

A PRACTIUM ON UNCERTAINTY: CREATION OF AN HGIS DATABASE

A Thesis
by
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Abstract

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Integrating Geographic Information Systems (GIS) historical sources and geospatial technology offers a fruitful new approach to mapping, analyzing, and modeling the past. This project employs sources freely available online to create a historical geodatabase of the A Line of the Mexican National Railroad circa 1910. The project utilizes satellite imagery, census data, historical maps, train schedules along with postcards and photography from the period, to reconstruct the rail line and its stations shortly before the Mexican Revolution. These sources are combined in a GIS to create a highly accurate map and associated historical database of the system as it existed in the first decade of the 20th Century. The database suggests the potential of future scholarship combining GIS software, satellite imagery, and online source materials.

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Thesis Introduction

This study documents the creation of a Historical Geographic Information System (HGIS) database created entirely from data acquired online. The project models a major rail line, including stations, running from Veracruz to Mexico City circa 1910, a critical period directly before the outbreak of the Mexican Revolution. The aim of this project is to be instructive. Hopefully, by providing a guide to the decision-making processes, that directed the creation of a HGIS database, from the beginning to the end will help demystify the process.

HGIS in the last decade has emerged as an increasingly important method of historical inquiry. However, it remains underutilized from a variety of reasons. Currently the academic literature contains no comprehensive guides to creating HGIS products from data acquisition to the final product. This study intends going through the process of creating such a database from the ground up.

Additionally, this study is an experiment creating an HGIS database with components assembled from purely online research. This approach adopted out of necessity due to time and funding constraints proved fruitful. Data from a large variety of sources, including geolocated photos and satellite imagery was used to satisfactorily reconstruct a key piece of historic infrastructure.

Beyond a basic guide to HGIS, this project is an argument for the greater utilization of consumer oriented geospatial tools such as Google Street View by scholars. As without such tools, the time taken on the project would have undoubtedly been measured in years

instead of months. Likewise, the project demonstrates, there are ample opportunities to create HGIS products even without large troves of digitized historical documents. Huge amounts of data, in a wide variety of forms, currently exist online that can be transformed into insightful spatial oriented historical data. I hope this study represents the beginning of such efforts.

Foreword

This thesis will be submitted to *Clidynamics*, an international peer-reviewed published by The University of California Riverside; it has been formatted according to the style guide for that journal.

A Practicum on Uncertainty: Creation of an HGIS Database

Abstract

Integrating Geographic Information Systems (GIS) historical sources and geospatial technology offers a fruitful new approach to mapping, analyzing, and modeling the past. This project employs sources freely available online to create a historical geodatabase of the A Line of the Mexican National Railroad circa 1910. The project utilizes satellite imagery, census data, historical maps, train schedules along with postcards and photography from the period, to reconstruct the rail line and its stations shortly before the Mexican Revolution. These sources are combined in a GIS to create a highly accurate map and associated historical database of the system as it existed in the first decade of the 20th Century. The database suggests the potential of future scholarship combining GIS software, satellite imagery, and online source materials.

Introduction

Historical Geographic Information Systems

The use of geospatial technology in historical scholarship has been touted as an emerging trend for over a decade (Gregory and Ell 2007), (Gregory and Geddes 2014). However, the widespread adoption of modern geospatial technologies has not yet occurred in academic history departments. Accordingly, the application of modern geospatial tools to historical scholarship is currently underutilized, with much of the methodology being underdeveloped and traditional data sources lacking. To be clear, the lack of adoption of geospatial technology is not primarily due to unfounded conservatism on the part of professional historians. The chief issue impeding the adoption of geospatial technology within academic history is the lack of a robust infrastructure for the subject. Specifically, there exists millions and millions of location specific data but only a minute fraction has been digitized and an even smaller amount has location related metadata. This creates a situation among scholars where more time is spent digitizing and entering data than engaging in historical analysis. As such, most current large historical geospatial projects are more technical exercises in database management and georectification¹ than exercises in historical imagination.

Unsurprisingly, reflecting these realities, most professional historians have shied away from the technology. Nonetheless, that is not to say that working with the technology is fruitless. Vital work is being done in a diverse set of historical fields, just rarely within history departments. Unfortunately, this work is over such a diverse range of subjects it is difficult for a specialized historian to be fully aware of it all. As Anne Knowles points out, the extreme diversity of potential subjects of historical study using geospatial tools works against it as a coherent field of research. Knowles (2014) summarizes the problem as thus:

How can a scholar of medieval Britain, such as Keith Lilley, critique or borrow from a study of red-lining in the twentieth-century Philadelphia, such as that by Amy Hillier? They use similar GIS methods (e.g., georectifying historical maps) but their historical questions, sources, and periods are profoundly different, and the journals where their work was published probably

¹ Georectification is the process of modifying an image without a known geographic coordinate system to fit into a known system such as longitude and latitude. A closely related concept is georeferencing – which is taking an image with a known coordinate system and matching it to another image with a geographic coordinate system. Both processes are integral to Historical GIS and are used extensively in this study. See Pam Shipper’s “Georeferencing vs. Georectification vs. Geocoding.” ImagerySpeaks. January 24, 2012. <https://imageryspeaks.wordpress.com/2012/01/24/georeferencing-vs-georectification-vs-geocoding/>.

have no readers in common. Perceiving the similarities between such different research topics requires geographical and historical imagination. That combination is rare, because so few geographers are now trained to think historically and perhaps even fewer historians are trained to think geographically.²

While the use of geospatial technology history is still in its infancy, significant progress has been made in sorting out many of the philosophical and organizational issues, however, very few comprehensive projects have been completed.

A New HGIS?

This study is in part an attempt to work around the current of limitations of historical source material discussed in the previous section. Modern geographic information technology, in the past decade, has allowed open access to huge spatial databases and geospatial tools that can be used to explore both space and time. This project extensively uses those newly available tools to create an accurate representation of a rail line as it existed in the early 20th Century. This approach is a way both to augment traditional source material and as a new rich source of historical data previously unavailable to scholars.

This use of these new tools served the project well. Using Google Maps, particularly Google Street View, the author could locate most train stations along the 423 Kilometer rail line. This would have simply been impossible a decade ago before the advent of widespread street level photography by companies such as Google. This technology, created to augment commercial mapping services, proved invaluable at confirming the location of historical structures. Ultimately, the ability to remotely verify the location of railroad infrastructure allowed this project to be completed in a matter of months instead of potentially years needed to do this sort of work on the ground. It is this combination of dramatic time saving through remote viewing of streetscapes and the power of satellite imagery to both condense landscapes and magnify features that enabled this project and hopefully more in the future.

² Knowles, Anne. 2014. "The Contested Nature of Historical GIS." *International Journal of Geographical Information Science*, 28:206–11. Taylor & Francis Ltd.

The A Line

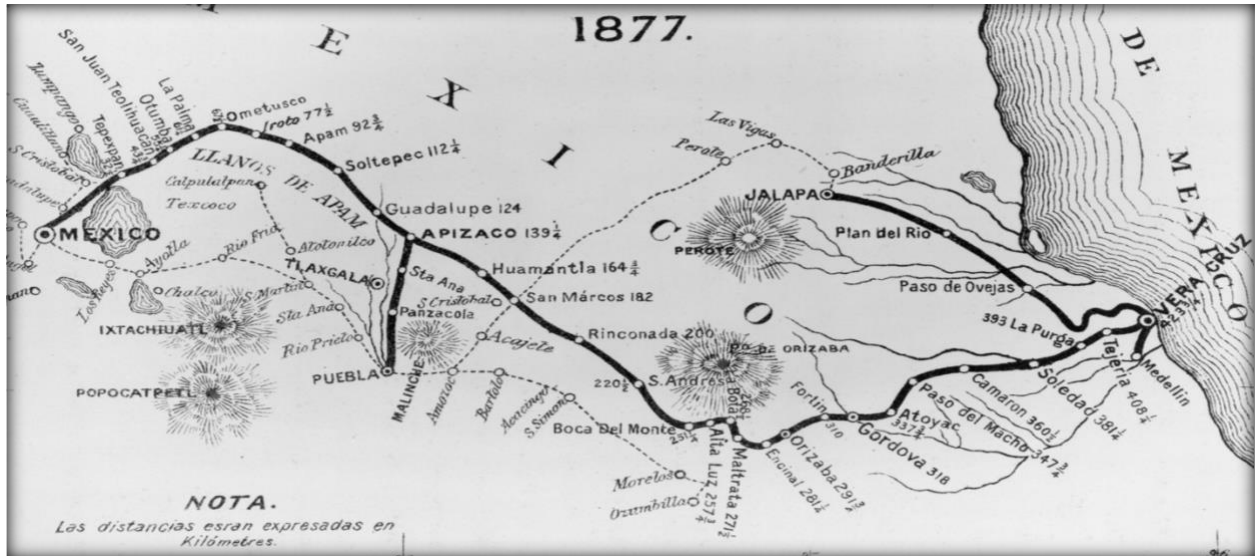


Figure 1. Original route of the A Line upon completion in 1877³

Railroads function as instruments of economic and social change are well documented in the academic literature. In short, railroads dramatically reduced the cost of transporting both goods and people in many cases transformed economies virtually overnight. During the 19th Century, railroad technology, along with the telegraph and the steam ship, ushered in the age of a global connectivity and economic integration hitherto unknown in world history. However, the transformative power of rail technology did not affect every region in the same manner. In areas which had industrialized early, such as the United Kingdom, railroad technology increased various forms of manufacturing and spurred even further industrial growth.

Conversely, in areas outside of northwestern Europe and the Atlantic seaboard of North America that had been excluded from the initial wave of industrialization in the first half of the 19th century, railroads create very different patterns of economic development (Parlee 1981), (Mathews 2014). In these areas railroads, did not spur industrialization, but instead intensified commodity production. These late comers were essentially locked into a subservient role in the world economy supplying raw materials exchange for manufactured goods from the newly industrialized world.

This project examines a portion of the rail system of one of the late comers -- Mexico. Mexico -- impeded by unfriendly topography and political instability was, in fact, one of the last countries in Latin America to construct a functioning rail network. The first lines, one of which this project models, were not completed until the late 1870s (Coatsworth 1979), (Randall 1985). This period in the late 19th and early 20th Century is an important moment where the transformative power of the new system had time to take hold, but before the dramatic changes ushered in by the Mexican Revolution. These rail connections between Mexico City and Veracruz, most importantly the recently nationalized A Line, connected the Mexican capital with the country's most important port and were key to the rapid integration of the Mexican economy into the new world system. Moreover, beyond the political and

³Adapted from *Mapa del ferro carril Mexicano y ramales de Puebla y Jalapa*. Mexico, 1877. Photograph. Retrieved from the Library of Congress, <https://www.loc.gov/item/2005691825/>. (Accessed June 22, 2017.)

economic importance of the Mexico City to Veracruz rail lines, these lines would serve as one of the key strategic assets during the Mexican Revolution. This project examines a single rail line during this end of this transformative period, shortly before the Mexican Revolution. The political and social history of this period has been well documented, what makes this project unique, as history, is the use of modern geospatial technology along freely available primarily and secondary source material to model the A Line, between Veracruz and Mexico City, the most important transportation link in early 20th Century Mexico.

The Project

This project documents the creation of a geohistorical database of a rail line that runs from Veracruz to Mexico City circa 1910. The following communicates some of the process and challenges of creating a relatively small historical geodatabase from scratch using free available data sources. This study is *not* intended as a how-to guide. It does not provide step by step instructions or troubleshoot any specific technical problems. Also, as such, some familiarity with the basics of database creation and the workings of basic GIS functions are assumed. Finally, the project is agnostic regarding the software used. QGIS 2.1x was primarily used in this project for mapping and data analysis, while Microsoft Excel was used to store and sort most of the individual databases used in the project. Though, everything described should be replicable in a variety of GIS and database software packages.

Ultimately, this study is intended as a step towards creating a more robust infrastructure for utilizing Geographic Information Systems (GIS) and as such is intended to be practical in nature. It puts a special emphasis on using easily accessible online sources. There is much vital work that can be done in the field through the creative use of available data sources. In fact, all data used in this project, from the satellite imagery to the period photographs and census data is readily available and free of charge online. This choice of datasets was intentional. This project began with the idea that scholars do not need large specialized data sets to create interesting work in historical GIS and the technology does not have to wait for large scale digitization of source materials. Instead, there is much important work that can be done currently from new and easily accessible source material that has been created and made freely available online in the past decade. In the past ten years, consumer information technology has advanced to the point, when combined with what historical data sets do exist, to allow the creation of robust and spatially accurate historical GIS (HGIS) databases in a wide variety of subjects.

Categories of HGIS Scholarship and the Problem of Uncertainty

Due to the wide variety of periods and regions that have been the subject of historical GIS studies the following review of the literature is divided by the methods employed – which conveniently tend to align with the infrastructure requirements for projects. I have categorized the reviewed literature into four broad types, historical GIS databases, cartographic analysis, historical spatial analysis, and included a final broader category on uncertainty in HGIS.

A short definition of each follows: HGIS database projects tend to be large scale projects that digitize historical sources primarily for the use of future historical scholarship. They are the most technical and resource intensive. These projects are also unique, in that they are more concerned with creating an information project than producing original scholarship. The second type of use of historical GIS is cartographic analysis. These projects compile and digitize sets of historic maps to study change over time. These projects tend to be less resource intensive than the creation of databases because map digitization is a simpler process as many have already been digitized. The third type is historical spatial analysis. This approach typically uses existing spatial data and databases to create historical models and locate areas that would be promising for further research. This sort of analysis tends to use GIS infrastructure that is already in place and therefore tends to be the least costly of the three methods.

Additionally, often this type of research is used in tandem with more traditionally methods. The final part of this section is not a categorization of a specific type of HGIS scholarship but a brief overview of the problems and dimensions of uncertainty in the field.

Historical GIS Database Projects

Historical GIS databases are the most ambitious type of GIS project covered in this review. A large database typically takes a team of experts in varying fields both technical and with the sources being used. Unsurprisingly, this sort of work tends to be slow, expensive, and the rarest type of work in the academic literature. These sorts of database projects also face some unique challenges associated with tracking objects in the database temporally. Tracking data over longer periods of time (e.g. decades or centuries) results in categories and objects used in the database to become less representative and more abstract. This effect becomes more pronounced the further the user moves away from the scale and temporal points the database were designed to capture. Likewise, attempting to design categorization system for long periods of time necessitates the greater abstraction in categorization schemes themselves. In many cases, taking the *longue durée* can create situations where the exaggerated temporal scale is incapable of producing useful data for a project, due to being overly abstracted and therefore incapable of detecting interesting temporal patterns. These challenges aside, this type of project enables the construction of a robust historical GIS infrastructure that the discipline is currently missing and are therefore likely the most critical to the widespread adoption of the technology among academic historians.

Perhaps the most ambitious recent historic GIS database project is documented in Carrion et al. (2016) 'From Historical Documents to GIS: A Spatial Database for Medieval Fiscal Data in Southern Italy.' This project digitized a vast set of tax records from the 15th century for the southern Italian province of *Terra d'Otranto*. The dataset contained the types of taxes paid, the name of tax collector, and the location of collection. Overall, the database contains over four million pieces of information making it one of the most ambitious historical GIS database project yet attempted.

The Carrion et al. study (2016) employed a large team who first created a database in Excel in which all records were entered. These records included the geographic location as recorded and that data was imported into a GIS system. However, unlike modern GIS projects, geolocation proved particularly difficult for a variety of reasons. First, the original records were written in Renaissance Latin and contain thousands of potentially archaic place names or simply places that no longer exist. Likewise, precisely geolocation proved difficult in cities whose areas have grown significantly in the past five centuries (often subsuming nearby villages). To deal with the difficulties of geolocation, the project employed a team of scholars familiar with the region's medieval toponyms. Despite these efforts, placing the locations indicated in the records precisely on a modern map will always contain errors. To account for these potential errors and give future scholars using the database some idea of the level of uncertainty associated with each location, each geolocated point was given a value of 1-5 indicating the confidence of the geolocation team's location of the point.

Geographic uncertainty when dealing with historical place names is a recurring theme in historical GIS, a problem that will appear in this study and one which makes constructing a historical GIS infrastructure considerably more time consuming than dealing with GIS projects that lack a significant temporal aspect (Charles 2013). For instance, place names tend to change over time, even minor spelling changes, can lead to major problems both geo-referencing the data using modern names and in general, the convenience of modern premade base maps and geolocation tools in GIS products is a major strength in these systems for most uses. However, they are simply not reliable enough to be used uncritically when working with historical data and, at very least, must be checked by a scholar in the field.

The *Terra d'Otranto* database has only become available to scholars last year, so no studies have been published that utilize it. However, the scholars involved in the database creation did some cursory queries and quickly reconstructed the percentage of different tax types paid by municipalities, gaining a

greater understanding of the trade patterns within the province. This is the sort of analysis that would have been virtually impossible even through the most herculean effort of scholars employing traditional historical methods, but one that GIS can accomplish with ease. Hopefully, much more scholarship using the database will be published soon allowing a host of spatio-temporal insights inaccessible to researchers without the new technology.

Cartographic Analysis of Historical Maps

One of the earliest uses of GIS technology in the study of history has been historical cartographic analysis. The early appearance of this method in historical scholarship is likely because cartographic scholars have closer connections to trends in geography as an academic discipline, and because the techniques are relatively simple, and rendered much easier in a GIS than on paper. Cartographic analysis, itself, overlays digitized versions of multiple historical maps from different periods in time and attempts to quantify the changes observed. This technique was, of course, possible before the advent of GIS technology. However, the automation of GIS allowed the comparison of multitudes of maps comparatively inexpensive and faster. Recently, ambitious scholars have used the technique to overlay hundreds of maps, and aided by modern spatial statistics arrive at sweeping conclusions that would be virtually impossible without modern GIS technology. This method also benefits from the large numbers of historical maps have been digitized. Even if potential source maps are not yet digitized, the cost, and potential for error are trivial compared to the creation of historical databases.

The most prominent recent example of this sort of scholarship is 'Maps and the Settlement of Southern Palestine, 1799–1948: An Historical/GIS Analysis' by Levin et, al. (2010). This study overlays over 350 historical maps and aerial photographs from periods of Ottoman and British rule over a century and a half to examine patterns of urbanization, desertification, cultivation, and sedentarization of Bedouin communities in the Negev (in modern southern Israel). This study, through its wealth of cartographic sources, pinpoints the precise location of Bedouin settlements, sometimes down to the level of individual tents. By documenting these settlements over time, the researchers were able to determine the ebbs and flows of nomadic Bedouin land use versus the agricultural settlements in the region. The study determined, in line with textual evidence, that during the Ottoman period Bedouin settlements recede to more marginal lands in the south, likely due to the Ottoman policy encouraging agricultural settlements in part to neutralize the perceived threat of Bedouin banditry. Conversely, during the period of British rule this policy seems to see a slight reverse, as the British largely neglected the region, and had no official policy towards settlement in the area.

Comparative analysis of hundreds of cartographic sources is something that was simply not possible before the advent of GIS systems, yet something that a modern GIS system can do with relative ease and lack of expense. The efficient storage and display of multiple cartographic sources is something that GIS technology excels at and can offer real historical insight with comparatively little investment. However, comparative cartography is not the only function of GIS in history, as discussed in the next section.

GIS Spatial Analyst Techniques

Geographic Information Systems, as we have seen, can produce new sorts of historical information hitherto unavailable to scholars. However, as we have discussed, many of those techniques, due to current lack of strong GIS infrastructure in history are frequently costly and time consuming. Nonetheless, there are hosts of uses for GIS that employ relatively simple methods and preexisting historical datasets that can be used to compliment traditional historical methods. A few of the most interesting of these studies are discussed below.

Ayhan and Cubku (2010) in 'Explaining Historical Urban Development Using the Locations of Mosques: A GIS/Spatial Statistics-Based Approach' use GIS technology to estimate urban growth through the tracing of mosques as a proxy for urban growth using the city of Izmir, in modern Turkey, as a test

case. This sort of analysis allows scholars to potentially go beyond scarce or non-existent census records and reach reasonably accurate estimates of both the extent of urbanized areas and potentially rough estimates of population at different periods over time. Mosques work especially well for this type of analysis because records of their construction, expansion, and demolition are much better documented in the Islamic world than population figures until the last half of the 20th Century.

Using these methods, the authors demonstrate that mosque expansion, did in fact, closely follow known growth patterns in Izmir. To establish this, the study uses a form of spatial analysis of the city's urban growth to establish that mosques were, in fact, equally spatially distributed throughout the city during the three-century study period. This distribution allows for the use of mosque locations as a good approximation of urban growth. Combined with estimates of population density, scholars can use this information to calculate rough estimates of historical population of cities that have hitherto lacked accurate population counts. Importantly, these findings are consistent with the wider archeological and historical scholarly consensus concerning mosques. Mosques were generally the first pieces of urban infrastructure erected during an expansion of urban boundaries throughout most of the history of the Islamic world, with growth occurring in rough concentric patterns around their location. Thus, new mosque construction in urban expansion makes them potentially a valuable indicator of urban growth in areas with large Muslim populations in the medieval and early modern period. This study is a prime example of GIS being used to test and verify the work of scholars using traditional methods while also pioneering a technique that could be used to open new avenues of research.

Another promising use of GIS is in reconstructing the location of abandoned communities. This sort of analysis requires little historical GIS infrastructure and often these features can be located and analyzed with historic topographic maps and the use of simple functions within a GIS. One of the most salient of these analysis is George Towers' (2010) 'Rediscovering Rural Appalachian Communities with Historical GIS'. In this study, Towers attempts to locate historical farming communities that existed the first half of the 20th century in Summers County, West Virginia. These communities largely disappeared in the second half of the 20th century due to large scale urban migration and the growth of an extractive economy based on coal mining.

To find these lost settlements, Towers uses least cost function in ArcGIS on a raster layer created from a 1912 USGS topographic map. According to Towers, the lowest cost function closely approximates the work of ethnographers of the region who have found that the topography closely dictated settlement sites and travel in rugged regions. The author then compares the areas he found to be in easy travel distance to one another with 1910 census data to see if the least cost path function could approximate residential settlement sites and connections to churches and schools (structures that typically functioned as centers of communities) in the county in the early 20th century. After running the least cost path operation, Towers found that the layer generated closely matched the observed settlement patterns in the county using the map and census data. Towers touts this method as a simple way to find historical connections among Appalachian communities, one that could be especially useful in reconstructing sites and settlement patterns in areas which were undercounted by the census (a serious problem in the region during the period being examined). Ultimately, this sort of relatively simple analysis seems like an area where historical GIS can prove immediately valuable in historical scholarship. As, this relatively simple and inexpensive work provides a wealth of new information that compliments traditional ethnography, historical sociology and economic history of the region.

Mixed-methods approaches have also recently been used in studies with a significant GIS component. In "GIS-based Modeling of Drought and Historical Population Change on the Canadian Prairies" (McLeman et al. 2010) the authors create a model to locate hotspots of historic drought activity in the Canadian prairie. The paper has a robust number of figures the model generated showing the primary areas effected by drought in the 1920s and 1930s. The authors use these layers along with census data to demonstrate a strong correlation between the hardest hit by drought and loss of population during the two decades of the study period.

However, this study does not conclude with these GIS results. The researchers, in turn, employ a mix methods approach employing traditional historical methods to further investigate the areas found by the model to have suffered most from the effects of drought and concomitant population loss. The mixed methods approach used in the study is used to both test the quantitative model and pinpoint areas that would be most fruitful for study using traditional historical methods. Thus, both sets of methods employed in equal measure to generate scholarship that would be difficult to achieve using either one exclusively. This is a novel approach. The study is one of the first to go beyond simply exhorting historians using traditional methods to follow-up GIS based work to actively attempting to integrate both approaches in the work.

Problems of Uncertainty

No matter the methods employed, HGIS projects all must deal with problems of uncertainty. Uncertainty is an underlying concern when dealing with any attempt to model geo-spatial data. This problem is even more acute when working with historical data that adds a critical temporal dimension. Uncertainty, in this context is defined as the acknowledgement and considerations of imperfections in data or, as the knowledge that our representations of reality are not precisely the same as reality, and that we must account for that fact. The problem of uncertainty when dealing with geo-historical data, to be clear, is not only temporal but encompasses the full range of geographic modes: space, time and theme. Uncertainty, is not a unique concern to geo-historical data, and dealing with uncertainty is a universal concern when utilizing a geographic information system, or any formal system for that matter.

However, geo-historical data runs into problems associated with uncertainty perhaps more than any other the use of the technology. The reasons for this are manifold. To name just a few: historical data is very often imprecise – ambiguity often exists in location in space and time. Likewise, ascertaining truth claims on pieces of a data set is often not a simple binary process. For example, a source of information can be purposefully or unintentionally incorrect (or correct) about numerous things. Similarly, extant sources, in many cases cannot be assumed to offer fully representative depictions of the thing being studied. Added to these range of uncertainties are limitations inherent in formal systems, such as attempting to convert qualitative data to quantitative or continuous landform data into discrete units (Gregory and Ell 2007). Moreover, various types of uncertainty are often present in even simple data sets, making the problem of precisely delimiting specific categories of uncertainty and methods of dealing with each an important element of any geo-historical research. Also, to reiterate, these types of uncertainties are by no means unique to geo-historical uses of GIS. However, it is the sheer level of uncertainties temporal, spatial, and thematic, that make the topic a rich area of study even for those with no direct interest in application of the technology to historical study (Gregory and Geddes 2014).

Fortunately, there exists a rich literature on uncertainty within GIS to at least attempt to identify and account for various sorts uncertainty. The most influential piece on uncertainty in GIS is Brandon Plewe's 2002 piece 'The Nature of Uncertainty in Historical Geographic Information' wherein the author sketches out the precise types of uncertainties encountered when working with geo-historical data and strategies of dealing with each. These categorizations have become the standard nomenclature for discussing types of uncertainty in historical uses of GIS and is the most referenced work on types of uncertainty within a geo-historical model. A full recount of this work is beyond the scope of this review; however, the following briefly lays out the authors broad categorizations of type and some of the discussion surrounding them.

Plewe (2002) first discusses the uncertainties introduced by the process of conceptualizing real-world entities. The author explains that conceptualization schemes invariably attempt to provide order to the irreducible complexity of real world entities and impose an order that is not fully present in the real world. The author proceeds to classify conceptual entities into two broad types. The first type are fiat entities. These entities are created by humans to administer sets of rules generally associated with administrative structures such legal systems. Things such as borders and census districts fall into this

category. The second type of entities are termed motivated entities. These entities form a much larger category than fiat entities. They are created when large scale phenomena are simplified by process of aggregation, categorization, et cetera. Objects such as mountain ranges, oceans, and human cultures would count as motivated entities. Unlike fiat entities, motivated entities have no official or easily determined boundaries, although often social convention or common knowledge at a time and place can provide relative boundaries. However, changes over time and differing individual opinions make these entities often impossible to define with certainty. Within these two broad categorizations, there are various subcategories, most acutely among motivated entities. However, the particulars of these subcategories are beyond the scope of this summary. Although, it is important to note that most types of uncertainty in geo-historical research arise among motivated entities and are caused by the ambiguities inherent in them.

Even more abstract is Couclelis' 'The Certainty of Uncertainty: GIS and the Limits of Geographic Knowledge'. (2003) Couclelis makes the distinction between information processing systems than can convert information into knowledge and systems which cannot. In the author's estimation, GIS systems are part of the latter and only humans the former. This is not a trivial distinction; GIS outputs certain kinds of information products, but the only way to graduate this information to valid knowledge (currently) is to have these outputs interpreted by humans. Couclelis goes on to explain that the two modes of geospatial knowledge production: data-driven and method-driven, have significant and often intractable limitations. Couclelis emphasizes that these limitations arise not just from the accuracy of the constituent data, but as an inherent property of these systems of knowledge production.

The data-driven method, per the author, is a form of abductive reasoning, commonly used in model production. This form of reasoning attempts to find an optimal solution for a given set of data. However, scholarship applying formal analysis to problems of abductive reasoning suggests that finding a single optimal model for non-trivial data is an intractable problem, and in most cases, adding variables only make the problem more abstruse. The method-driven model of knowledge production, deductive reasoning, stands on more solid ground, but even it can suffer from problems with heuristic adequacy⁴. Essentially, information from different sources can create dramatically different information sets. Likewise, models created from these sets, even if all the data was collected with similar tolerance for error or in the same fashion is liable to magnify these initial errors in ways unanticipated by the researcher.

⁴ Couclelis defines heuristic adequacy in narrow terms – the ability of inferential procedures to arrive at the desired conclusions.

Data and Methods



Figure 2. Map of the stations and rail line created for the project.

Stations

This project is built upon the 40 train station locations that made up the A Line in approximately 1910. These station locations make up the backbone of the project. All other classes of data used in the project are associated with these station locations. Which except in one case, correspond to organized municipalities recorded in the 1910 Mexican Census. All stations appeared, on passenger schedules at some point between 1898 and 1910. The stations are entered in the GIS as close to actual location station as possible, and thereby connected to a precise geographic location. They act as the basic geographic units from which analysis can be conducted. Likewise, as they are the points that connect the track locations, the stations act as points on a nodal network from which various types of network analysis can be conducted.

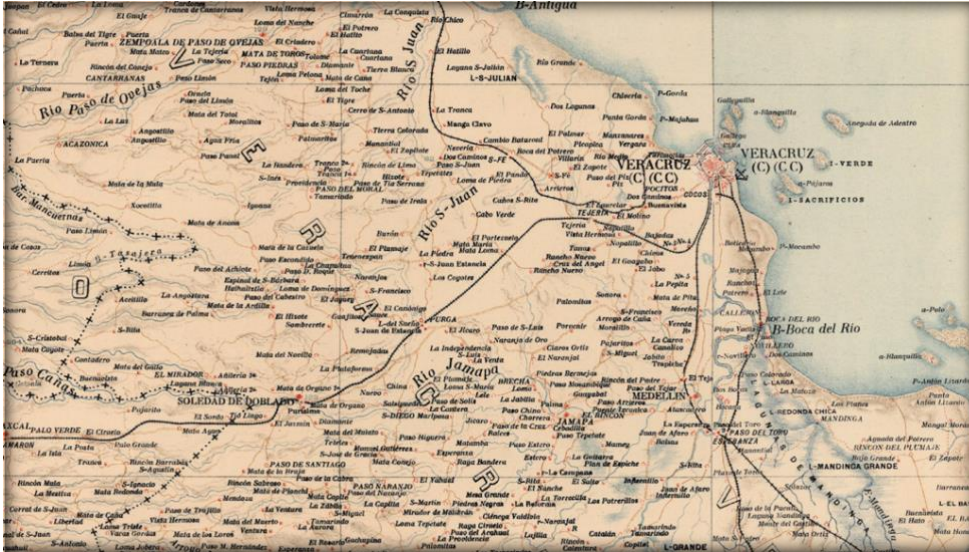


Figure 3. Portion of a map of Veracruz published in 1905 used to locate stations and track position⁵.

Sources

Modern railway maps, even those digitized, are of little use to understanding how an early 20th Century railroad operated. For instance, modern highways took over much of the passenger traffic of railway systems and therefore they have far fewer station stops than at the beginning of the 20th Century. This has led to a marked reduction in the number of operating stations. So, for example, the A line of this study uses roughly a third of the stations it did in 1910. Consequently, the dramatic reduction in stations make modern maps of limited use in understanding how railroads operated more than a century ago. To reconstruct railroad operations of a century ago, period maps and train schedules must be consulted.

The historical station list was constructed using two types of primary sources, railroad maps, and train schedules. The most important source materials were digitized historical maps from approximately 1880 to 1915. In total, approximately 50 high resolution digitized maps from the period of the study were imported into a GIS. After georeferencing, the maps were transposed over one another. Next a rough sketch was created of the route during the period. With this sketch, along with maps created around 1910 and train schedules and travel guides, a station list was created of stations active during the early 20th Century. These sketches and the primary source material were also used to locate historical track locations a process explained in more detail in the next section.

⁵ Image adapted from Comision Geografico Exploradora. 1905. "Carte General del Estado de Veracruz." Composite Map. Comision Geografico Exploradora. David Rumsey Map Collection. http://www.davidrumsey.com/luna/servlet/detail/RUMSEY~8~1~274195~90047968:Composite-Map--Carte-GeneraldelEs?sort=Pub_List_No_InitialSort%2CPub_Date%2CPub_List_No%2CSeries_No&qvq=w4s:/where%2FVeracruz%2B%252528Mexico%252529;q:veracruz;sort:Pub_List_No_InitialSort%2CPub_Date%2CPub_List_No%2CSeries_No;lc:RUMSEY~8~1&mi=23&trs=24.

Identifying Stations

MAIN LINE.									
August 1, 1905.									
LEAVE	ARRIVE	Kilos	2	6	4	8			
+	Mexico	424	715	8 30	10 45			
.....	San Cristobal	401	6 43	8 00	10 13			
.....	Tepexpam	391	6 30	7 47	10 00			
.....	San Juan-Teotihuacan	379	6 15	7 30	9 45			
.....	Otumba	368	6 02	7 17	9 33			
.....	La Palma	362	5 54	7 09	9 25			
.....	Ometusco	356	5 46	7 01	9 17			
.....	Irolo	346	5 30	6 46	9 03			
.....	Apam	331	5 11	6 27	8 46			
.....	Soztepec	314	4 47	6 03	8 24			
.....	Guaialupe	300	4 25	5 41	8 07			
arr.	Apizaco	285	4 00	5 20	7 45			
lve.	Apizaco	285	3 50	5 10	7 35			
.....	Huamantla	259	3 20	4 39	7 00			
.....	San Marcos	242	2 59	4 18	6 43			
.....	Rinconada	223	2 34	3 53	6 18			
.....	San Andres	203	2 08	3 29	5 54			
arr.	Esperanza	179	1 40	3 00	5 25			
lve.	Esperanza	179	1 15	2 48	5 17			
.....	Boca del Monte	174	1 02	2 38	5 17			
.....	Alta Luz	166	12 27	2 00	5 17			
.....	Maltrata	154	11 38	1 08	5 17			
.....	Nogales	140	10 59	12 27	5 17			
arr.	+	Orizaba	133	10 45	12 16	5 17			
lve.	Orizaba	133	10 35	12 06	5 17			
.....	Fortin	114	9 58	11 25	6 10			
+	Cordoba	106	9 37	11 06	6 45			
.....	Penuela	102	9 17	10 48	6 29			
.....	Paraje Nuevo	98	0 08	10 38	6 17			
.....	Atoyac	87	8 48	10 18	4 55			
.....	Paso del Macho	77	8 28	9 58	4 30			
.....	Camaron	64	8 05	9 35	4 02			
.....	Soledad	43	7 34	9 05	3 20			
.....	La Purga	31	7 15	8 46	2 55			
.....	Tejisman	16	6 51	8 24	2 30			
+	Vera Cruz	0	6 25	8 00	2 00			
ARRIVE	[LEAVE]								

MARLBOROUGH R. PRYOR, Chairman, London, Eng.									
WALTER MORCOM, General Manager, City of Mexico, Mex.									
C. F. MELLICK, General Freight and Passenger Agent, "									
E. F. HUNDLEY, Asst. Gen. Fht. and Pas. Agt., "									
G. W. KERSE, Resident Auditor, "									
C. G. H. GILLE, Chief Accountant, "									
M. ZENDEJAS, Car Accountant, "									
THOMAS A. CORRY, Superintendent of Permanent Way, "									
E. M. WISE, Superintendent, Orizaba, Mex.									
W. COCKFIELD, Locomotive Superintendent, "									
H. P. GALLAGHER, General Baggage Agent and Supt. of Express, City of Mexico, Mex.									
J. A. MARTINEZ, Commercial Agent, Vera Cruz, Mex.									
R. M. MONDRAGON, Gen. Agt., Calle de Gante No. 8, City of Mexico, Mex.									
F. A. FULWILER, Gen. Eastern Agent, 29 Broadway, New York.									
H. C. GLENN, Customs Agent, Vera Cruz, Mex.									
CARLOS E. RAMIREZ, Commercial Agent, City of Mexico, Mex.									
J. R. McDONOUGH, Commercial Agent, "									
J. R. HARDY, Storekeeper, "									
LUIS MAYORA, Trav. Freight and Pas. Agent, Puebla, Mex.									

PUEBLA BRANCH.											
3	19	21	23	Mis	STATIONS.						
P M	P M	A M	A M		LEAVE	ARRIVE	Kilos	4	20	22	24
*720	*415	*1050	*535	0	.....	.....	47	7 40	10 00	3 50	11 55
7 38	4 40	11 15	5 58	7	.....	.....	36	7 18	9 30	3 00	11 10
7 47	5 00	11 35	6 10	11	.....	.....	30	7 06	9 15	2 45	10 55
8 10	5 40	12 30	6 41	22	.....	.....	12	6 41	8 40	2 10	10 20
8 25	6 00	12 30	7 00	29	.....	.....	0	*6 25	*8 15	*1 45	*10 00
P M	P M	Neen	A M		ARRIVE	[LEAVE]					

PACHUCA BRANCH.										
No. 34	No. 32	Mis	STATIONS.							
*6 00 P M	*9 45 A M	0	lve.	Ometusco	arr.	Kilos	No. 31	No. 33		
6 20	9 45	7	.....	.....	.....	46	8 30	A M	5 10 P M
6 35	10 00	11	.....	.....	.....	35	8 18	"	4 55 "
7 10	10 35	22	.....	.....	.....	28	7 55	"	4 40 "
7 30	10 55	28	arr.	.....	.....	10	7 15	"	4 00 "
			.....	.....	.....	0	*7 00	A M	*3 45 P M

Connections.—At Cordoba—With Vera Cruz and Pacific R.R. At Mexico—With Mex. Cent. Ry. and Nat. R.R. of Mex. At Puebla—With Mex. So. Ry. At Pachuca—With Mex. Cent. Ry. At Vera Cruz—With trans-Atlantic steamers and steamers for United States, West Indies, etc.

Figure 4. Passenger Train Schedule of the line from 1905⁶.

The next step was to identify all the stations active during 1910, the target date for the project. As discussed in the prior section, many maps exist at reasonable scales for this project from the 1880s until shortly before the revolution. However, rail lines and stations are not static things, and as such station numbers fluctuated throughout the period. To be certain that each station in the database existed in 1910, passenger schedules and maps from the circa 1910 were cross referenced. All stations that are recorded in the database appear in two or more of these sources within a few years before or after 1910. This method of course does not preclude the event of a station opening and then closing and then reopening, but beyond this unlikely scenario this method establishes with reasonable certainty what stations were operating during the target year of 1910.

At the beginning of the project, name changes were not considered as a potential issue, implicitly working from a North American model where name changes were rare after the middle of the 19th Century. However, it quickly became apparent that numerous place names on modern and the historical maps differed. Most cases were easy to rectify as they were in the same locations and often it was possible to locate pictures of historic stations with signs that identified them by their older name. However, for stations with that existed only a few kilometers apart, the process was more difficult. Often these stations had served what at the time construction were independent villages that had in grown together into urban amalgamations. Many had undergone name changes or older station name had fallen

⁶ Table is from page 1,169 Allen, W.F., and E.S. Allen, eds. 1909. *The Official Guide to Railways and Steam Navigation Lines of the United States, Porto Rico, Canada, Mexico, Cuba, and Central America*. Vol. 8. 41. New York, New York: The National Railway Publication Company.

<https://books.google.com/books?id=4D8GBxGnDnYC&printsec=frontcover&dq=the+official+railway+guide&hl=en&sa=X&ved=0ahUKEwje2u2zvMzUahWI7CYKHQX0As4Q6AEIKDAA#v=onepage&q=the%20official%20railway%20guide&f=false>

out of use in place of a directional designation of an encroaching city. Properly identifying these stations with their historical names took some time. However, all are properly identified in the database by both the current place name and their historic station name.

Locating Stations

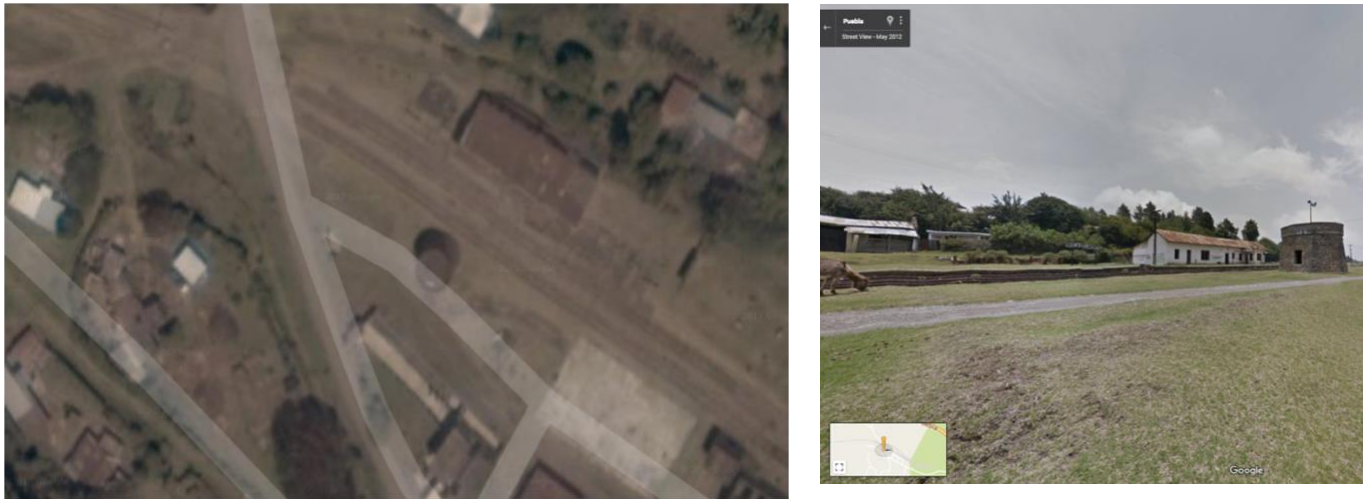


Figure 5. Satellite imagery (left) and Google Street View (right) of same location. The white building is the rail station of Esperanza. The circular building is a water tower used to cool steam engines.

After sketching out likely historic station locations, the process of locating them via satellite imagery began. Google Maps satellite imagery overlaid with the rough vector outline in QGIS was principally used in this process. After locating a potential train station via satellite image, the location was verified via Google Street View if possible. If locating a satisfactory view of the potential station using Street View was not possible, geotagged user submitted photographs were consulted. Conveniently, Google Maps has integrated a gallery of proximate geotagged photos into the Google Maps interface. These photo collections, often taken by tourists, are primarily made up of prominent local buildings and frequently include the local railroad station.

For those stations that could not be located view geotagged imagery, the location process involved following the railroad tracks and looking for particular building shapes near railroad tracks. All the stations except a few larger urban ones were of a similar rectangular shape and size. They also had similar roofs, slanted red tile roofs in the Veracruz's lush lowlands and flat abode roofs in the highlands of Puebla. And of course, they were oriented towards and located next to railroad track. Fortunately, buildings with non-metal roofs stood in most of the smaller towns and villages making the locating process easier in most of the less populated areas.

This method had worked well on the prior project. However, these initial stations locations were not representative of all the stations on the line. In that project, the stations were all in heavily populated areas that had significant modern rail traffic, were using the same names, and operating on the same track configurations as stations in 1910. Unfortunately, this was not true for a large portion of the stations on the route as documented in the following.

Locating the precise historical station locations, as opposed to say a point on the track near the city center, unsurprisingly improves accuracy. However, adopting a procedure focused on finding actual historical structures is not without its drawbacks. First the station must still exist. Perhaps, surprisingly

most still do. They tend to be well constructed of stone and brick with tile roofs and some portion of them is still standing even if they are in disrepair. The areas where older stations no longer exist were nearly exclusively in urban areas where smaller stations were torn down to make room for larger modern accommodations. In these cases, the new stations were built on top of the old or there is ample documentation of where the old station was located. As such, the problems caused by defunct stations buildings are minor.

The most difficult area for station location was the areas around Cordoba, Veracruz. Seemingly, every issue that made the complicated the process of station location was present in this area. First, the area is in the lowlands of Veracruz --primarily verdant lowland rainforest. Vegetation blocks buildings and high reflectance values of plant life makes it more difficult to get clear images. Multiple additional spur lines originate from the area and have stations of their own unconnected to this project, additionally the modern track configuration only partially follows the track configuration at the beginning of the 20th Century. This unused track is sometimes visible in satellite imagery, making it difficult to follow. Likewise, some of this unused track is part of rail lines unconnected to this project. These factors make it easy to confound unrelated stations that were not a part of the A Line with stations along the line.

These issues are compounded by the fact that this area has the highest station density on the entire line, with stations located every few kilometers. Additionally, these stations are named after the village or town they were located nearest to at the time of the railroads construction in the 1880s. However, since that time much of the urbanized areas have grown closer together making individual villages and towns unidentifiable via satellite imagery. To disentangle all of this, and locate the names of the stations the project was forced to revert to the historical map overlays in the GIS, instead of the much less computationally intensive vector sketches. Through a painstaking process of comparing the most detailed maps of the region older village units and track configurations were defined to narrow the search for each station. Eventually, all but, a few of the stations were located. However, several stations locations remain uncertain, with one likely having been destroyed at some point. The location of this station, was entered along the track that was closest to maps from the period. The probable location of the other station has been located. However, no imagery from the ground has been found to independently corroborate the location. The location of that building is used as the location within the database, with a note on the uncertain location.

Track

After the station locations were documented track connecting the stations was added. It is possible to reverse these steps. This method was selected so station locations could function as *de facto* ground truth points. Much of the process of representing the track in GIS was simple. For the bulk of the rail line, I traced the existing track lines on a satellite map and converted the lines into vector data. However, the active rail line does not entirely follow the path of the 1910 line. Several large bridges have been constructed in the state of Veracruz over a series of wetlands and rivers between the cities of Veracruz and Cordoba. These bridges bypass sections of the original route that winded along the river until a suitable location for a modes bridge was found. Secondly, a major section of the track on the border of the states of Veracruz and Puebla has been completely rerouted. This former section track ran through the mountains from Maltrata, Veracruz to the village of Esperanza in the state of Puebla. The abandoned track was approximately 40 kilometers long and contained four stations and had to be recreated in their entirety.

Creating vector data files representing track location in areas without currently maintained track was a more difficult process. To map the track first the approximate route of the line in the past had to be established. This was established by employing the same georectified map data used to identify station locations. Next after consulting the map data, indications of the abandoned track upon the topography were located. Sometimes this was a simple process. A large portion of the track still exists, and although at places overgrown with vegetation, it remains visible enough from space to recreate it with a high

degree of accuracy. However, some portions of the former track have been since converted into surface streets most notably in the city of Maltrata, luckily this winding street connects directly with the defunct line and is named “Ferrocarriil Mexicano” giving clear indications of its origins. This pattern was repeated across numerous small towns and villages along the line. Luckily, the serpentine structure of railroad tracks was often clearly visible along the street grids, and as in Maltrata the street names often give away their origins as rail corridors.

Historical GIS Database

After identifying station locations and adding track connecting them, a map of the A Line was sketched in a GIS as it appeared in 1910. However, for the project to go beyond historical cartography, data must be associated with cartographic objects. Data capable of being used in this project must meet two broad criteria. First it must be from as close to the idealized period, 1910, as possible. Secondly, the data must make sense when organized by geographic categories present on the map. So, for instance, states, municipalities, station locations, or track segments be coherent organizational categories for any data used.

Stations were used as the primary organization point for the data collected, chiefly because stations could be useful in organizing data about train schedules, and serve as reasonably accurate proxies for the municipalities in which they were located. Using station locations as the primary organizational unit is not without its problems however. The choice to use station locations as stand-ins for larger more complex geographic entities is itself limiting. First, because stations locations do not always correspond with their service areas. Secondly, and directly related to the first point is that using stations as proxies for larger geographic entities can be problematic due to their loose connection both organizationally and conceptually to the data. Caution must be used in including data from the stations larger geographic designator. These sorts of limitations are omnipresent when developing databases of this sort. As such, using another set of organizational principles would have led to its own sets of limitations or require much more data than was warranted for the needs of the project. The creation of effective historical GIS databases and models are predicated upon understanding these tradeoffs and choosing appropriate scalar entities that can represent the data effectively within those restraints of time and place.

Municipal population data from the 1910 Mexican Census, train schedule data from approximately 1905, and elevation data were included -- information that could be used to calculate track grade. This is a small number of categories, but could easily be expanded depending on data located and the needs of future researchers. Ultimately, the goal of the database was to be as simple and interoperable as possible, allowing researchers to expand on the basic framework as needed.

Future Work and Conclusions

The project began as an exploration of technologies and concepts, as such, it did not have definite final product in mind. This approach afforded a lot of freedom. Nonetheless, as documented, the project was influenced by a series of initial decisions in data collection, methods and procedure that frequently had larger implications than were initially anticipated. Having a fixed idea of a testable hypothesis before beginning a project is of course less time consuming. Likewise, the project ran head-on into the problems of uncertainty inherent when attempting to adapt formal systems like GIS to a world that is much messier.

Currently none of the track data, composed of a series of vector files, has any data associated with it besides locational data. The current lack of a data associated with track information is not based on any technical or philosophical issues. Instead, constrained by time, data was collected that could be associated with stations, as it was more easily accessible, and more representative of the database categorizations. Associating data with track location is less ideal for most demographic and economic data, the information the current database contains. However, data associated with track can be used for to establish travel times and conditions between station data.

The data sources that work well with track locations can create complex and potentially historically interesting models. With elevation and accurate travel data, two things that the database already contain, models can be rebuilt to estimate things such as military reaction times to rebel attacks during the Revolution or even more mundane things such as mail delivery times. As some of this data is already recorded in the database, it just needs to be categorized and organized in a format more suitable for queries relating to transportation times. With the addition of major arterial roads that intersect with the rail road tracks, models could be created with minimal effort that can potential recreate the military constraints the Mexican Central government faced during the height of the revolution in this region lasting from approximately 1912 to 1916⁷.

Notes on Project Creep

The free form beginning of this project was an asset in that it allowed the author to experiment with a variety of approaches. As such the author worked on acquiring and classifying data for several months without any solid organizational principles. This lack of a strong definition as to what the final project data requirements allowed for creativity in discovering and integrating sources material in to the project. However, it also allowed project creep, a process where the need for data, accuracy and scope expand beyond any purposeful need and become time consuming and burdensome ends in themselves. Accuracy morphs into a goal not an assessment tool, as acquiring more data becomes a drive that can only improve accuracy with the scope naturally ballooning as data proliferates. This system of circular bloat did not go unnoticed. In fact, this sort of creep occurs precisely because the project lacks definite end goals and thereby the need to locate what granularity of data was “good enough”. The lesson here is that it is a good idea for more directed projects to create a smaller version of the project – a prototype – to judge what the needs of accuracy and data along with a proper scope.

Final Words

The project was created in the matter of a few months with no prior knowledge of the subject area or source availability. In that time, a digital map of the route of an important historical railroad line was created that precisely located all passenger stations along with all major bridges and tunnels. Likewise, enough freely available data online about each of these stations was collected to create a small historical database with a variety of data entered for each station, including population figures and scheduled arrival and departure times for all stations in the early 20th Century. Encouragingly, considerably more data was located that could potentially be used in more expansive database of the rail line -- data omitted from the present database due to time and method constraints.

Overall, this study demonstrates that concerns about data availability for HGIS projects, at least those based in the well-documented areas of the last century, are overblown. While the data may not be the same as those currently utilized in historical scholarship there are rich alternative spatio-historical

⁷ As early as 1920 scholars theorized that the Mexican army was incapable of operating effectively outside of a narrow zone close to rail lines, severely limiting its ability to contain rebels. Using this database and the additional track data discussed this becomes a testable hypothesis. See A.W. Donly 1920. “The Railroad Situation in Mexico.” *The Journal of International Relations* 11 (2): 234. doi:10.2307/29738399.

datasets available many associated with recent advances in modern consumer information technology, such as Google Maps. These tools have been become viable research tools over past decade. All that remains are for scholars in geography and history to set aside skepticism of the technology and realize the current potential of geo-spatial tools combined with the voluminous free data sets currently available online.

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Vita

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