnstown, Pennsylvania that served as the link between two sections of the Pennsylvania Mainline Canal or the climb up from the Ohio River at Madison, Indiana where the Madison to Indianapolis Railroad began) as well as the more familiar locomotive. These are all included in the railroad mappings here. Inclined planes and gravity railways were eventually replaced by locomotive-based railroads as excavating and construction methods improved and engines became more powerful.

The vast majority of railroad investment went into the right-of-way, especially grading, cuts and fill, drainage ditches and culverts, bridges, railroad crossings and the like as well as the roadbed, sleepers and rails (United States. Census Office. 1883). Once built, these features have tended to remain although over time some have been repurposed into highways or into trails for recreational purposes. Consequently, even where railroads have been abandoned, enough clues generally remain from which to retrace their route.

Elsewhere, I have written about creating my earlier generation of historical railroad shapefiles (Atack 2013). Those began with digitized small scale, state-level maps of the rail system for 1911 by Matthews Northrup Co. for the "New Century Atlas" (Whitney and Smith 1911) and worked backwards through time using ever earlier maps at approximately decadal intervals. My rationale for starting with these 1911 maps was a combination of their availability and the accuracy with which they appear to have been drawn despite the limitations of their scale. Where specific railroad lines are still in operation today or appear on USGS topographical maps (including historical maps from the late nineteenth or early twentieth centuries), the 1911 maps have proved to be very accurately and carefully drawn.

My earlier procedure was as follows. I geo-referenced the 1911 maps against NHGIS state boundary files for that year and traced the rail lines shown on them into a polyline SHP file. Those tracing thus defined both the location and the extent of railroads in 1911. Mappings for earlier years were created by working backwards in time, based upon what were thought to be the "best" mapping of the rail system for a particular year and then deleting lines from the later SHP file that did not appear on that earlier map but without modifying their location. Railroads were thus consistently located in the same place that parts of them would appear on the 1911 maps.

The new SHP files described here now replace those earlier ones. I began with clean slate. This new mapping is far more accurate both with respect to location and to timing than its predecessors. Like the earlier versions, the current SHP file ends in 1911 and makes use of the digitized maps from the "New Century Atlas" (Whitney and Smith 1911). However, the current mapping only uses the "New Century Atlas" maps as evidence of the existence of a railroad in 1911 that connected specific points together. The 1911 maps are not used to determine the exact spatial location of the railroads shown upon them. Instead, the precise spatial location of any railroad comes from the union of modern railroad SHP files derived from satellite imagery and published as a part of the National Atlas database by the U.S. Department of Transportation (http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/) and USGS 7.5 minute topographical maps from the late nineteenth century onwards. This rendering has taken several years to complete. During that time the entire library of USGS topographical maps (both historical and contemporary) has been visually examined many times at scales of 1:24000 and 1:10000.

According to the metadata on the National Atlas railroad file, the railroad track data are taken from the Federal Railroad Administration (FRA) and were created at a scale of 1:100000 or better. Unfortunately no additional is provided in the metadata and the FRA web site is silent on this point. Among my first actions was to strip as many tracings of multi-tracking, sidings, turnouts for trains to pass one another, and large switching yards from these SHP files as possible since we have absolutely no information regarding when these were built. The modified National Atlas SHP file was then overlaid on freshly georeferenced state level maps from the New Century Atlas for 1911. All digitized maps were geo-referenced using ArcGIS 10's spline algorithm against the National Historical

Geographic Information System's 2008 TIGER-based historical state and county boundary files (see www.nhgis.org) and the U.S. National Atlas's database of cities and towns.

Rather than showing miles of railroad track, the new mappings (like the earlier ones) show miles of railroad linkage between points. This distinction is an important one, not least because data on miles of track (whether reported by the railroads themselves or in sources like Poor's Manual or reports by the Interstate Commerce Commission) represents the miles of rail divided by two (since the track consists of two parallel rails separated by the gauge) and counts track in switching yards, sidings and turnouts in that total. It would also count a stretch of double track as double the distance. None of these (except for errors) are included in my shapefiles for the reasons given. Mileages calculated from my shapefiles using GIS software will thus NOT generally match up to those reported by the Census (1883), Poor (1860), or other such sources.[31] Like my earlier shapefiles, these new ones measure the distance between origins and destinations via rail.

Like everything else, however, there are exceptions to this rule. For example, in 1861, we know that the broad gauge (72") Delaware, Lackawanna and Western railroad connected to the Central Railroad of New Jersey, a standard gauge road, near Hampton, New Jersey. Rather than break gauge at that point or build an entirely separate right of way, however, the Lackawanna Railroad continued on to Jersey City via the New Jersey Railroad (a "New Jersey" gauge line—58") by means of a third rail attached to the

[31] Of course, significant questions surround those mileage data anyway as shown by the latest edition of Historical Statistics (Carter et al. 2006) as well as earlier authorities such as Wicker (1960).

railroad ties so that broad gauge trains used the outer pair of rail while standard and New Jersey gauge trains used the inner rail and the appropriate outer rail (Taylor and Neu 1956, 25). I have represented this arrangement in my SHP files by the creation of parallel tracks, one of each gauge. I used the same procedure in southeastern Indiana and southwestern Ohio where the broad gauge Ohio and Mississippi line met up with the standard gauge Indianapolis and Cincinnati line into Cincinnati. In that case, however, the historical record so far as I can tell is silent on whether a third rail was added or two tracks with separate gauges were laid along the right of way.

Railroad lines in the National Atlas SHP file that did not match up by origin, route and destination with lines shown on the 1911 maps were deleted. When a railroad was shown on the 1911 maps but for which there was no corresponding railroad in the modern data by origin, route and destination, the USGS topographical maps for the area in question were examined carefully. These invariably showed an "old railroad grade" feature in the expected general location and between the expected origin and destination. I also examined the registration between the modern active railroad lines and those shown on the topographical maps, including those from late nineteenth and early twentieth centuries. If satisfied, I traced the route of the old railroad grade into the edited SHP file of modern railroad data.

Where there were gaps in "old railroad grade" features, I looked for roads and trails that might have been built atop the track. I also examined satellite imagery for variations in vegetation that might reveal the drainage provide by old railroad bed and boundary lines (including fences and trees) that might indicate an earlier right-of-way. I even looked for evidence of railroad-related structures like bridge piers remaining in river and streambeds.

As with the previous generation of railroad SHP files, the SHP file that these procedures generated for 1911 was copied and the copy used as an overlay for the next earlier digitized railroad map. The closer together in terms of copyright date that those maps were, the greater the likelihood of conflicting information. Where conflicts were spotted, efforts were made to resolve them by consulting other maps from a year or two earlier and later. In some cases, as a result of this procedure, the 1911 mapping was reviewed and adjustments made to the base SHP file whenever it appeared that the "wrong" line(s) between particular origins and destinations from among several possibilities had been chosen.

Whereas my earlier generation of railroad SHP files map the nation's railroads at approximately decade intervals, these new mappings are approximately five years apart, except for the decade of the 1850s where the frequency was increased to every two years.[32] Moreover, a conscious effort was made to locate consecutive maps from similar sources wherever possible. In particular, the six maps series covering from 1877 through 1903 were produced by Rand McNally (for example, Rand McNally and Company. 1879). These were all versions of their "Business Atlas" intended to inform businesses how best to ship products nationwide. Similarly, the two mappings for the 1860s make use of maps produced by Lloyd (1868, 1863) with a similar goal. The specific source(s) used for each year's SHP file is shown in Table 1. Additional information appears in the

[32] Specifically, railroad SHP files have been generated for 1911, 1903, 1898, 1893, 1889, 1881, 1877, 1872, 1868, 1863, 1861, 1858, 1856, 1854, 1852 and 1850 using the map-based procedures described above.

metadata (XML) files that are a part of the SHP files.[33]

Table 1
Map Sources Used to Determine the Existence of Rail Links in Each Specific Year

Year	Map source for existence of rail links in that year
1911	William D. Whitney and Benjamin E. Smith (eds) *The Century dictionary and cyclopedia, with a new atlas of the world*, New York: Century Co., 1911. State maps.
1903	Rand McNally, Rand McNally & Co., *Enlarged Business Atlas And Shippers' Guide ... Showing In Detail The Entire Railroad System ... Accompanied By A New And Original Compilation And Ready Reference Index…*, Chicago: Rand McNally & Company, 1903.
1898	Rand, McNally & Co.'s *New Business Atlas Map of the United States…*, Chicago: Rand McNally & Company, 1898. Regional maps.
1893	Rand McNally and Company, *Rand, McNally & Co.'s enlarged business atlas and shippers guide ; containing large-scale maps of all the states and territories in the United States, of the Dominion of Canada, the Republic of Mexico, Central America, the West Indies and Cuba.* Chicago: Rand McNally, 1893. State maps. Louisiana, Maryland/Delaware, Michigan, and Mississippi from Rand McNally, *Universal Atlas of the World*, Chicago: Rand McNally, 1893. Texas: Rand McNally & Co. *Indexed county and railroad pocket map and shippers' guide of Texas : accompanied by a new and original compilation and ready reference index, showing in detail the entire railroad system ...*Chicago: Rand McNally & Co., 1893.
1889	Rand McNally, *Rand, McNally & Co.'s enlarged business atlas and shippers guide…*, Chicago: Rand McNally & Co., 1889. State maps.
1881	Rand McNally, *New Indexed Business Atlas and Shippers Guide*, Chicago: Rand McNally & Co., 1881. State maps.
1877	Rand McNally and Company, *Rand McNally & Co's Business Atlas*, Chicago: Rand McNally & Co., 1877. State maps.
1872	Warner & Beers, *Atlas of the United States*, Chicago: Warner & Beers, 1872. Regional maps

(Table 1, continued)

1868	J. T. Lloyd, *Lloyd's New Map of the United States The Canadas and New Brunswick From The Latest Surveys Showing Every Railroad & Station Finished ... 1868*, New York: J. T. Lloyd, 1868. National map.
1863	J. T. Lloyd, *Lloyd's New Map of the United States The Canadas And New Brunswick From the latest Surveys Showing Every Railroad & Station Finished*

[33] In particular, I wish to acknowledge the generosity of Murray Hudson (Antiquarian Books, Maps, Prints & Globes, 109 S. Church Street, Halls, TN 38040) who scanned and provided me with copies of most of the state maps used for my 1893 railroad SHP file. See http://www.antiquemapsandglobes.com/.

	to June 1863, New York: J. T. Lloyd, 1863. National map.
1861	G. R. Taylor and Irene D. Neu, *The American Railroad Network 1861-1890*, Cambridge, Mass: Harvard University Press, 1956. Regional maps.
1858	Hugo Stammann, *J. Sage & Son's new & reliable rail road map comprising all the railroads of the United States and Canadas with their stations and distances*, Buffalo, NY: J Sage & Sons, 1858. National map.
1856	Richard S. Fisher, *Dinsmore's complete map of the railroads & canals in the United States & Canada carefully compiled from authentic sources by Richard S. Fisher, editor of the American Rail Road & Steam Navigation Guide*, New York, 1856. National map.
1854	E. D. Sanford, *H. V. Poor's rail road map showing particularly the location and connections of the North East & South West Alabama Rail Road*, by E. D. Sanford, Civil Engineer, n.p.: 1854. National map.
1852	J. H. Colton, *Colton's Map Of The United States, The Canadas &c. Showing The Rail Roads, Canals & Stage Roads: With Distances from Place to Place*, New York: J. H. Colton, 1852. National map.
1850	Curran Dinsmore, *Dinsmore & Company's new and complete map of the railway system of the United States and Canada; compiled from official sources, under the direction of the editor of the "American Railway Guide."*, New York: 1850. National map.
Notes: See also the SHP file metadata for the specific source(s) of individual maps.	

As the sources in Table 1 indicate, the earlier maps tended to be regional or national. Their resulting (relatively) small scale may have obscured some details and rail links, especially in more compact and densely settled areas like what is now the Northeast Corridor. Later on, the maps providing information on the existence of a rail link tended to be of individual states, many covering both verso and recto pages. These could clearly show much greater detail with greater accuracy.

This map-based procedure generated sixteen separate SHP files between 1850 and 1911. Prior to the Civil War, however, it is clear that the geographic accuracy of maps declines sharply (see also Modelski 1987), making their use more difficult and error-prone. As a result, rather than base my mapping of rail links upon increasingly questionable maps, I have instead relied upon the work of railroad enthusiasts and historians.

Specifically, I have generated maps for 1826 through 1850 using a database of railroads by year built that was assembled by Professor Milton C. Hallberg (deceased, Pennsylvania State University). It is hosted on the web site http://oldrailhistory.com/. When I produced my previous generation of SHP files, I also consulted this source. At that time, however, detailed individual maps of each railroad showing when specific sections of track were built were also a part of the WWW site. Unfortunately, these are no longer available and I have not been able to locate them in any of the WWW archives.

The Hallberg database has been supplemented by various published railroad histories, on-line Google search results and the Wikipedia entries for specific railroads appearing in the database. The combination of these sources made it possible to generate SHP files for 1845, 1840, 1835, 1830 and 1826—the earliest (gravity coal) railroads in Hallberg's database.

Those earlier SHP files were generally consistent with my 1850 SHP file based on the map published as a part of Dinsmore's Travel Guide (Dinsmore 1850) and produced under the direction of the editor of the "American Railway Guide" that my procedure based upon working backwards from 1911 had produced. Where necessary, a few minor adjustments were made to the Dinsmore mapping to make it consistent with the evidence for earlier years (that is say, I treated the database from 1826-1850 as the more authoritative source, in part because of the questions regarding pre-Civil War maps).

The approach that I describe above where the SHP files for successively earlier years were based off a copy of the SHP file for the next later year, generated multiple SHP files, one for each year. These were then merged into a single SHP file covering the entire period by using the "Erase" command to determine what track was added between each successive pair of years. These were then merged to combine the results back into a single SHP file.[34] The gain from this procedure was that publication (copyright) date for the later of each pair of maps was used to populate the "InOpBy" field and provides a rough dating as to when each stretch of line was built.

In addition, the Hallberg database provides an exact dating for when each section of track was opened to traffic. This has been preserved in the database field "Exact" although adjustments were made if Hallberg's dating was contradicted by multiple or by more authoritative sources (such as the National Park Service's history of the Alleghany Portage Railroad).

Prior to the Civil War, the SHP file database also indicates the operator of the track. During the 1850s, this is the name assigned by Taylor and Neu (1956) for 1861. For 1850 and earlier, the name assigned to the track sections is that given in the Hallberg database. This scheme is imperfect and these data should only be used with care. For example, early on, railroads typically changed names at state borders as they were generally only chartered for operation in one state. They also changed name frequently as construction plans changed (many names were intended to be broadly descriptive as to route, as in "Baltimore and Ohio" and "Missouri Pacific") or bankruptcy or merger forced corporate reorganization. Thus, for example, the Pendleton and Indianapolis Railroad, organized in 1848, was quickly renamed the Indianapolis and Bellefontaine Railroad when it joined up with an Ohio railroad from Bellefontaine in January 1853 at

[34] Specifically, I used the following pairs 1826-1830, 1830-1835, 1835-1840, 1840-1845, 1845-1850, 1850-1852, 1852-1854, 1854-1856, 1856-1858, 1858-1861 (the Taylor-Neu map is explicitly dated April 1861), 1861-1863, 1863-1868, 1868-1872, 1872-1877, 1877-1881, 1881-1889, 1889-1893, 1893-1898, 1898-1903, and 1903-1911.

Union City, Indiana (Bogle, 218) and became the first railroad in Indiana to connect to East Coast cities through those Ohio links. In 1855, it was restyled the Bellefontaine and Indiana Railroad which was shortened to the Bellefontaine Railway in 1864, becoming the Cleveland, Columbus, Cincinnati and Indianapolis Railway in 1868, and finally the Cleveland, Cincinnati, Chicago and St. Louis Railway in 1889.

For 1861, Taylor and Neu (1956) also identify railroad track gauges in their maps. These gauges have been preserved in the database field "Gauge" and are presumed to be the gauge not only in use in 1861 but also the original gauge when the railroad was built. Many of the non-standard gauges (i.e. those other than 4' 8.5") changed in the decades that followed as described in the contemporary literature and by Douglas Puffert (2000, 1991). However, I have made no effort to date changes in gauge or incorporate those changes into my SHP file database and all track added after 1861 is coded as having a gauge of -1 (i.e. missing/unknown). By 1890, however, most of the railroads in the nation, outside of mountainous mining areas where narrow gauge still enjoyed a technical advantage, had converted to standard gauge.

Work by Christian Hung translating my preliminary railroad SHP files into a network as part of his study of the economic impact of breaks in transportation in the mid-nineteenth century has helped me identify hundreds of possible connectivity issues such as dangles (dead-ends) and micro-fractures in routes between origins and destinations.[35] I reviewed all of them and fixed those that I believe represented errors in

[35] Micro-fractures and dangles were much more prevalent in my previous (less geographically accurate) generation of SHP files (Atack 2013) that form the basis of Donaldson and Hornbeck's (2015) reassessment of Fogel's (1964) social savings from the railroad. Those errors were assiduously hand-corrected by Hornbeck to generate the network that they use for their market access analysis and the

my SHP files. Most of these were very small—a matter of feet or yards on the ground. Indeed, many were visible only at maximum zoom. These were generally caused by mistakes in snapping polylines to a vertex, an end, or the edge of an existing feature to which they were supposed to connect. A few were the result of minute line segments that were not properly erased when the SHP file from a later year was adjusted to reflect the preceding year's mapping. Some likely remain.

Some breaks and dangles, however, properly remain in the SHP file. Early on, for example, many breaks are located where rivers were not yet bridged. As noted in the discussion regarding the river SHP files above, there were legal impediments to bridging navigable waterways. Eventually, the law was interpreted as prohibiting "unreasonable" restrictions to navigation–that is, they could not permanently block navigation. What this meant in practice, however, was determined case-by-case and it could be a drawn-out and expensive process. Moreover, large rivers presented technical engineering challenges in terms of constructing suitable approaches, providing adequate structural support, navigation clearances, and coping with periodic extreme flooding, etc.. As a result, many larger rivers were not crossed for many years after a railroad was built to the river's banks. Rather, passengers and cargo were ferried across the rivers. This increased handling costs and created delays and inconvenience.

In determining when a particular waterway was bridged, I made considerable use of internet resources, particularly http://www.bridgehunter.com, a "database of historic or notable bridges in the United States, past and present" although this sometimes proved incomplete or wrong. I also made use of http://cs.trains.com/trn/f/507/t/42151.aspx

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resulting network files are available as a part of Donaldson and Hornbeck's replication files for their *Quarterly Journal of Economics* article.

listing Mississippi River crossings. Where I found a specific date for a particular bridge, it is recorded in the "InOpBy" field of the SHP file database for that segment of line that crosses the river. In some cases, however, no information has been found as to when specific bridge crossings were opened to traffic. For these crossings, the date of bridging is presumed to be the same as the date when the track leading to and from the river was in operation.

Other network breaks between lines occurred in larger cities and towns although most of the maps—especially those national in scale—imply continuous lines. Work documenting and dating these breaks in cities is in progress by Hung but is, as yet, incomplete and thus not (generally) reflected in my SHP file. Many of the city breaks were the result of competing railroad lines failing to agree on a common "Union" station.[36] For example, according to a 1854 map, Boston had seven different rail depots in six distinct locations as far as 2.5 miles apart (Williams 1854). Indianapolis was the exception. There, the three railroads serving the city in 1850 (the Madison and Indianapolis Railroad, the Terre Haute and Richmond Railroad and the Indianapolis and Bellefontaine Railroad) jointly agreed to build a "Union Station" serving everyone. It opened in 1853 and was subsequently connected to other railroads as they also reached the city.[37] However, it was not until the early twentieth century that the Indianapolis solution became the model almost

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[36] Strictly speaking, the Union Stations were passenger terminals but the same issue arose with freight facilities. Early on there was needless duplication and difficulties in interchanging rolling stock among competing lines. These issues took decades to resolve.

[37] See http://www.nps.gov/nr/travel/indianapolis/unionstation.htm

everywhere.[38]

Dangles also occur at docks along the coastline (as at Brooklyn and Bayonne or at Buffalo) and at major rivers estuaries (like the Delaware, around Philadelphia and Camden, or the Hudson at Hoboken). Others were to be found in mining areas like the iron ore mines in Minnesota, the copper mines of Arizona and the Vermont marble quarries.

Concluding Remarks

In the foregoing, I have made every effort to detail the various issues associated with the creation of the river, canal and railroad SHP files but many individual decision had to be made "on the fly." By doing all of the work myself, I have tried to bring a degree of consistency to this decision-making. However, it is also clear that my thinking and resultant decision-making evolved over the years that it has taken to complete this project. I have also struggled to be as accurate as possible in my tracing of routes (both with regard to location and timing) though I am sure further improvements could be made as a close examination of the registration between my SHP files and the USGS topographical maps or satellite imagery will show. Moreover, dating could almost certainly be improved if the annual reports of individual railroads, accounts in the press at the time (including trade journals such as the *American Railroad Journal*), or railroad schedules like those published in travel guides such as Appleton, Cobb or Disturnell (Disturnell 1847, Cobb 1945, Appleton and Company 1847) were used rather than maps. Hopefully, however, any errors are small especially relative to the utility of these

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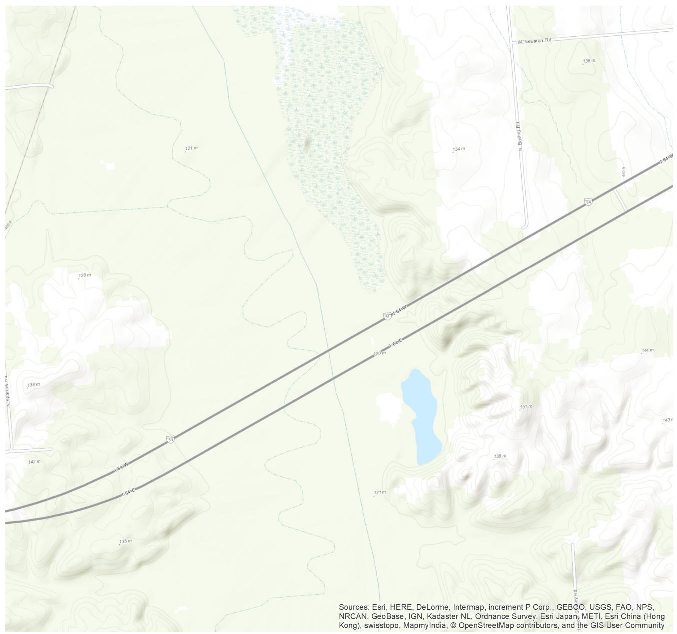
[38] See, for example, Union Station in Washington DC: https://en.wikipedia.org/wiki/Union_Station_%28Washington,_D.C.%29, St Louis: https://en.wikipedia.org/wiki/Union_Station_%28St._Louis%29 or Union Station in Chicago: https://en.wikipedia.org/wiki/Chicago_Union_Station and Mayer (1945)

historical GIS SHP files.

Appendix A
The Reduced Detail in 2009 Series Topographic Basemaps from the USGS
(Compare with Figure 1 which covers the same geographic area)



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