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Tracy Whelen

June 30, 2014

ABSTRACT

Increased interest in rail transportation, and specifically high-speed rail, has led to research on how can people and goods be transported more efficiently by the United States rail system. Rail is an important form of transport because, not only does it release far fewer pollutants per ton-mile than road or air transport (WSDOT, 2009, Exhibit 2-2), but it is also over 20 times safer than driving (SSO, 2009, p. 15). Currently, the United States rail system lags far behind high-speed rail systems in Europe and Asia, and is only in the earliest of stages of planning and building (USDOT FRA, 2009, p. 7). A handful of megaregion corridors around the country have been noted as potential sites for future high-speed rail, but they still have significant infrastructure challenges to overcome before speeds of over 120 mph can be reached. Current methods of identifying choke points areas consist of rail traffic algorithms and shareholder interviews, leaving the opportunity for additional forms of analysis.

My thesis research uses GIS as a novel way to spatially examine railroad infrastructure-related choke points, with my project focusing on the track between Portland, OR and Vancouver, BC. I studied how passenger speed limits compared with the location of bridges, tunnels, crossings, curves, incline, rail, ties, and stations. My data consisted of a collection of a geodatabase, track charts, a timetable, and shapefiles, the data from which I combined and reorganized into a geodatabase. As railroads use a linear referencing system similar to highways, I was able to use vector reselectment and dynamic

segmentation to analyze the various infrastructure components. My analysis consisted of comparing the speed limit layer with each of the different infrastructure component layers.

From my analysis I found twenty-nine slow sections with speeds below 60 mph and determined that the most problematic infrastructure components were curves, populated areas, bridges, and tunnels. GIS was able to identify infrastructure-related choke points, which show similar patterns to choke points identified by traditional methods. Using GIS allows for more thorough choke point analysis than can be achieved by previous methods. Identification of infrastructure-related choke points is the first step towards improving infrastructure in the development of higher-speed rail.

Identifying Infrastructure Impediments to Higher-Speed Rail in the Cascadia Megaregion Using GIS Analysis

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April 2014

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LIST OF ABBREVIATIONS

DOT – Department of Transportation
GIS – Geographic Information Systems
I-5 – Interstate 5
USDOT – United States Department of Transportation
WSDOT – Washington State Department of Transportation

INTRODUCTION

Importance of high-speed rail

Rail transportation, and in particular high-speed rail, is becoming increasingly important in the United States. Rail has benefits over road and air travel when comparing environmental impacts, speed, traffic congestion, and safety. It is also far more energy efficient and less polluting than either motor vehicles or airplanes, releasing far fewer greenhouse gases per ton-mile for pollutants including, carbon dioxide, nitrogen oxide, particulate matter, carbon monoxide, and sulfur dioxide (WSDOT, 2009, Exhibit 2-2). The difference in pollution amounts between transportation modes is important because more than half of all greenhouse gas emissions in Washington and Oregon are due to transportation. Along the Cascadia corridor a train with 56 passengers breaks even with single passenger vehicles for pollution per person. This is a significant pollution reduction considering that the Amtrak Cascades train averages over 100 passengers per Seattle to Portland trip (America 2050, 2010, p. 7).

Another benefit of rail is that it is a significantly safer form of transportation than driving. From 2003-2008 in the United States the passenger fatality rates per 100 million passenger miles traveled were 0.03 for Amtrak and 0.06 for commuter rail, as compared to 1.42 for motor vehicles (SSO, 2009, p. 15). These rates show that a passenger is over 20 times more likely to be killed riding in a motor vehicle than they are while riding in a train.

In densely populated areas with heavy road traffic, improving rail networks is additionally beneficial by lessening the number of vehicles on the road and by lessening airport congestion (America 2050, 2009, p. 5). In France, when the TGV high-speed rail line from Paris to Lyon was established in the 1980s, the total number of rail passengers along the corridor went from 12.5 million in 1980 to 22.9 million in 1992. Most of this increase was in the first five years. Correspondingly, Paris-Lyon air traffic halved between 1980 and 1985, and the parallel A6 motorway grew at about one-third the rate of similar motorways. Some of the increase of passengers was due to entirely new trips. Similar patterns of traffic diversion have been seen along high-speed rail corridors in Germany and Spain, with slightly lower rates of diversion in Germany being attributed to its patchier implementation of rail improvements (Vickerman, 1997, p. 24, 29). Lessening airport congestion is important considering that short haul flights of less than 600 miles can consist of some of the largest flight markets. For example, the three main stations along the Northeast Corridor for rail are Boston, New York City, and Washington. Flights between those three cities alone are the three largest regional air markets in the Northeast, consisting of over 3.2 million passengers per year. When considering that New York City (JFK, LaGuardia, and Newark airports), Boston, and Washington Dulles are respectively the 1st, 2nd, 3rd, 7th, and 9th most congested airports in the nation, the importance and value of high speed rail increases significantly if one has the goal of transporting passengers as efficiently as possible (America 2050, January 2011, p. 17). Diversion of air traffic to high-speed rail is particularly effective when high-speed rail services are offered at large hub airports, allowing for fast and seamless transfers between transportation modes (Givoni, 2006).

The result of the many variables, including time, cost, traffic, and safety, that go into determining the best type of transportation for a given market is that rail is competitive with both motor vehicles and air travel for distances of 100-600 miles (USDOT FRA, 2009, Figure 1). High-speed rail works best when connecting large cities within the 100-600 mile range, whereas automobiles and buses are better for shorter trips, and air has the advantage for distances over 600 miles (America 2050, 2011, p. 10).

State of high-speed rail in the United States

Although there is no single definition of high-speed rail (HSR), the general consensus is that the rolling stock and infrastructure must be capable of operating at normal speeds of at least 200 km/h (124 mph). Many rail systems in Europe and Asia are designed for speeds of over 300 km/h (186 mph) (UIC, April 2013). Japan, France, Spain, and China have some of the fastest and most expansive systems, which respectively first opened their systems in 1964, 1981, 1992, and 2003. Currently, twenty-three countries including the United States have plans for future high-speed rail, and fifteen of them already have some form of high or higher-speed rail in operation (UIC, November 2013).

While speeds of 300 km/h may be a goal for many countries, it has been recognized that in many regions even speeds of 200 km/h would be a significant improvement over the existing system (UIC, April 2013). This in-between speed range has been described by various terms including “emerging rail” or “higher-speed rail”. The United States is a prime example of planning for a variety of stages of higher-speed rail, with “Emerging Rail” at maximum speeds of 90-110 mph, “Regional HSR” at 110-150 mph, and “Express HSR” at over 150 mph, as defined in parts of the American Recovery and Reinvestment Act of 2008. In contrast, traditional rail lines in the United States run at less than 90 mph, and most of them have a top speed of only 79 mph (USDOT FRA, 2009, p. 2). Currently, in the United

States the only rail line classifiable as high or higher-speed rail is the Amtrak Acela, running between Boston and Washington D.C., which can reach speeds of up to 240 km/h (149 mph) (UIC, November 2013, p. 12).

Legislation during the Obama administration has put in place plans to increase the amount of high and higher-speed rail in the United States, both by improving existing corridors and by building new lines dedicated to high-speed rail. Current plans consist of improving rail lines along the Northeast Corridor (consisting of Boston to Washington, D.C.) and the Seattle-Portland, Chicago-St. Louis, Chicago-Detroit, and Charlotte-Washington, D.C. corridors. The only new line slated to be built will run from Los Angeles to the San Francisco Bay Area. These projects and others continue to face challenges with funding and political opposition (Peterman et al, 2013, p. 1). Concerns have been raised in the United States and elsewhere in the world whether the potential time benefits of high-speed rail outweigh the costs of construction, maintenance, and wider social and economic effects. De Rus and Nombela point out that these costs are project specific and hard to generalize, so a high-speed rail line that might be profitable in one area may not be worth building in a different area (De Rus and Nombela, 2007, p. 20-21). Due to the challenges faced by high-speed rail in the United States, this thesis focuses on implementation of higher-speed rail as a first step towards improving the United States' rail system.

What is the Cascadia Megaregion and why should it have higher-speed rail?

The Cascadia Megaregion is a population corridor based around Portland, OR, Seattle, WA, and Vancouver, BC. This distinct region spans two states (Washington and Oregon), a province (British Columbia), and an international border (USA/Canada)

(America 2050, 2005, p. 1), as can be seen in Figure 1. Cascadia shares many traits, including climate, political attitudes, similar economies and industries, an appreciation of the environment and livability, and Pacific-oriented internationalism. With these shared traits come the shared challenges of managing increasing population growth and the transportation of goods and people within the region (Discovery Institute, 1994).

Cascadia has the population and interconnectedness to make it a viable location for future higher-speed rail. Consisting of medium sized metropolitan areas Portland and Seattle and slightly larger Vancouver, BC, Cascadia lacks a single dominant center. However Seattle and Portland are more compact than many other metropolitan regions in the United States and have larger than normal central business districts, allowing a large portion of population and jobs to be reached from a single central station (America 2050, January 2011, p. 44). Beginning in the 1970s, land use policies for the Portland Metro area have encouraged urbanization of the city rather than suburban sprawl that takes over surrounding agricultural and forest lands (Metro, 2000, p. 2). Dense cities with dominant urban cores tend to work better than dispersed cities for achieving high average speeds along a rail line because they allow for fewer stations with more distance at high speeds in between the stations (Givoni, 2006). The entire region, including smaller cities along the corridor, is predicted to grow by roughly 40% between 2010-2050, continuing steady growth patterns that began prior to the 1990's. There is already a strong travel demand within Cascadia. Between Portland and Seattle nearly 50 percent of Interstate 5 (I-5) operates at above 75 percent of design capacity during peak hours (America 2050, January 2011, p. 44, 47). In 2012, Portland, OR and Vancouver, BC were two of the top destinations for planes departing from Seattle-Tacoma International Airport (Sea-Tac).

Figure 1. Cascadia Megaregion and Environs. This figure shows the population corridor of Vancouver, BC in the north, Seattle, WA at the center, and Portland, OR to the south, that forms the foundation of the Cascadia Megaregion (America 2050, 2010).

Portland, OR had 10,387 departures, and Vancouver, BC had 4,207 departures. These two destinations accounted for nearly 10% of all departures from Sea-Tac, not including other frequent destinations within the greater Pacific Northwest such as Spokane, WA or Victoria, BC (Port of Seattle, 2012, p. 10-11). If some of these passengers shifted from flying to rail travel, the airports would have room for more long distance flights. Rail ridership has increased steadily and significantly since intercity rail began between Vancouver, BC and Portland, OR in the mid-1990s, jumping from 180,000 passengers in 1994 to 836,000 in 2012, with increases expected to continue. As a result, the Washington and Oregon Departments of Transportation have begun to plan and invest in future higher-speed rail, starting with incremental improvements along the existing track (WSDOT, 2013, p. 66, 70).

Importance of infrastructure

Train speed limits are due to a combination of factors, but are mostly based around safety concerns. While the engine may be capable of producing higher speeds, infrastructure components such tight curves may require slower speeds so that the train does not tip over or otherwise derail. Additionally federal laws require safety precautions for signaling and crossings. Automatic cab signals, automatic train stop, or automatic train control must be installed for any passenger train to be permitted to go over 79 mph (McDonald, 1993, p. 18). Federal Rail Administration (FRA) safety principles for grade crossings are that for speeds of 80-110 mph the most sophisticated warning or traffic control devices suitable for the location should be installed. At speeds of 110-125 mph, approved barrier systems are required for any grade crossing, and at speeds above 125 mph grade crossings are completely prohibited (Gilleran, 2011, slides 6-8).

Choke points are specific physical locations along the rail system at which there is recurring congestion, and train delays are currently experienced or are anticipated in the near future (Ohio Rail, 2010, p. 5). Most of the rail lines in the Cascadia corridor were originally built over 100 years ago, leaving this corridor with a number of infrastructure challenges, including many grade crossings, old and undersized bridges and tunnels, and tight curves along shorelines. These challenges combined with the current level of passenger and freight service mean that infrastructure improvements must be made if speeds or service are going to be increased (WSDOT, 2006, Chapter 5 p. 4-5).

Existing methods for studying choke points

Currently, choke points are identified by operations analysis, as well as through outreach and interviews with stakeholders such as railways and local planning agencies. Operations analysis consists of computer modeling programs that allow analysts to add more and more trains to a given route under varying dispatch conditions, such as changing the train speed, length, or priority. The main modeling program used by BNSF Railway and Union Pacific Railroad is known as the Rail Traffic Controller (RTC) Model. RTC simulates dispatch decisions made to send trains through a network that includes track lengths, speeds, signals, and switches. Algorithms are used to resolve dispatching conflicts, although operator input is also allowed. The model also tracks the progress of trains in order to gather information on sources of train delay (I-5 Trade and Transportation Partnership, 2003, Chapter 1). This data is combined with input from a variety of stakeholders, and negotiations are held until a final plan for improvements has been determined (WSDOT, 2006, Chapter 5 p. 1-2).

Potential of GIS for rail analysis

Geographic information systems (GIS), is where mapping and computer technologies join together. It allows for the visualization and manipulation of multiple layers and types of data that all relate to a single project. Spatial data is stored in GIS files as point, polyline, or polygon features when part of a vector-based system, or in a grid system when being stored as a raster system. My project was completely vector-based, and used only point and polyline features. The track is an example of a polyline feature, whereas a station is an example of a point feature. The industry standard vector GIS software that I used was ArcGIS. GIS is already in use by the rail and transportation planning industries, which use it both for storing infrastructure data, as well as for analyzing existing population statistics when planning potential high-speed rail lines (Mischke, 2011 and America 2050, January 2011, p. 4). GIS has the potential to be a useful additional form of choke point analysis because it enables the user to see the geographic spatial patterns of the track and infrastructure components, unrelated to the timing or number of trains along the route. This provides an additional analysis perspective when studying potential choke points, which could be particularly useful when studying rail lines that are currently underutilized but slated for increasing traffic.

Thesis outline

Following this introduction into the relevancy of high-speed rail, the Cascadia Megaregion, choke points, and GIS in the first section, I will next focus on the main questions and purpose of this thesis in the second section. This project is based around the use of GIS as a potential method for analyzing choke points. In the third section I will discuss my methods of data collection and data organization, including my combination of multiple data sources and coloration of each layer prior to analysis. I also explain my methods of GIS analysis, including linear referencing and dynamic segmentation. After that, in the fourth section I will examine the results of my analysis. This section includes the locations of track with reduced speed limits and the relationship of the different infrastructure components with each of the areas with reduced speeds. In the following fifth section comes the discussion of these results, including the categorization of different types of choke point locations, potential choke point solutions, and the correlation between these solutions and ongoing improvements along the route. Finally, I conclude with a summation of knowledge gained from this project, both regarding this specific region and the use of GIS as an analysis tool, as well as suggestions for further research.

QUESTIONS AND STATEMENT OF PURPOSE

The main research question of this project is: “Which portions of rail infrastructure between Portland, OR and Vancouver, BC are limiting rail speed?” with the follow up question of: “How can GIS be used to model this problem?” As this project has been developed while examining the potential for higher-speed rail along the Cascadia Megaregion, I am researching passenger rail speed limits along the main line and how they compare with a variety of infrastructure components. In particular I am focusing on the sections with slow speeds limits, i.e., the potential choke point areas. The infrastructure components under analysis are the bridges, tunnels, crossings, curves, incline, rails, ties, and stations.

I wanted to investigate new methods of choke point analysis because there is currently one main form of choke point analysis, and there is little literature available about it. As previously stated, the current method of choke point analysis consists of rail traffic algorithms combined with stakeholder input. Current algorithms also take into account only a few infrastructure components, such as track length and speed limits (Hernando et al, 2010 and I-5 Trade and Transportation Partnership, 2003). My decision to investigate the effectiveness of GIS as a form of analysis was because the location of choke points and infrastructure components is essentially a spatial problem, and GIS is useful tool for spatial analysis. I thought that GIS would be a useful tool due to its ability to convey the exact spatial location of the track and various infrastructure components, as well as their relationship with speed limits along the route.

My data consists of spatial infrastructure data from a combination of geodatabase data, track charts, a timetable, and shapefiles, which I reorganized into a single geodatabase organized by linear referencing. GIS tools, namely vector reselectment and dynamic segmentation, will be used to spatially compare the locations of speed limits and infrastructure components. In particular I am looking at which infrastructure components are located in sections that have slow speed limits. From these comparisons I hope to be able to pinpoint infrastructure-related choke points, with the eventual goal that improvements at choke point locations could lead to higher-speed rail in the region.

METHODS

Data set location and sources

The study region is the main track between Portland, OR and Vancouver, BC, which is the current route of the Amtrak Cascades train. BNSF Railway, formerly Burlington Northern Santa Fe Railway, owns most of the track, except for the part in Oregon, which is owned by Union Pacific Railroad. While the Amtrak Cascades route extends down to Eugene, OR, I chose to focus on the section north of Portland as the region incorporating the three main cities and the largest ridership. A map of the study region can be seen in Figure 2 on the next page.

Rail, like highways, is organized on a milepost system. This means that description in miles along a rail line does not necessarily imply sections of 5,280ft. While most train miles are approximately that long, there were “miles” along the study region that were less than 4,500ft or more than 6,000ft long. When referring to distances along the track in this project, miles refers to the number of mileposts (MP), so from MP 0 to MP 5 would be five miles whether or not it measures to five times 5,280ft. Using these calculations the study area spans a distance of 341.73 miles, of which 9.5 miles are in Oregon, 36.55 miles are in British Columbia, and the rest are in Washington.

The data came from a combination of a geodatabase, track charts, and a timetable, all provided by BNSF Railway, supplemented by a shape file of Amtrak stations

Figure 2. Overview map of the research area. The P is at the approximate location of Portland, OR, the S is by Seattle, WA, and the V is by Vancouver, WA. The study track consists of the lines connecting from Portland to Vancouver, BC. This map is a portion of the BNSF Railway Northwest Division Map.

downloaded in October 2013 from the United States Department of Transportation's Bureau of Transportation Statistics. A geodatabase is the common data storage and management framework for ArcGIS, which allows the user to combine multiple layers of spatial data and additional tables into a single GIS file. The geodatabase consists of layers of tracks, stations, mileposts, crossings, and turnouts, as well as tables for incline, curve, train density, and train count. Shapefiles are another type of GIS file, which spatially locate vector features made of points, polylines, or polygons, plus descriptive attributes for each feature. In GIS files, data is organized into thematic layers so that a user can decide which pieces of data are visible at a given moment, and how this data should be shown. For example, a project could have land-use, water features, and roads as data layers, and at one moment the user could choose to show water features on top of the land use layer, but not have the road layer visible.

Track charts are the railroad industry's standard form of recording rail attribute data in relation to milepost location. They are linear diagrams that show the rail in sections of five miles. Since track data has the potential to be updated any day, software has been developed to update track charts using GIS data (Bain & Smith, 2012, slides 3-4 and 13-17). The track charts I used contain data for the method of operation, speed limits, curves, incline, crossings, tunnels, bridges, signals, sidings, rail, ties, and ballast for the Bellingham, Fallbridge, New Westminster, Scenic, and Seattle Subdivisions as of October 2013. A modern track chart is shown in Figure 3 below. The timetable is for all of the Northwest Division, and is dated August 31, 2011. It contains a wide variety of data, including operations procedures, speed limits, and locations of bridges and tunnels. All of these BNSF data sources are listed in the references section.

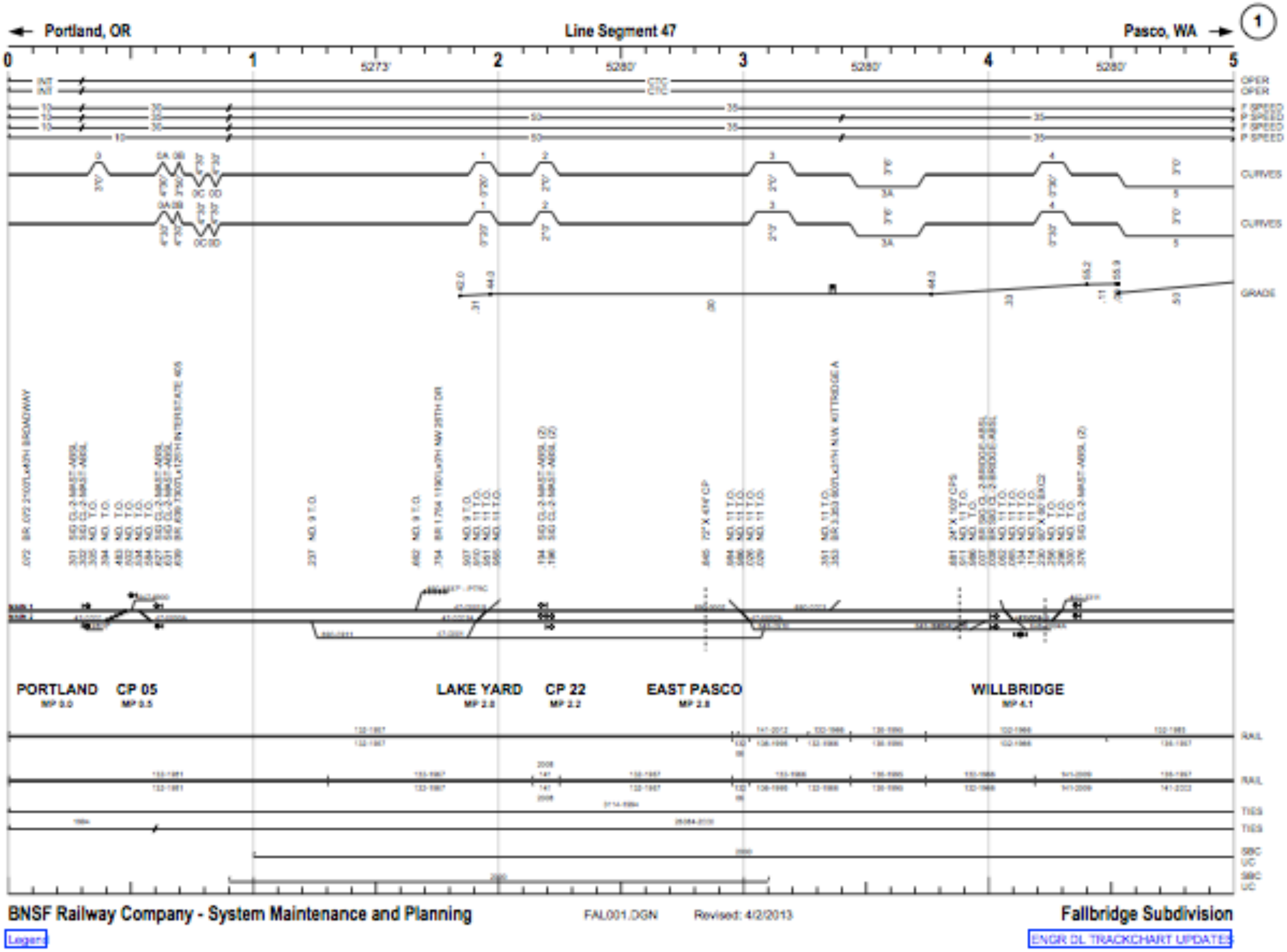


Figure 3. Example of a modern track chart diagram – Fallbridge Subdivision, Line Segment 47, MP 0 – MP 5.

Use of GIS analysis

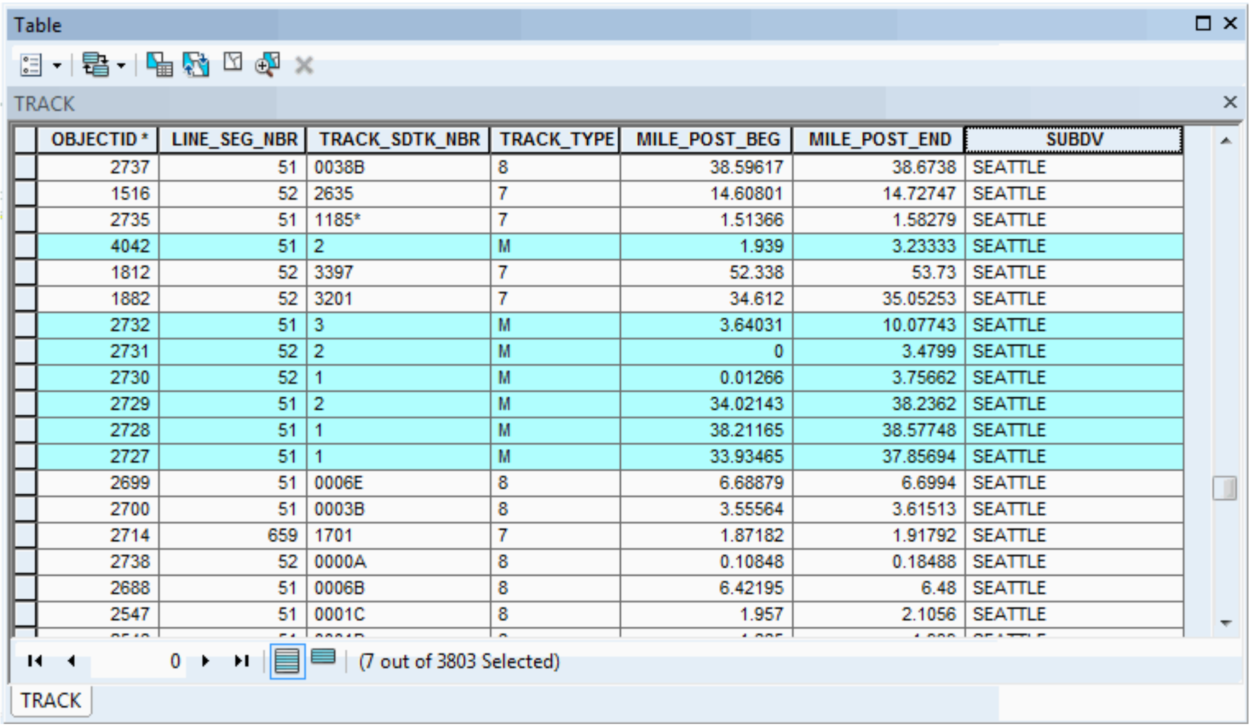
GIS provides an alternative way to analyze choke points, which can be compared with results produced by existing computer modeling methods and stakeholder input. GIS has the potential to not only determine choke point locations, but also to highlight similar attributes between multiple choke points because GIS does not depend on existing service schedules. My methods only take into account existing rail infrastructure, but this includes possible choke points. There is also the potential to examine multiple generations of choke points as improvements are made along the line. An example of this would be that a section capable of 70 mph today is not an infrastructure-related choke point, but could become one if speeds in proximal areas were increased to 90 or 120 mph.

Since rail is organized using a milepost system, I was able to use linear referencing and dynamic segmentation to compare the different infrastructure components with the speed limit data. Linear referencing is when the location of a data point is defined as the distance along a linear feature, for example, how many miles from the start of a section of track. Dynamic segmentation is the process of computing and mapping the location of data points listed in a table that uses linear referencing. Dynamic segmentation allows for multiple data sets to all be associated with a single linear feature. The linear feature is known as a "route", the data sets in table form are known as "event tables," and the layers resulting from dynamic segmentation are known as "route feature layers." Using highways as an example, the Mass Pike might be one route and Interstate 91 another route. Both routes could have event tables and route feature layers for related data such as on/off ramps or speed limits. Due to the layout of track in my project, the track was organized into multiple routes, and the data for each of the infrastructure components were formatted into event tables and then into route feature layers. An advantage of dynamic segmentation is that it is very easy to update event table data. For example, extending a 30 mph speed zone along a route from MP 5 to MP 7 only requires changing a few numbers in a table, rather than manually adjusting the length of two polylines representing the different speed limits.

Creation of routes and route feature layers

Routes:

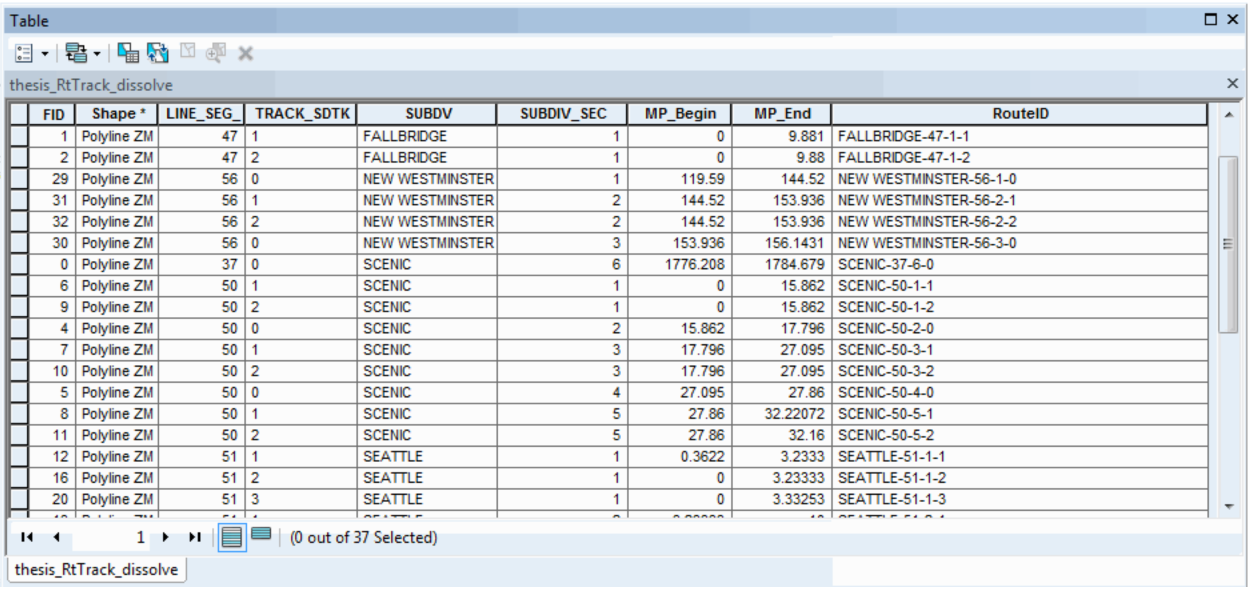
The first step of modifying the original data was to form the track into routes, which involved four steps. First the main track was selected from all of the other track types by using the Select by Layer function to select for “M” in the TRACK_TYPE column of the attribute table. Other track types included track for sidings and spur lines. Next the track selection was further refined based on the desired subdivision names and line numbers, which again was done by using Select by Layer on the SUBDV and LINE_SEG_NBR columns. Line segment numbers are used to divide subdivisions into geographic sections, so for example, in the Seattle subdivision Line Number 51 is from Seattle to Tacoma, and then Line Number 52 is from Tacoma south to Vancouver, WA. An example of the attribute data columns can be seen in Figure 4. The third step was manually dividing up the track into sections based on how many tracks are in a given location. As an example, if a portion of track goes from single track to double track, and then back to single track it would be divided into segments such that the single track is Section 1, the double track is Section 2, and then the final section of single track is Section 3. The track numbers are recorded in the TRACK_SDTK_NBR column, where a value of 0 represents single track, 1 and 2 represent each of the tracks in sections of double track or the first two tracks in triple track, and 3 is used for the third track in sections of triple track. Dividing the track into sections helped me to break the track into continuous lengths that could each be used as a route. In the example above this would create four different routes, consisting of Section 1 Track 0, Section 2 Track 1, Section 2 Track 2, and Section 3 Track 0.



OBJECTID *	LINE_SEG_NBR	TRACK_SDTK_NBR	TRACK_TYPE	MILE_POST_BEG	MILE_POST_END	SUBDV
2737	51	0038B	8	38.59617	38.6738	SEATTLE
1516	52	2635	7	14.60801	14.72747	SEATTLE
2735	51	1185*	7	1.51366	1.58279	SEATTLE
4042	51	2	M	1.939	3.23333	SEATTLE
1812	52	3397	7	52.338	53.73	SEATTLE
1882	52	3201	7	34.612	35.05253	SEATTLE
2732	51	3	M	3.64031	10.07743	SEATTLE
2731	52	2	M	0	3.4799	SEATTLE
2730	52	1	M	0.01266	3.75662	SEATTLE
2729	51	2	M	34.02143	38.2362	SEATTLE
2728	51	1	M	38.21165	38.57748	SEATTLE
2727	51	1	M	33.93465	37.85694	SEATTLE
2699	51	0006E	8	6.68879	6.6994	SEATTLE
2700	51	0003B	8	3.55564	3.61513	SEATTLE
2714	659	1701	7	1.87182	1.91792	SEATTLE
2738	52	0000A	8	0.10848	0.18488	SEATTLE
2688	51	0006B	8	6.42195	6.48	SEATTLE
2547	51	0001C	8	1.957	2.1056	SEATTLE

Figure 4. Attribute table for original data. In this table the TRACK_TYPE, SUBDV, LINE_SEG_NBR, and TRACK_SDTK_NBR columns are all visible. The highlighted rows are track segments that are part of the project route.

Finally I dissolved the track data into unique routes based on the subdivision, line segment number, track segment, and track number, which were used to make a unique identifying route number, known as the RouteID. An example of the attribute data for the reorganized thesis route track, including the RouteID, can be seen in Figure 5. Each route also has a beginning and ending milepost associated with it, marking the route location and allowing components to be spatially associated with the route. The milepost columns are also visible in the attribute data table. The four steps used to create the routes are shown in the flowchart in Figure 6.



FID	Shape *	LINE_SEG_	TRACK_SDTK	SUBDV	SUBDIV_SEC	MP_Begin	MP_End	RouteID
1	Polyline ZM	47	1	FALLBRIDGE	1	0	9.881	FALLBRIDGE-47-1-1
2	Polyline ZM	47	2	FALLBRIDGE	1	0	9.88	FALLBRIDGE-47-1-2
29	Polyline ZM	56	0	NEW WESTMINSTER	1	119.59	144.52	NEW WESTMINSTER-56-1-0
31	Polyline ZM	56	1	NEW WESTMINSTER	2	144.52	153.936	NEW WESTMINSTER-56-2-1
32	Polyline ZM	56	2	NEW WESTMINSTER	2	144.52	153.936	NEW WESTMINSTER-56-2-2
30	Polyline ZM	56	0	NEW WESTMINSTER	3	153.936	156.1431	NEW WESTMINSTER-56-3-0
0	Polyline ZM	37	0	SCENIC	6	1776.208	1784.679	SCENIC-37-6-0
6	Polyline ZM	50	1	SCENIC	1	0	15.862	SCENIC-50-1-1
9	Polyline ZM	50	2	SCENIC	1	0	15.862	SCENIC-50-1-2
4	Polyline ZM	50	0	SCENIC	2	15.862	17.796	SCENIC-50-2-0
7	Polyline ZM	50	1	SCENIC	3	17.796	27.095	SCENIC-50-3-1
10	Polyline ZM	50	2	SCENIC	3	17.796	27.095	SCENIC-50-3-2
5	Polyline ZM	50	0	SCENIC	4	27.095	27.86	SCENIC-50-4-0
8	Polyline ZM	50	1	SCENIC	5	27.86	32.22072	SCENIC-50-5-1
11	Polyline ZM	50	2	SCENIC	5	27.86	32.16	SCENIC-50-5-2
12	Polyline ZM	51	1	SEATTLE	1	0.3622	3.2333	SEATTLE-51-1-1
16	Polyline ZM	51	2	SEATTLE	1	0	3.23333	SEATTLE-51-1-2
20	Polyline ZM	51	3	SEATTLE	1	0	3.33253	SEATTLE-51-1-3

(0 out of 37 Selected)

Figure 5. Attribute data for the thesis route track.

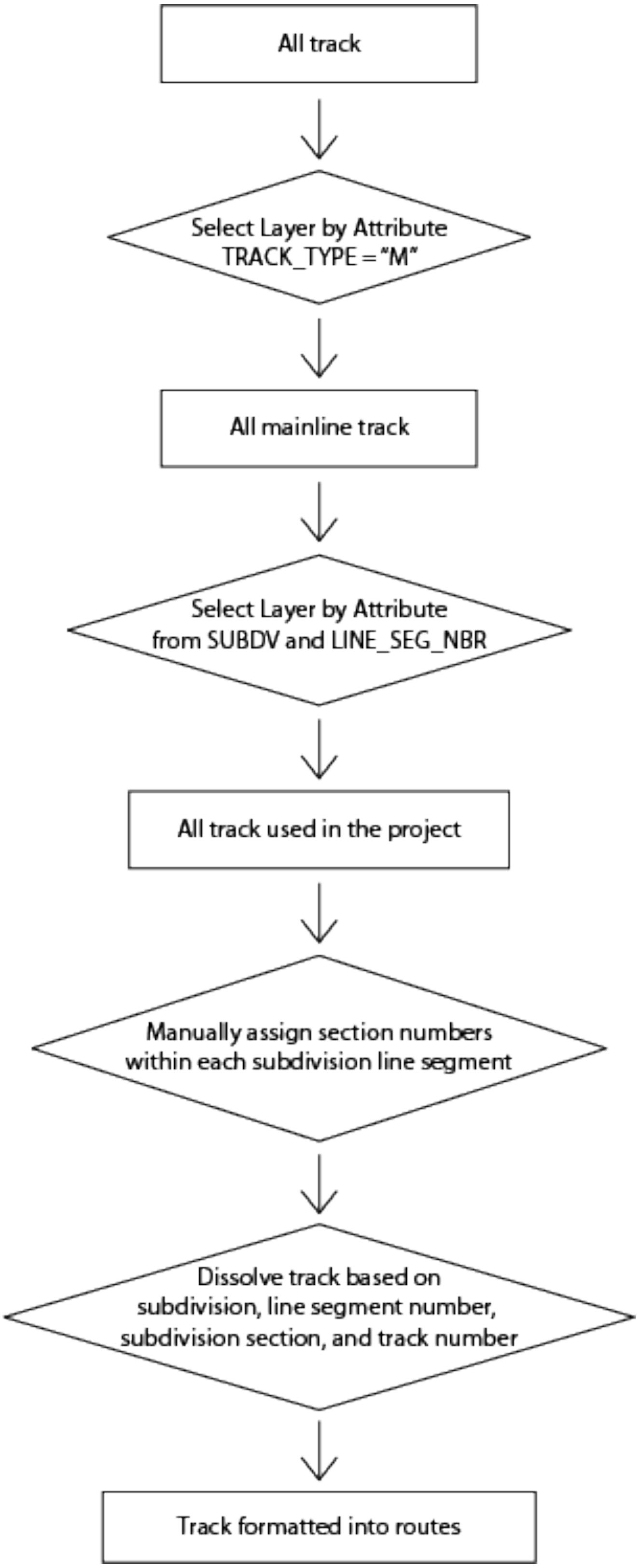


Figure 6. Flowchart for creating routes.

Route feature layers:

The second step of the data preprocessing was organizing the infrastructure components into route feature layers. All of the component layers use the RouteID to distinguish the route identity, and then use mileposts to locate where specifically along the route the infrastructure component is located. Because components consist of a variety of point and line features, cover different amounts of the track, and come from multiple data sources, each route feature layer used slightly different methods of creation. Some data had to be manually recorded from the track charts, which involved using a straight edge to connect features with the measuring tapes printed at the top and bottom of the track chart, as can be seen in Figure 7. This allowed me to record data down to two decimal places, or 0.01 miles. Data taken from the geodatabase mainly involved attaching RouteIDs to data that was already linear referenced. The location data in the geodatabase was normally recorded to two or three decimal places, so my manual measurements showed similar precision.

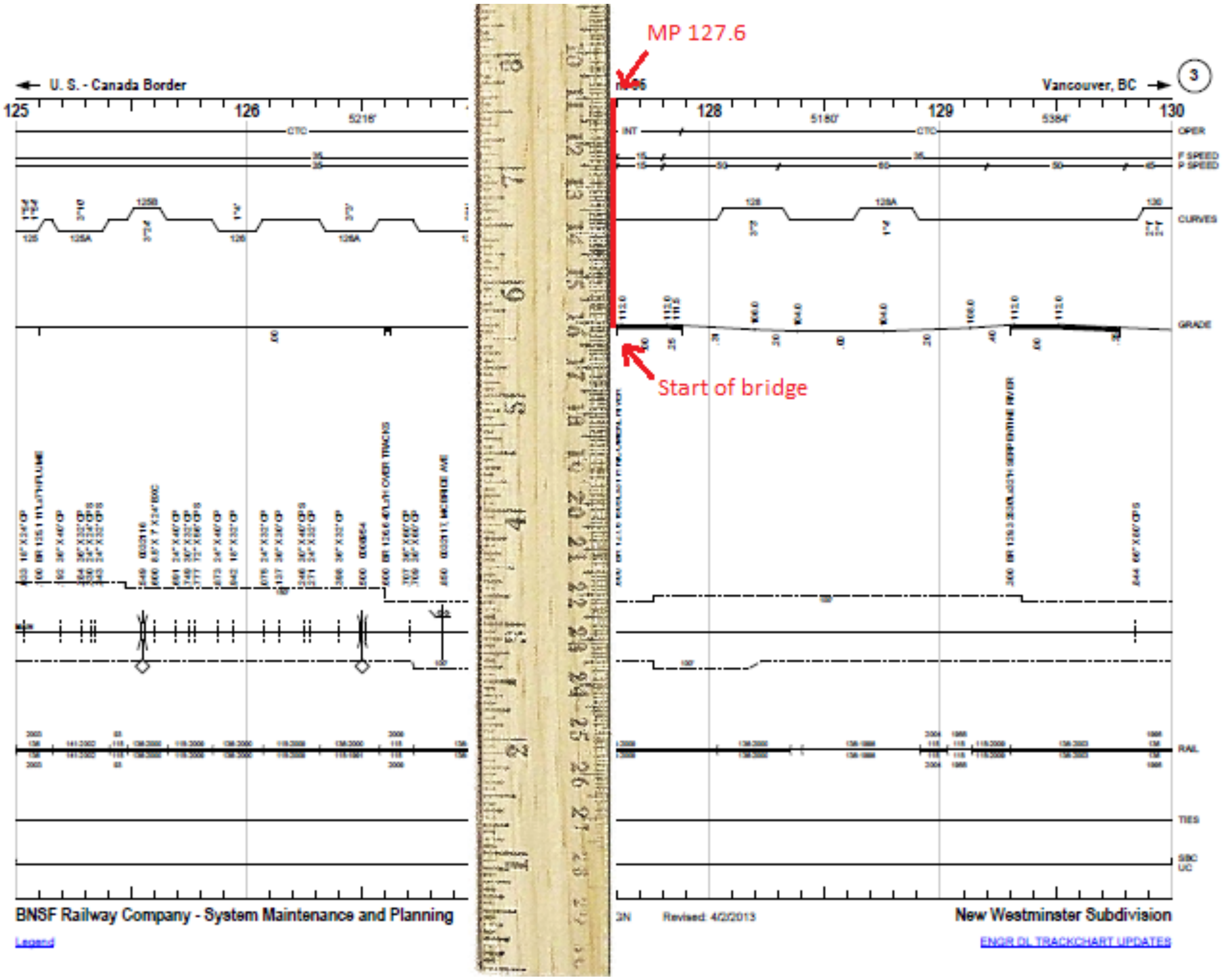


Figure 7. Manually recording data from a track chart using a straight edge. In this example the beginning of the bridge is measured to be at MP 127.6.

The methods of creation for each route feature layer are as follows.

- Crossings – all data from the BNSF geodatabase.
- Curves – most of the data is from the BNSF geodatabase. A few short sections, including line sections 37, 407, and 408, were missing from the geodatabase, so the curves along these sections were manually recorded from the track charts.
- Incline – most of the data is from the BNSF geodatabase. A few short sections, including line sections 37, 407, and 408, were missing from the geodatabase, so the incline along these sections was manually recorded from the track charts.
- Speed – data was manually recorded from the track charts, and double-checked with the timetable to include speed limits for the Talgo trains in use on the Amtrak Cascades line. I chose the Talgo train engine and car sets because these engines and cars use tilting technology that allows for higher speeds, especially around curves. Any discrepancies followed the speed limits stated in the track charts, as they were updated most recently.
- Stations – most of the data is from the shape file of Amtrak stations downloaded from the USDOT's Bureau of Transportation Statistics. Milepost data is from the stations layer in the BNSF geodatabase, confirmed using known landmarks (such as road crossings) visible in Google Earth aerial imagery.
- Ties – all data manually recorded from the track charts.
- Rail – all data manually recorded from the track charts.
- Tunnels – start mileposts recorded from lists in the timetable. End mileposts were calculated from the tunnel length and track mile length, both as listed in the track charts.

- Bridges – the original plan was to record the bridges similarly to how the tunnel data had been calculated. However on the first bridge I noticed that according to these methods the far end of this bridge was inaccurately recorded as being noticeably past the edge of the river, all the way into a section of track not being used for this project. After checking a few other bridges along the route I discovered that inaccuracy with bridge location was a frequent problem. Due to these discrepancies I used aerial imagery from Google Earth overlain with the BNSF geodatabase milepost layer, and the ruler tool in Google Earth to measure the milepost at one end of the bridge. The milepost at the other end was calculated based on the bridge length listed in the track charts divided by the measured track mile length. I did confirm that the ruler tool gave the same bridge length when compared with the lengths listed in the track chart. I only included bridges over waterways, as bridges over roads or other rails are already accounted for in the crossings feature layer. Bridges less than 50 feet long were also ignored, as this is less than approximately 0.01 miles, which is the smallest length I was able to record manually.

Feature layer color adjustment

With the goal of using GIS to visually display the spatial location of the different feature layers, I needed to color the layers so that the relevant attribute data was visible. The features fell into two broad categories for coloring, either a single color for all of the features or colored by category. The stations, bridges, and tunnels all used a single color, and all other features were colored by category with details as follows. The default I used for colorization by category is Natural Jenks Breaks, which is a classification system that groups similar values and maximizes the difference between categories. It is a standard categorization system used in ArcGIS, and is very data based. The opposite would be a more arbitrary categorization system that does not take into account outliers, or what range of values contains most of the data, for example, categorization based on fixed intervals (Esri, 2012).

Speed – Natural Jenks Breaks, five categories. The five categories use the speed limits for Talgo trains, and consist of 10 – 25 mph, 26 – 42 mph, 43 – 57 mph, 58 – 70 mph, and 71 – 79 mph. See Figure 8 for an example of the coloration scheme.

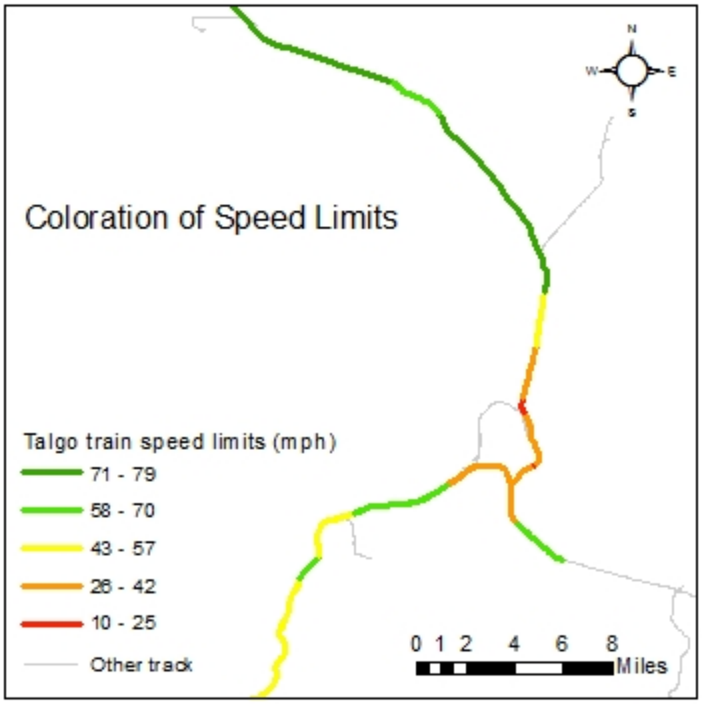


Figure 8. Coloration scheme for speed limits. Everett, WA area.

Crossings – grade crossings are colored red and all other crossings (above and below grade) are colored green. Grade crossings are where the rail line crosses the road or other rail line at the same level. Crossings above and below grade use overpasses and underpasses. Both categories contain road, rail, and pedestrian crossings. See Figure 9 for an example of the coloration scheme.

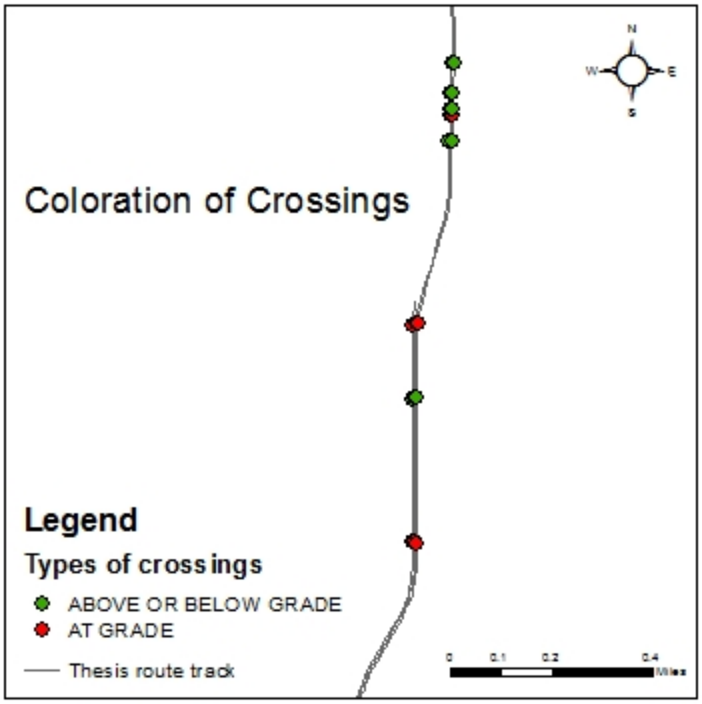


Figure 9. Coloration scheme for crossings. Seattle, WA.

Curves – Natural Jenks Breaks, five categories. The five categories use the degree of curvature (DEG_OF_CRV), and consist of 0° – 1.333°, 1.333° – 2.4°, 2.4° – 3.533°, 3.533° – 5.683°, and 5.683° – 14.667°. See Figure 10 for an example of the coloration scheme.

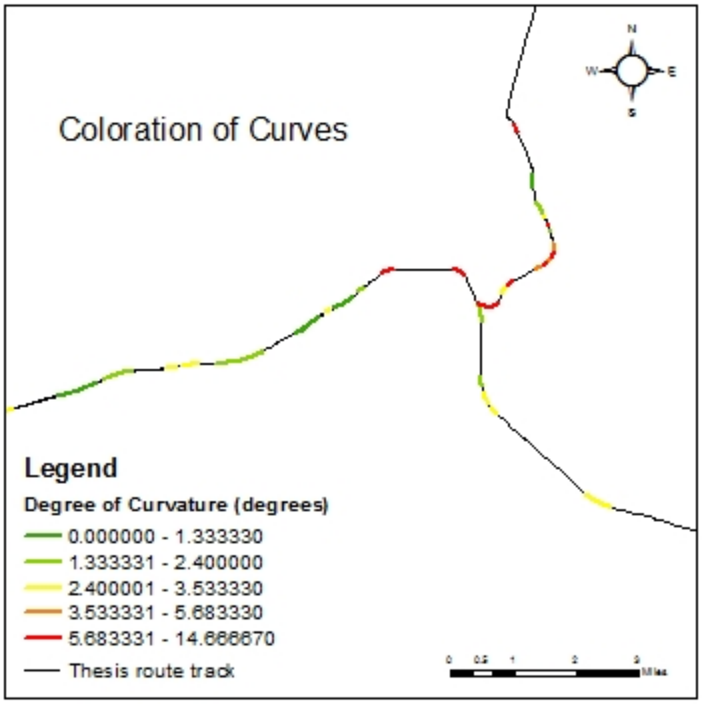


Figure 10. Coloration scheme for curves. Everett, WA area.

Rails – Rail was examined in three ways, for weight, type, and year. Weight and type were colored by categories, with the weight categories of 112, 115, 132, 136, and 141 lb/yd, and the type categories of bolted or welded. The coloration by year was done using Natural Jenks Breaks with five categories consisting of 1945 – 1959, 1961 – 1975, 1976 – 1990, 1991 – 2002, and 2003 – 2013. Three short sections did not have the year labeled, so they were left out of the other five categories and placed in a separate sixth category. See Figure 11 for an example of the coloration scheme.

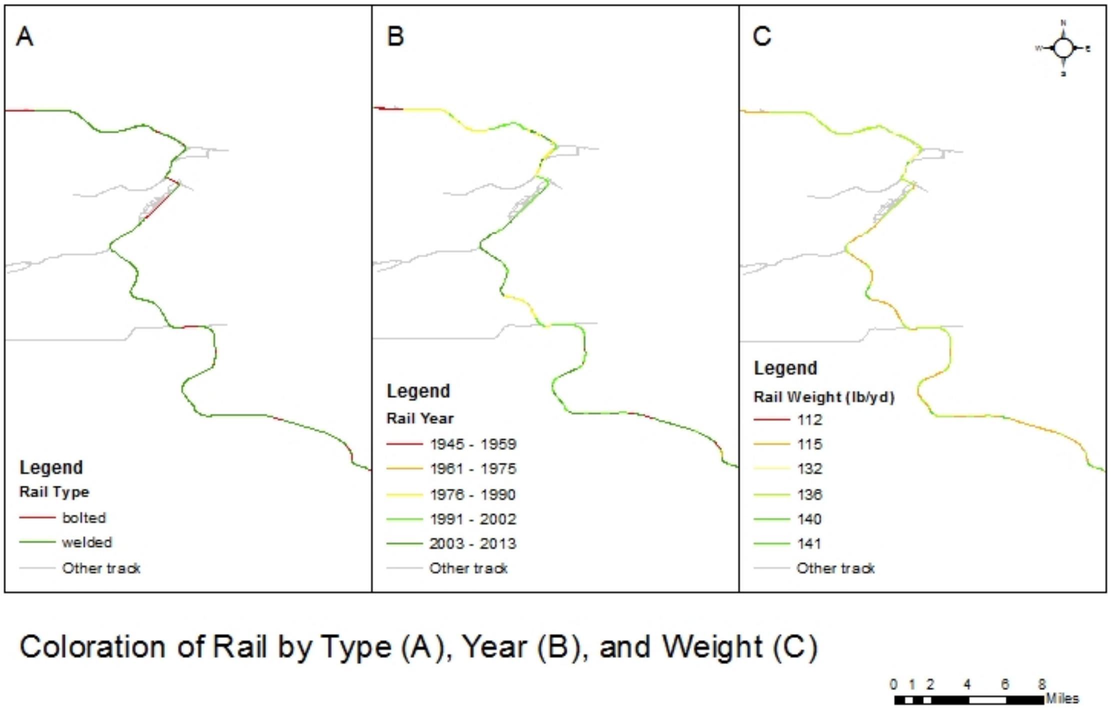


Figure 11. Coloration scheme for rails. Southern British Columbia.

Ties – Ties were examined in two ways, for material and year. Material was colored by categories, which consisted of concrete or timber. Year was colored using Natural Jenks Breaks with five categories consisting of 1982 – 1990, 1991 – 1996, 1997 – 2002, 2003 – 2008, and 2009 – 2011. See Figure 12 for an example of the coloration scheme.

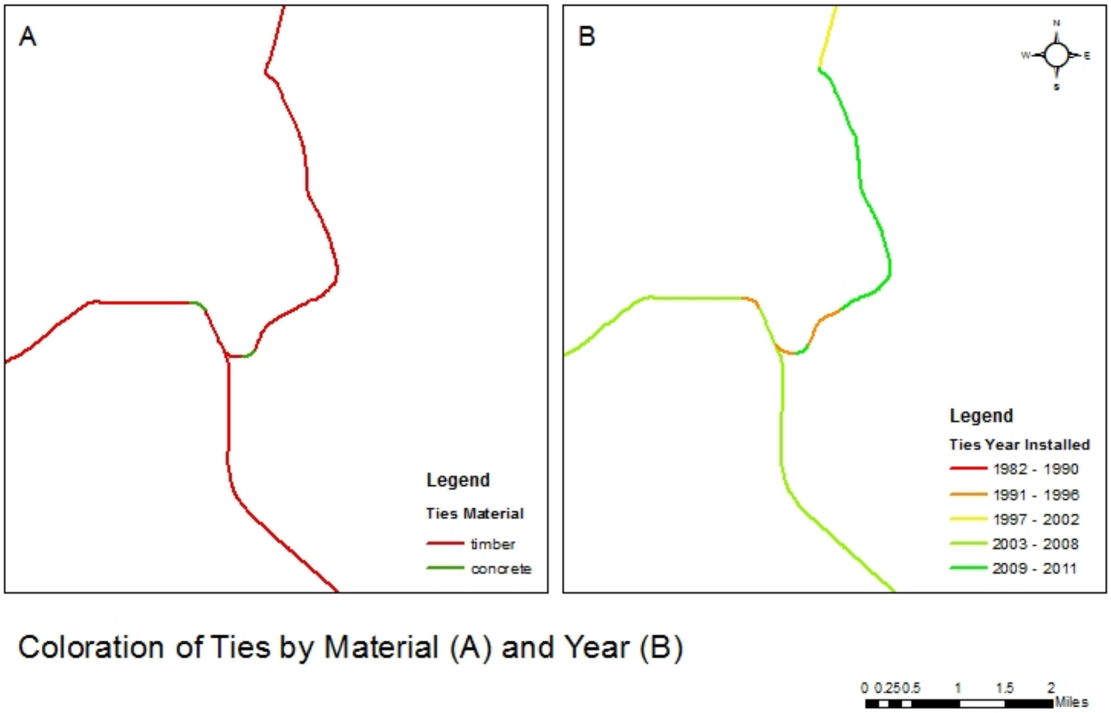


Figure 12. Coloration scheme for ties. Everett, WA area.

Incline – Four categories, splitting on a 1.5% incline as suggested by a member of BNSF Railway's GIS Department (personal communication with B. Smith, October 16, 2013). The four categories go from the most extreme negative incline (-4.2367%) to -1.5%, -1.5% to 0%, 0% to +1.5%, and +1.5% to the most extreme positive incline (+2.64%). See Figure 13 for an example of the coloration scheme.

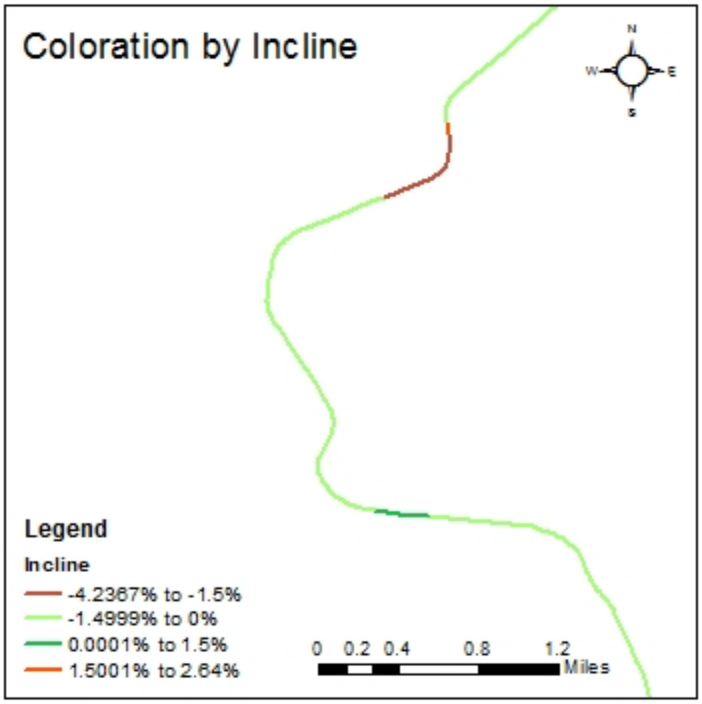


Figure 13. Coloration scheme for incline. Bellingham, WA.

Methods for defining slow areas

I chose to use the speed limits for the Talgo train sets, rather than the basic passenger rail speeds because the Talgo sets are closer to high-speed rail trains. The Talgo train sets are used on the Amtrak Cascades route between Vancouver, BC and Eugene, OR, whereas the regular passenger speeds are for the long distance trains that run to Los Angeles and Chicago. The Talgo train sets are single level and have tilting technology that allows them to travel around curves at faster speeds than the double-decker long distance trains, making them a more realistic measure of higher-speed rail technology.

The breakpoint I used for speed was 60 mph because that is the standard automobile speed limit along much of the I-5 corridor. If a train is to be faster than driving an automobile it will need to travel at a minimum of 60 mph. I started by coloring the speed limit feature layer as described above. Selecting by attributes allowed me to confirm that even though the second fastest category is 58 – 70 mph, there are no sections with speed limits of 58 or 59 mph, making this category effectively 60 – 70 mph. This means that it is clear when looking at the speed limit feature layer, as shown in Figure 14, where the slow areas are, as speeds under 60 mph are colored yellow, orange, and red, whereas sections over 60 mph are a shade of green.

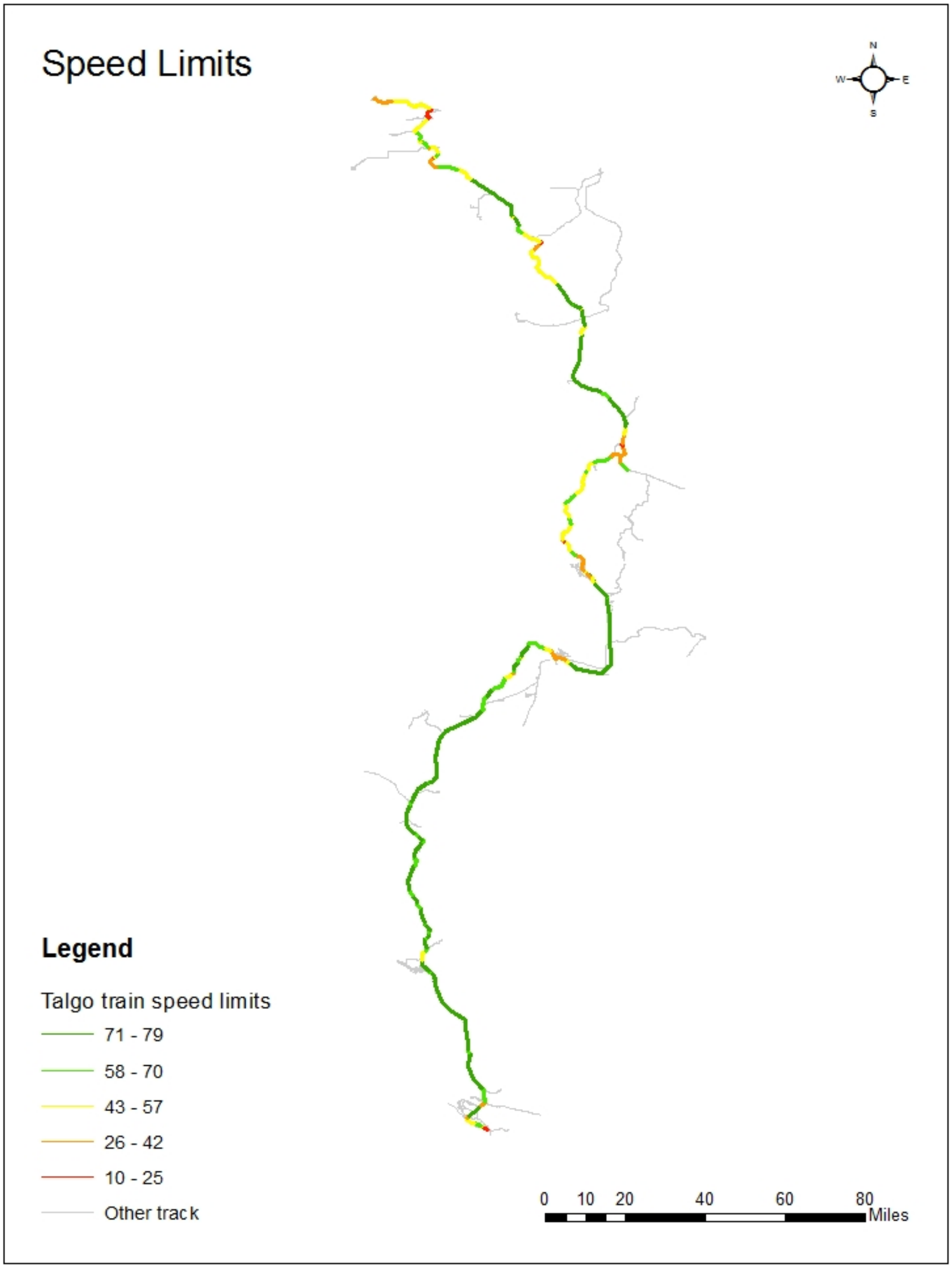


Figure 14. Speed limit feature layer. Slow sections with speeds under 60 mph are shown in yellow, orange, or red. This map is of the entire project area.

Comparisons between layers

There were two main steps to comparing the component feature layers with the speed layer. First I examined each layer as a whole to see if there were any overall patterns in the component layers that matched the patterns in the speed layer, such as a particular component or component attribute being consistently part of the slow areas. This step was most important for the rail, tie, and incline layers, which cover every section of track. An example of this type of comparison can be seen in Figure 15 below.

The second step was to focus in on each of the slow speed sections and examine all of the infrastructure components within the slow section. In this step I was looking for components or component attributes that are different in the slow section as compared to right outside of the slow section. Examples of this would be if the slow section contains a bridge or a section with a steeper incline. This section of comparison is also where I scrutinized potential interactions between feature layers, such as a section with a steep incline and a curve. An example of this type of comparison can be seen in Figure 16 below.

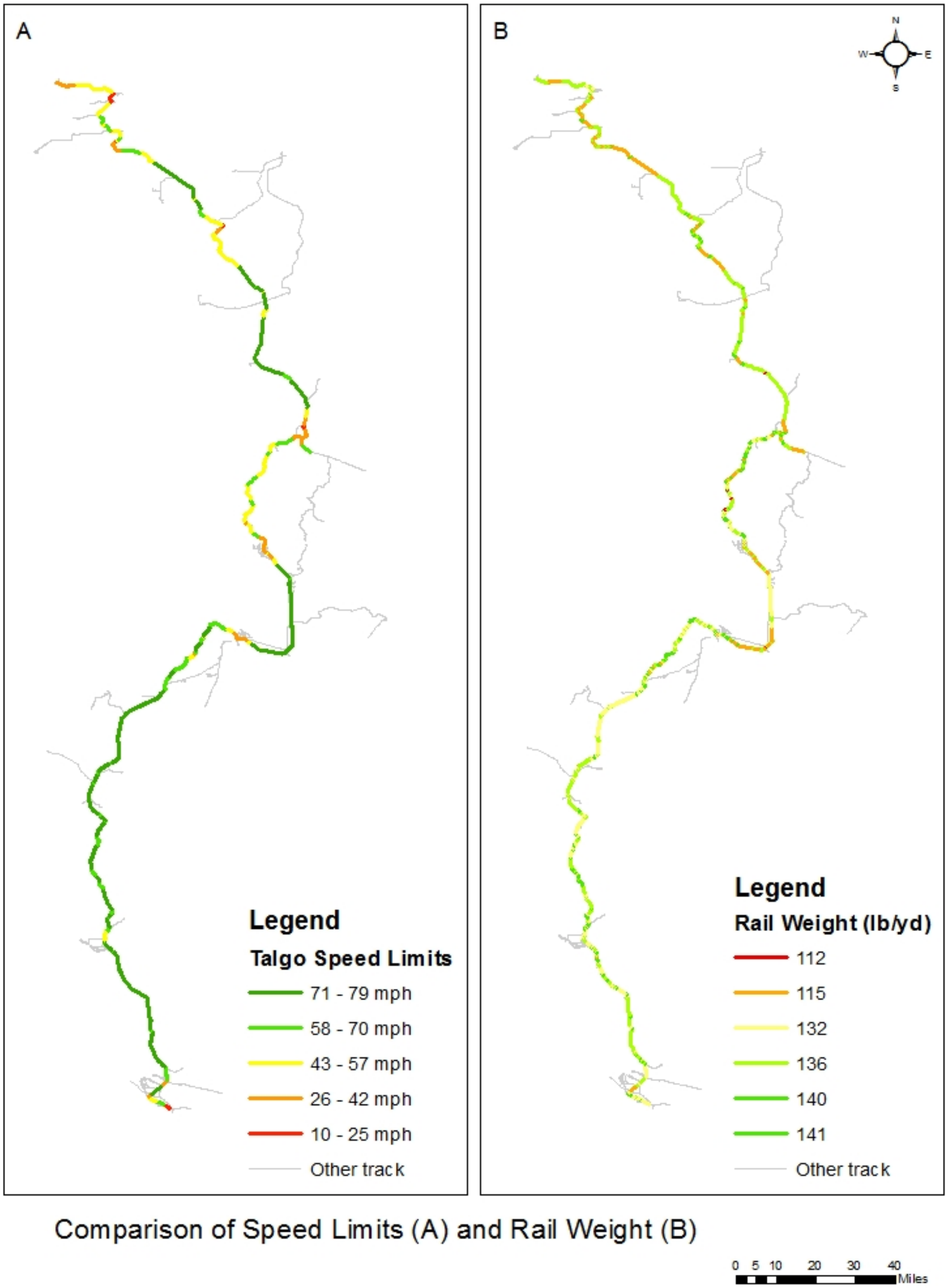


Figure 15: Full layer comparison between speed limit and rail weight layers.

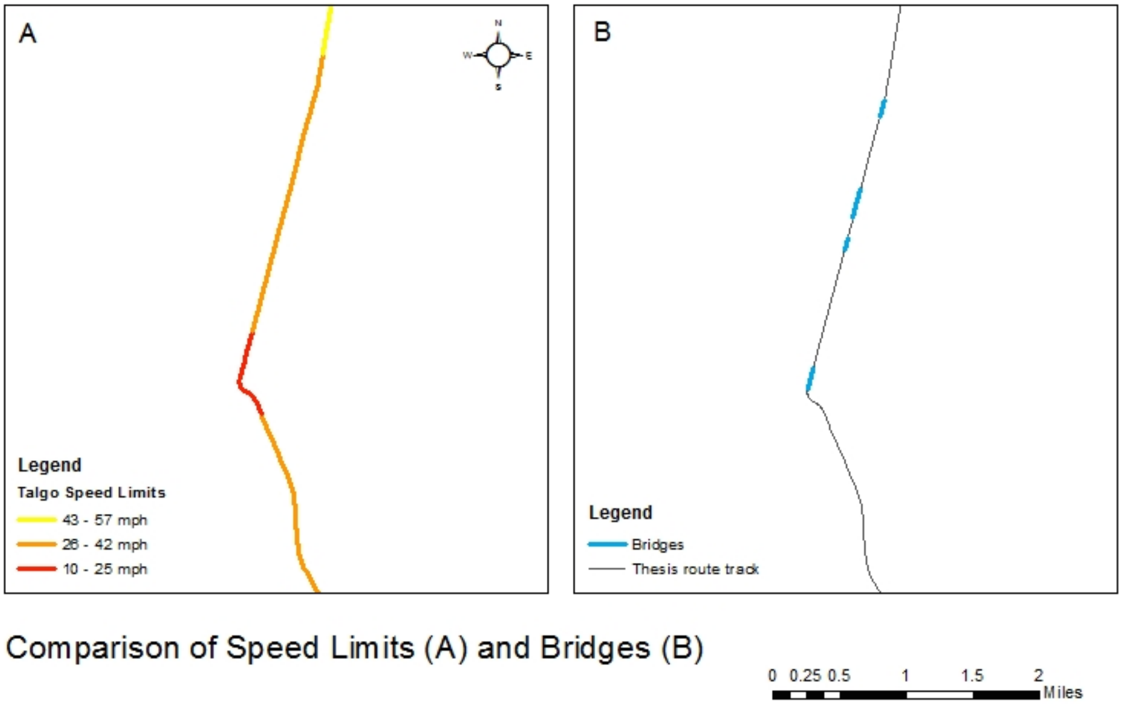


Figure 16. Close-up comparison of speed limit and bridge layers. Everett, WA.

RESULTS

In my analysis I compared eight different infrastructure components with the speed limits along the entire mainline track between Portland, OR and Vancouver, BC. The infrastructure components consisted of bridges, crossings, curves, incline, rail, stations, ties, and tunnels. For the rail, ties, and incline layers I compared the overall layer with the speed layer because these three components cover the entirety of the track. The rest of my analysis consisted of a focused examination of the slow sections of track with speed limits of less than 60 mph, in order to study infrastructure components within each section. A flow chart for the analysis process can be seen in Figure 17.

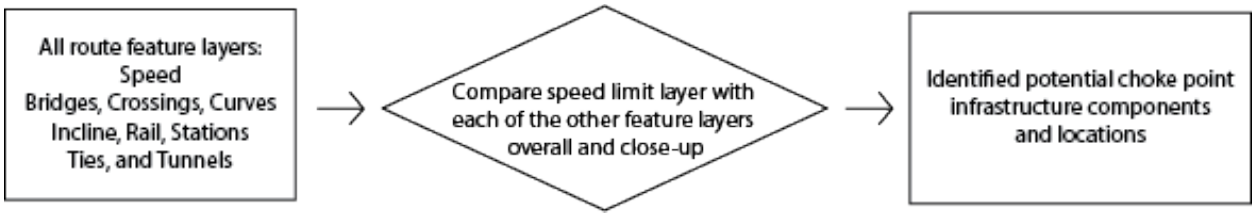


Figure 17. Flowchart of analysis procedure. The analysis involved multiple iterations of comparisons as the results of one comparison sometimes made me reconsider the analysis and conclusions of previous analysis. Comparisons included doing overlays and intersections.

While doing this I also took a second look at the rail, ties, and incline layers to confirm that the wider patterns still held true. I found twenty-nine sections of track with speed limits of less than 60 mph, ranging in length from 0.2 miles to 19.5 miles. From examining the slow sections I came to the conclusion that the most frequent causes of slower speed limits were curves, followed by crossing through populated areas (i.e. the main section of a town or city), and bridges. Populated areas will be discussed later in further detail. Twenty-four of the twenty-nine slow sections involved curves, nineteen involved going through populated areas, and eleven involved bridges. Tunnels, incline, and a few unique situations caused slow points on only a few sections. Most sections had two or three possible causes for slower speeds, such as a combination of curves while crossing through a town. A list and map of all of the slow sections, including location and infrastructure problems that might cause slower speeds is shown in Figure 18 and Table 1.

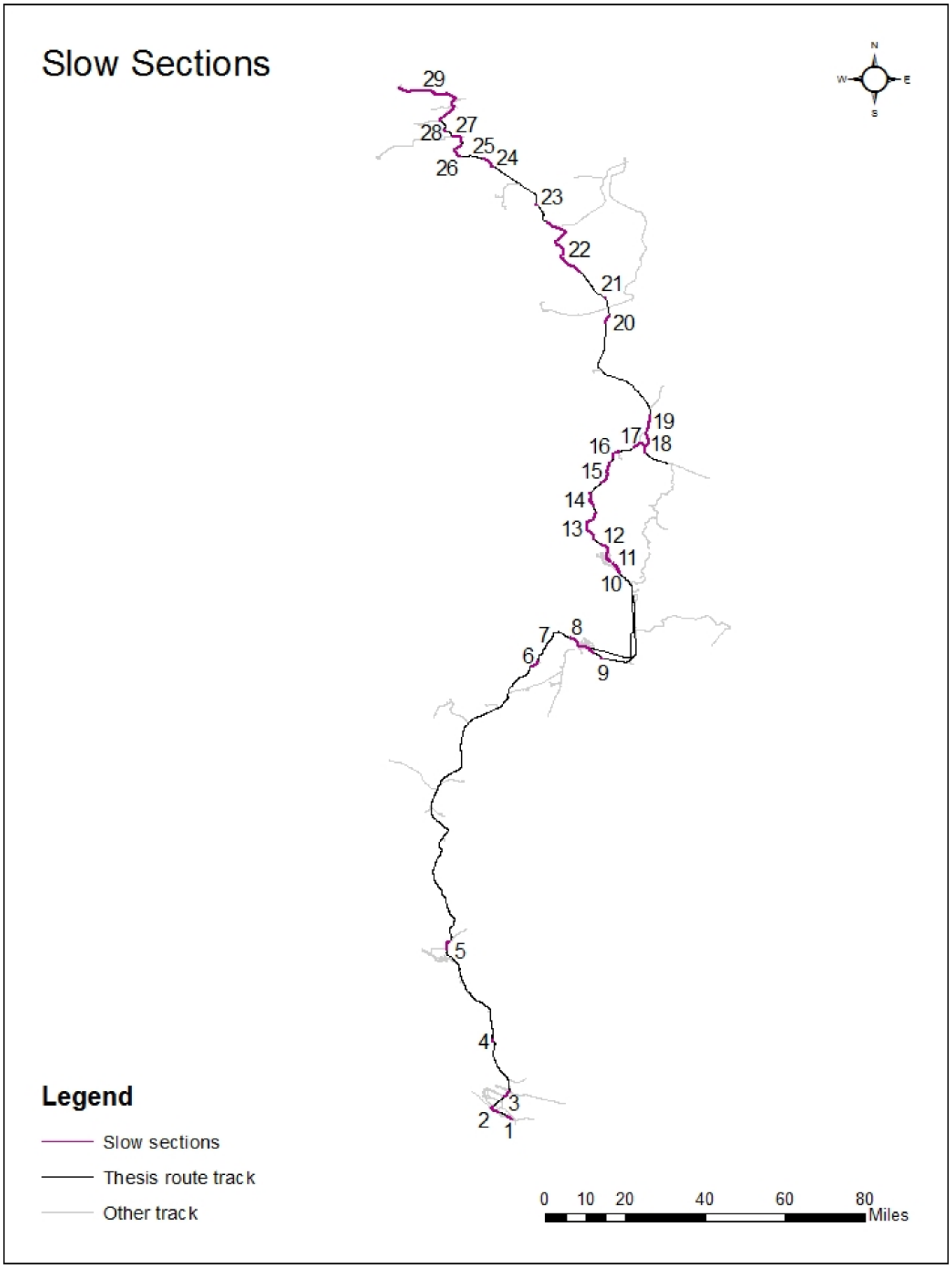


Figure 18. Map of all the slow sections.

Table 1. List of all the slow sections including data on routes, speed limits, length, and infrastructure problems.

Slow Section	Subdivision	Start MP	End MP	Routes	Speed Limits (mph)	Total Length (miles)	Infrastructure problems
01	Fallbridge	0	1.5	Fallbridge-47-1-1, Fallbridge-47-1-2	10-50	1.5	Populated area, curves
02	Fallbridge	3	5.5	Fallbridge-47-1-1, Fallbridge-47-1-2	30-50	2.5	Bridge, curves
03	Fallbridge and Seattle	8.5	136.2	Fallbridge-47-1-1, Fallbridge-47-1-2, Seattle-52-7-1, Seattle-52-7-2	30-40	1.7	Bridges, station
04	Seattle	122.3	122.9	Seattle-52-7-1	53	0.6	Curve
05	Seattle	95.3	97.2	Seattle-52-7-1, Seattle-52-7-2	45-52	1.9	Populated area, tunnel, curves
06	Seattle	14	15.9	Seattle-52-7-1, Seattle-52-7-2	40-50	1.9	Populated area, bridge
07	Seattle	9.5	9.8	Seattle-52-7-1, Seattle-52-7-2	35-52	0.3	Built up track along a lagoon, curves
08	Seattle	36.4	2.8	Seattle-51-3-1, Seattle-51-3-2, Seattle-51-4-1, Seattle-51-4-1, Seattle-51-4-3, Seattle-52-5-1, Seattle-52-5-2, Seattle-52-5-3	37-57	6.5	Populated area, curves
09	Seattle	34.4	34.6	Seattle-51-3-1, Seattle-51-3-2	55	0.2	Curve
10	Seattle	3.6	6.7	Seattle-51-2-3	40-50	3.1	Populated area?
11	Seattle	0	3.4	Seattle-51-1-1, Seattle-51-1-2, Seattle-51-1-3, Seattle-51-2-1, Seattle-51-2-2	30-56	3.4	Populated area, curves
12	Scenic	0	1.9	Scenic-50-1-1, Scenic-50-1-2	30	1.9	Populated area, tunnel, curves
13	Scenic	3.4	11.5	Scenic-50-1-1, Scenic-50-1-2	20-55	8.1	Populated area, bridge, curves
14	Scenic	13.2	17	Scenic-50-1-1, Scenic-50-1-2, Scenic-50-2-0	50-55	4.8	Curves, populated area
15	Scenic	20	25.8	Scenic-50-3-1, Scenic-50-3-2	50-55	5.8	Curves, populated area
16	Scenic	26.9	29.2	Scenic-30-3-1, Scenic-50-3-2, Scenic-50-4-0,	45-55	2.3	Populated area, curves

				Scenic-50-5-1, Scenic-50-5-2			
17	Scenic	32	1782.5	Scenic-50-5-1, Scenic-50-5-2, Scenic-50-3-0	33-40	2.2	Populated area, tunnel, curves
18	Bellingham	0	11	Bellingham-407-1-0, Bellingham-408-2-0	10-42	3.9	Populated area, curves
19	Bellingham	37	41	Bellingham-50-3-0	10-50	4	Bridges, populated area
20	Bellingham	67.9	70.3	Bellingham-50-3-0	50	2.4	Populated area, curves, bridge
21	Bellingham	74.5	74.7	Bellingham-50-3-0	50	0.2	Curve
22	Bellingham	82.6	101	Bellingham-50-3-0	20-50	18.4	Populated area, curves, bridge, incline, tunnel
23	Bellingham	105.8	106.2	Bellingham-50-3-0	45	0.4	Curve
24	Bellingham	118.2	119.6	Bellingham-50-3-0	50	1.4	Populated area, curves, border
25	New Westminster	119.6	120.9	New Westminster-56-1-0	50	1.3	Border, bridge
26	New Westminster	124.5	128.3	New Westminster-56-1-0	15-50	4.8	Bridge, populated area, curves
27	New Westminster	129.2	131.9	New Westminster-56-1-0	40-50	2.7	Curves, bridge, crossings
28	New Westminster	133.7	134.3	New Westminster-56-1-0	50	0.6	Curve
29	New Westminster	136.6	156.1	NewWestminster-56-1-0, NewWestminster-56-2-1, NewWestminster-56-2-2, NewWestminster-56-3-0	10-50	19.5	Populated area, bridge, curves, incline

Curves

The Federal Rail Administration (FRA) sets speed limits for curved track based on the sharpness of the curve, superelevation of the track, and cant deficiency. When objects travel along a curve, centrifugal force causes the object, in this case the train, to tilt towards the outside of the curve. If curves are sharp enough and trains fast enough the centrifugal force can lead to discomfort for the passengers, such as objects falling off of tables inside the train or passengers suffering from motion sickness. To counteract the centrifugal force, rail curves are often built with the outside rail a few inches higher in elevation, so that the forces acting on the train are closer to the normal gravitational forces in effect on a straight section of track. This elevation difference between the outside and inside rail is known as the superelevation, and is measured in inches. The superelevation needed to completely counteract the centrifugal force of passenger trains at full speed is often so high that it would be dangerous to trains running at lower speeds. This leads the trains to still tip outwards slightly, just not as much as they would with zero superelevation.

This tipping factor is known as the cant deficiency, and is officially defined as the amount of additional superelevation that would be needed to completely balance the forces acting on the train. Cant deficiency is also measured in inches. The relationship between superelevation and cant deficiency can be seen below in Figure 19. In the United States passenger trains are normally limited to a maximum of six inches of superelevation, and the default is that trains may travel with five inches of cant deficiency (USDOT FRA, March 13, 2013, p. 16054, 16067). Canada has almost identical regulations for speed limits along curves, except that the default is three inches of cant deficiency (Transport Canada, 2011, p. 12-14). For the track in this project I knew the sharpness of the curve and the delta angle or distance around a circle traversed by a curve, both of which can be seen in Figure 20 below. The delta angle is measured in degrees and the sharpness of the curve is measured in degrees per 100 feet (Calvert, 2004). I used the standard five-inch default for cant deficiency in the United States and three-inch cant deficiency in Canada, but superelevation data was unavailable, resulting in a range of possible speed limits for any curve.

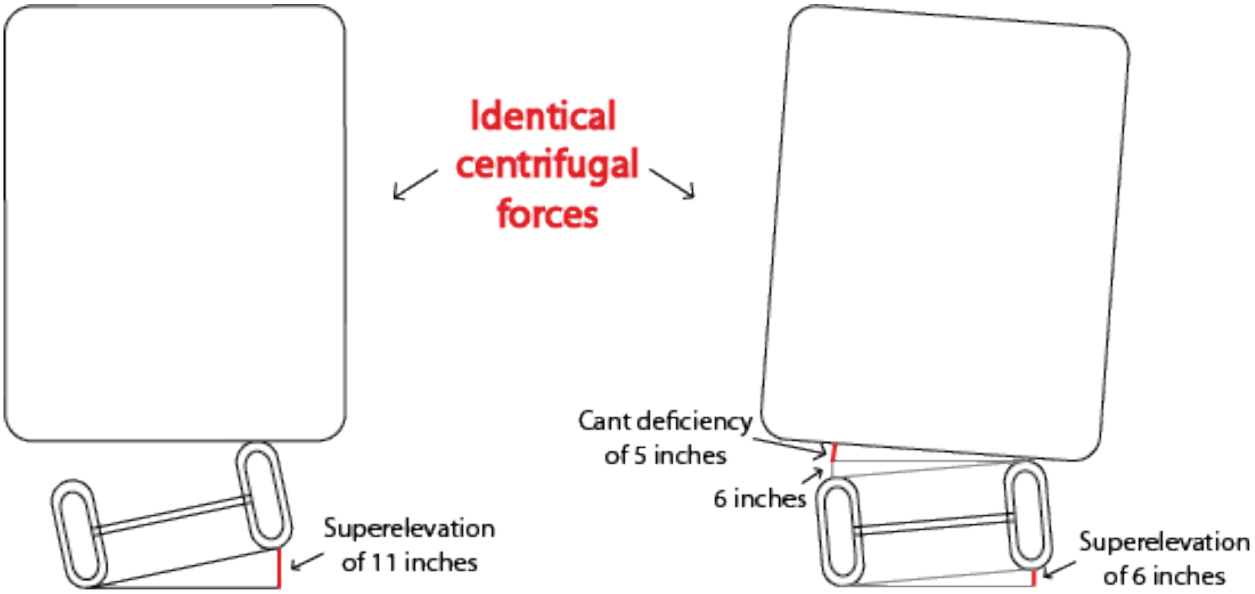


Figure 19. Relationship between superelevation and cant deficiency.

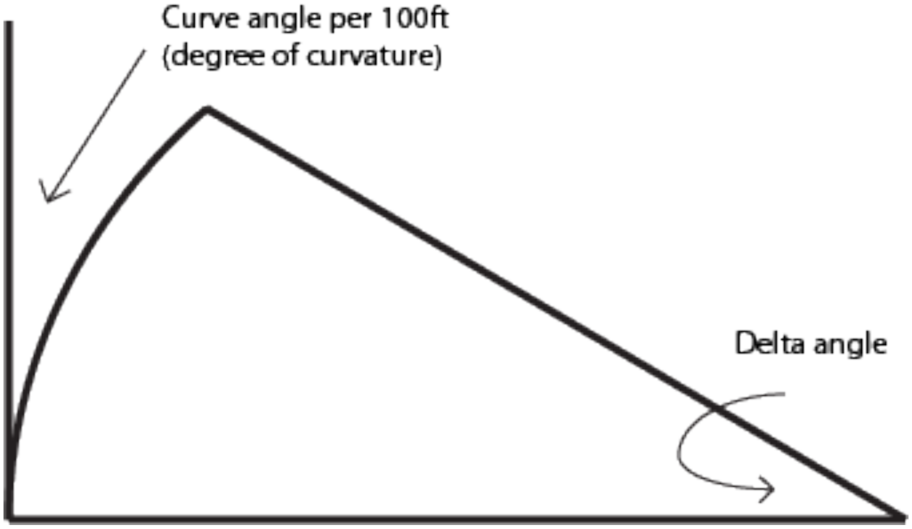


Figure 20. Relationship between curve angle and delta angle.

Twenty-four of the twenty-nine slow sections had curves as potential causes of slow speeds, with a single curve being recorded no matter if that section is single or double track. The sharpest curve in the project area was 14.67°; however most of the problematic curves were between 3° and 7°. Of the 234 curves in slow sections, 147 were 3° or greater, but only 13 were 7° or greater. The frequency of curves based on the degree of curvature can be seen below in Figure 21. For speed comparisons, 3° allows speed limits of 49-72 mph, 7° allows 32-47 mph, and 12° allows 24-36 mph. Exact speed limits are dependent on the superelevation of the curve in question, and 12° is the sharpest curve listed by the Federal Rail Administration (USDOT FRA, March 13, 2013, p. 16114). Some of the speed limits were slightly slower than would be expected for just the curves in the area, which I attributed to a combination of factors, such as a delta angle of more than 70°, or multiple turns in a row leading to shortened sightlines. An example of this would be Slow Section 27, located along the New Westminster subdivision, which has two curves with delta angles of over 80°. One of the two curves has a curve angle of only 2°, which at three inches of cant deficiency would suggest speeds of 46-80 mph; however the maximum speed limit along that section is only 45 mph. Specific details for each section effected by curves can been seen in Figure 22 and Table 2 below.

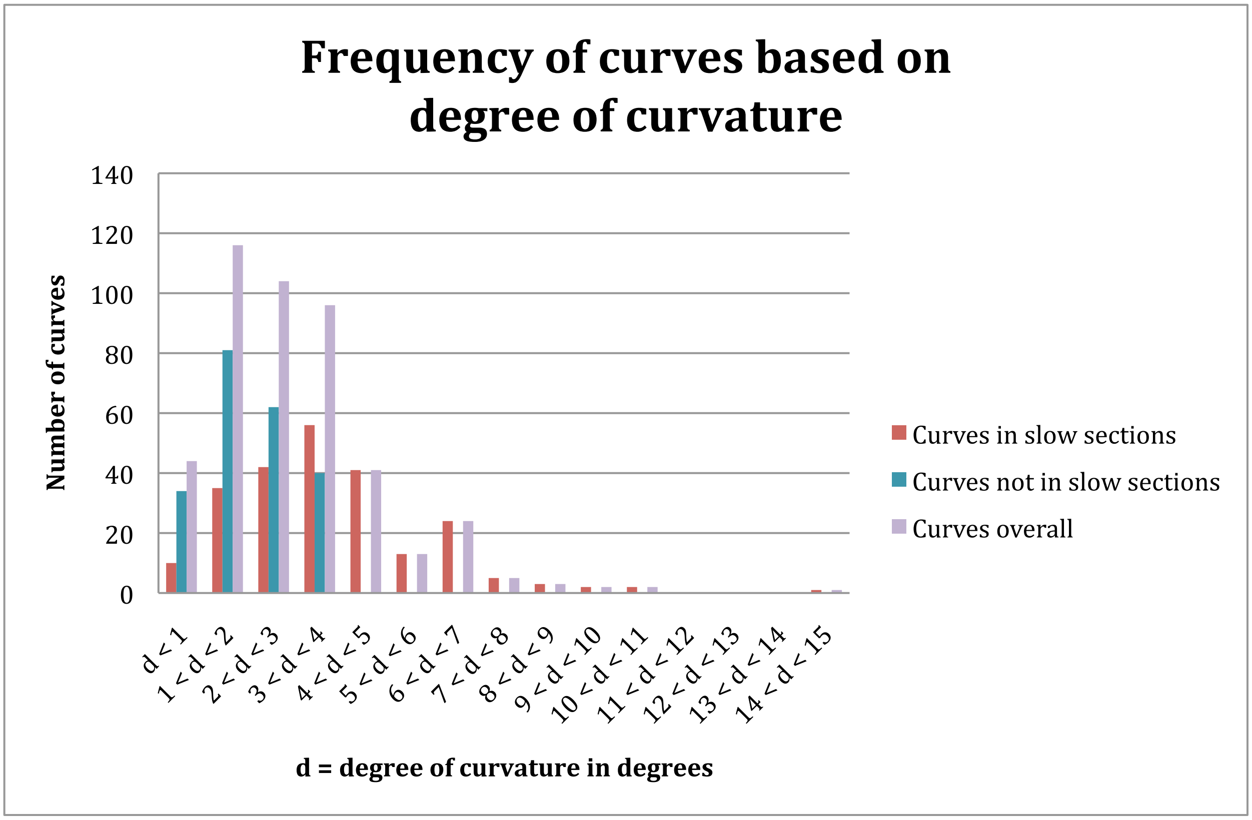


Figure 21. Graph of the frequency of curves based on the degree of curvature. Each bar shows how many curves are within a one-degree range for degree of curvature, such as between 1° and 2° of curvature. In this graph it is clear that the curves in the slow sections (red bars) are on average sharper than the curves that are not located in a slow section (blue bars). The purple bar shows the frequency of curves located along the entire route.

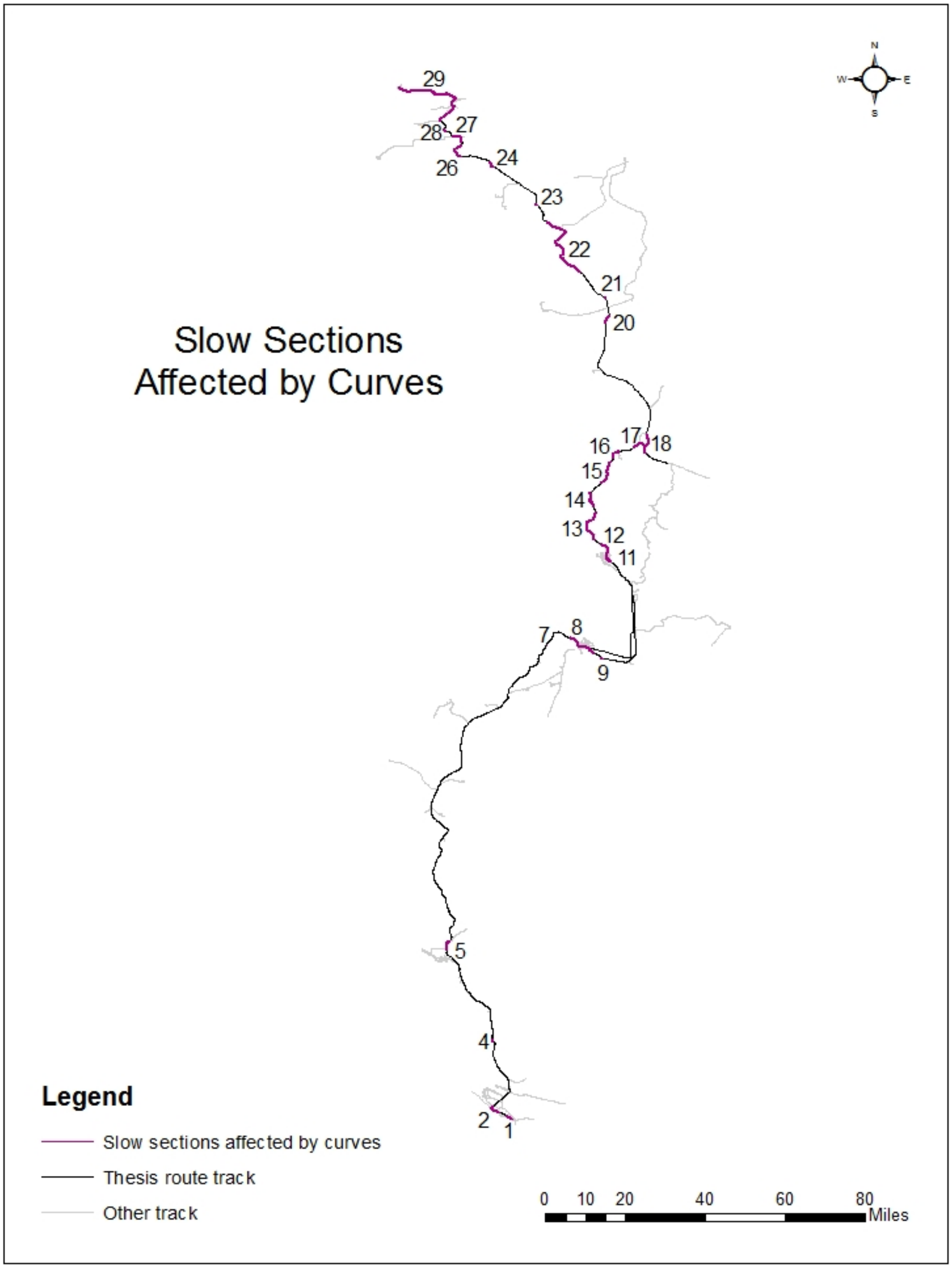


Figure 22. Map of slow sections affected by curves.

Table 2: List of slow sections affected by curves. The unknown delta angles are due to these sections being manually recorded, and delta angles are not listed in the track charts.

Slow Section	Number of Curves	Minimum Curve (deg)	Maximum Curve (deg)	Minimum Delta Angle (deg)	Maximum Delta Angle (deg)	Total Length (miles)
01	5	3.0	4.5	4.59	12.6	1.5
02	4	0.5	3.1	3.97	85.35	2.5
04	1	--	2	--	47.68	0.6
05	4	2	3.1	6.92	32.52	1.9
07	1	--	3	--	21.36	0.3
08	20	1	10.01	2.65	74.32	6.5
09	1	--	4.5	--	35.33	0.2
11	11	1	8	1.59	41.06	3.4
12	8	2	7.57	3.91	39.36	1.9
13	17	1	5.33	13.18	119.31	8.1
14	8	1	5	4.61	62.95	4.8
15	16	0.5	4.5	4.02	47.95	5.8
16	3	0.5	3.33	13.17	51.3	2.3
17	5	1.2	10.23	Unknown	Unknown	2.2
18	14	1	9.93	Unknown	Unknown	3.9
20	4	2	3.87	16.34	62.14	2.4
21	1	--	5.12	--	47.23	0.2
22	48	0.5	8	4.15	103.03	18.4
23	1	--	5.15	--	47.07	0.4
24	5	2	4.1	5.44	69.54	1.4
26	7	1.07	3.4	8.0	50.54	4.8
27	3	1.62	3.06	2.85	89.62	2.7
28	1	--	3.03	--	56.31	0.6
29	27	0.75	14.67	1.18	154.91	19.5

Populated areas, including grade crossings and stations

Populated areas were the next most problematic feature, affecting nineteen slow sections. This designation was determined by a combination of grade crossings, stations, and examining aerial images via Google Earth, and was developed as a categorization during data analysis. While trying to decipher causes for some of the sections that did not seem to have a distinct infrastructure problem, I started checking Google Earth and noticed that slow speeds mostly occurred when the track crossed populated areas, such as residential or commercial areas, rather than farmland. Populated areas included everything from the centers of small towns to large cities, meaning that this designation included all but one of the problematic grade crossings and seven of the eight stations located in slow sections. The one exception station, Vancouver, WA, is located in an industrial area just past a long bridge. The one section with problematic crossings that was not in a populated area appears to be in an active agricultural area. There are Surrey, BC residential neighborhoods located on the outskirts of the agricultural area. There were six other stations that were not directly located in slow sections, which suggests that the presence of a station does not automatically lower speeds to less than 60 mph. Further details for each section affected by populated areas can been seen in Figure 23 and Table 3 below.

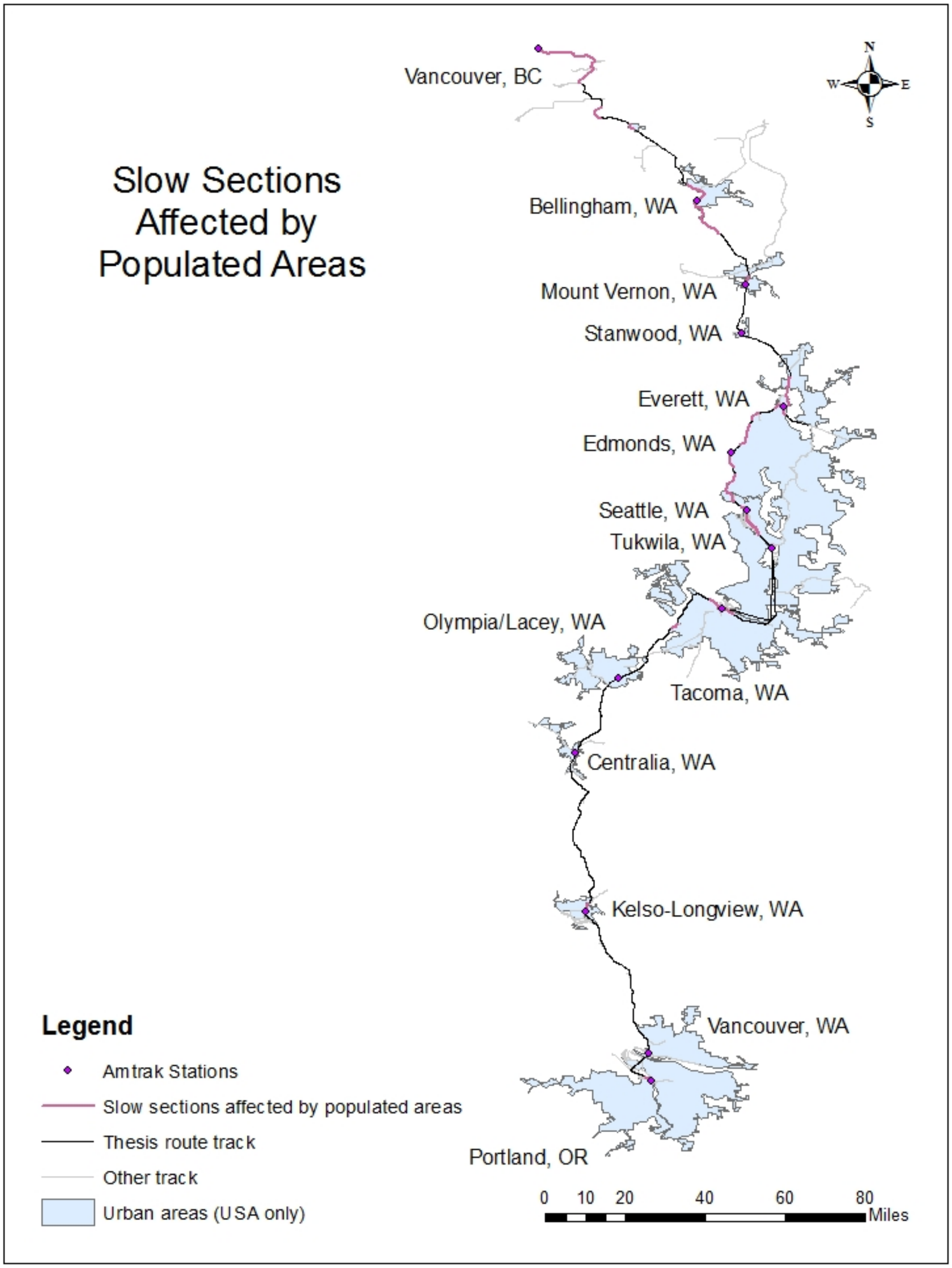


Figure 23. Map of slow sections affected by population.

Table 3. List of slow sections affected by populated areas.

Slow Section	Town/City, State	Number of Grade Crossings	Amtrak Station	Total Length (miles)
01	Portland, OR	5	Union Station (Portland)	1.5
05	Kelso-Longview, WA	2	N/A	1.9
06	Steilacoom, WA	2	N/A	1.9
08	Tacoma, WA	4	Tacoma Amtrak Station	6.5
10	Seattle, WA	1	N/A	3.1
11	Seattle, WA	9	King Street Station (Seattle)	3.4
12	Seattle, WA	4	N/A	1.9
13	Seattle, WA	0	N/A	8.1
14	Shoreline, WA	0	N/A	4.8
15	Edmonds, WA Lynnwood, WA	2	N/A	5.8
16	Mukilteo, WA	1	N/A	2.3
17	Everett, WA	0	Everett Amtrak Station	2.2
18	Everett, WA	6	N/A	3.9
19	Marysville, WA	13	N/A	4
20	Mount Vernon, WA	7	Skagit Transportation Center (Mount Vernon)	2.4
22	Bellingham, WA	18	Bellingham Amtrak Station	18.4
24	Blaine, WA	1	N/A	1.4
26	Crescent Beach, BC	2	N/A	4.8
29	Surrey, BC Vancouver, BC	17	Pacific Central Station (Vancouver, BC)	19.5

Bridges

Bridges affected eleven slow sections, making them the third most common infrastructure problem. Bridges in the project area ranged from 56ft to 4755ft, crossing bodies of water from small creeks to the Columbia and Fraser Rivers, which are the two largest rivers in the Pacific Northwest. Some bridges can be inferred as a cause of slower speeds by being the main infrastructure feature along part of a longer slow section, such as the bridge over the Skagit River in Slow Section 20. Other bridges show more definitive slow speeds by having the slowest speed in the section for only the length of the bridge, such as the bridge over Salmon Bay in Slow Section 13. Bridges also resulted in the slowest speed limits overall, with major bridges in six of the seven sections of track having speed limits of 20 mph or less. Further details for each section can be seen below in Figure 24 and Table 4.

Table 4. List of slow sections affected by bridges.

Slow Section	Number of Bridges	Shortest Bridge Length (ft)	Longest Bridge Length (ft)	Main Bodies of Water
02	1	--	1767	Willamette River
02	2	1577	2808	Oregon Slough, Columbia River
06	2	238	262	Chambers Creek, 5th Street Waterway
13	1	--	1135	Salmon Bay
19	4	534	1072	Snohomish River, Union Slough, Steamboat Slough, Ebey Slough
20	1	--	1004	Skagit River
22	9	60	544	Whatcom Creek, Squalicum Creek, Chuckanut Bay, ravine
25	1	--	208	Campbell Creek
26	1	--	1505	Nicomekl River
27	1	--	2530	Serpentine River
29	3	90	4755	Fraser River, Brunette River

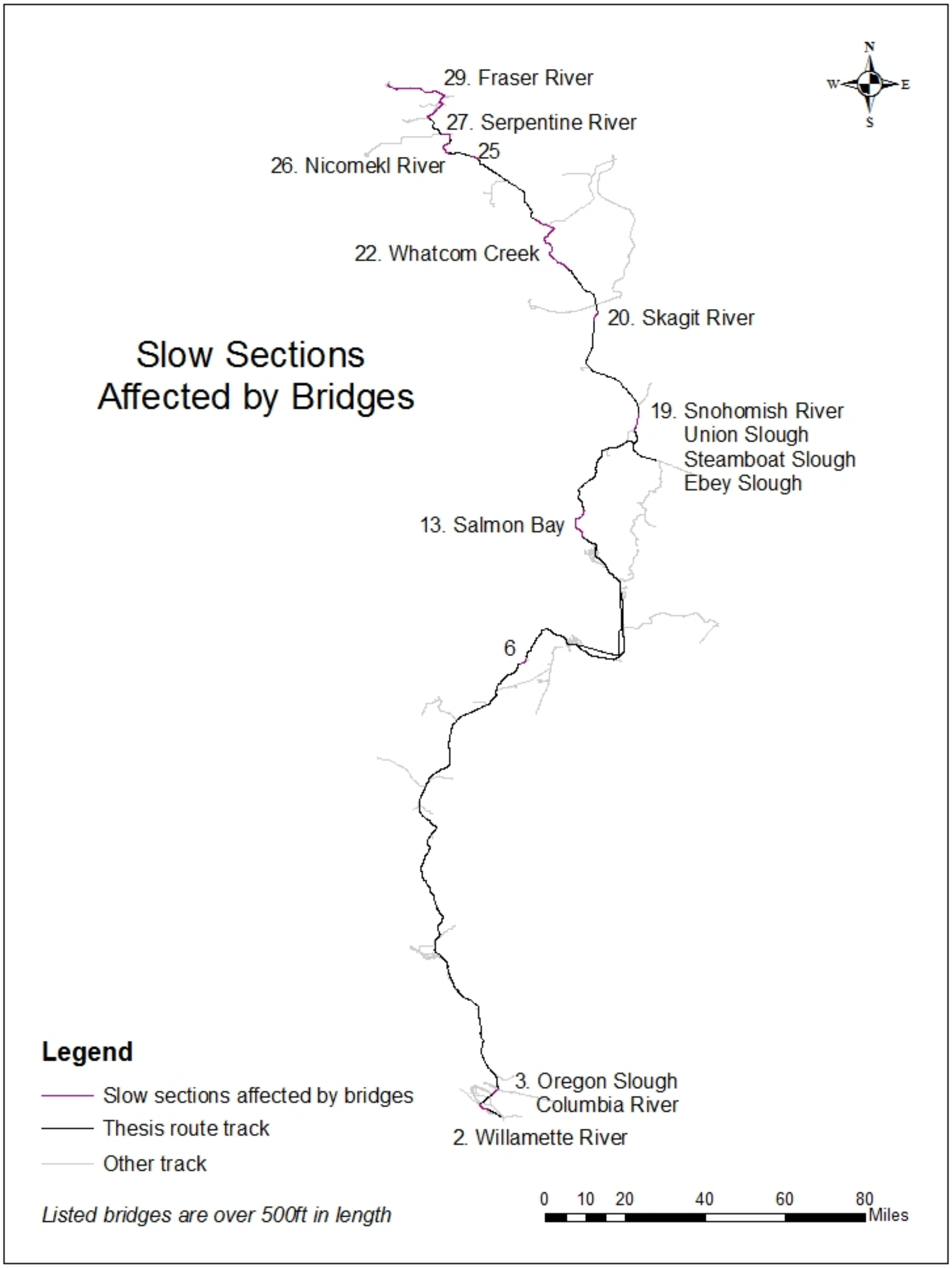


Figure 24. Map of slow sections affected by bridges.

Tunnels

Four of the slow sections contained tunnels that seemed to contribute to the slower speeds, and included seven of the nine tunnels in the study area. The tunnels ranged in length from 141.3ft to 5141.5ft. The speed limits in these areas ranged from 30-45 mph, with the two slowest sections also having two of the longest tunnels. These two tunnels additionally are located under the centers of Seattle and Everett, WA, which may contribute to the slower speed limits. The two tunnels that were not in slow sections are located just south of Tacoma, WA in a 60 mph speed zone, and include the second longest tunnel overall, the Nelson-Bennett Tunnel. The seven problematic tunnels can be seen in Figure 25 and Table 5 below.

Table 5. List of slow sections affected by tunnels

Slow Section	Tunnel Name(s)	Tunnel Length (ft)	Speed Limit (mph)
05	Ostrander Tunnel #3	1165	45
12	Seattle Tunnel #17	5141.5	30
17	Everett Tunnel #16	2440	33
22	Samish Tunnel #18	1115	45
22	Samish Tunnel #19	141.3	50
22	Samish Tunnel #20	326.5	50
22	Samish Tunnel #21	712	46

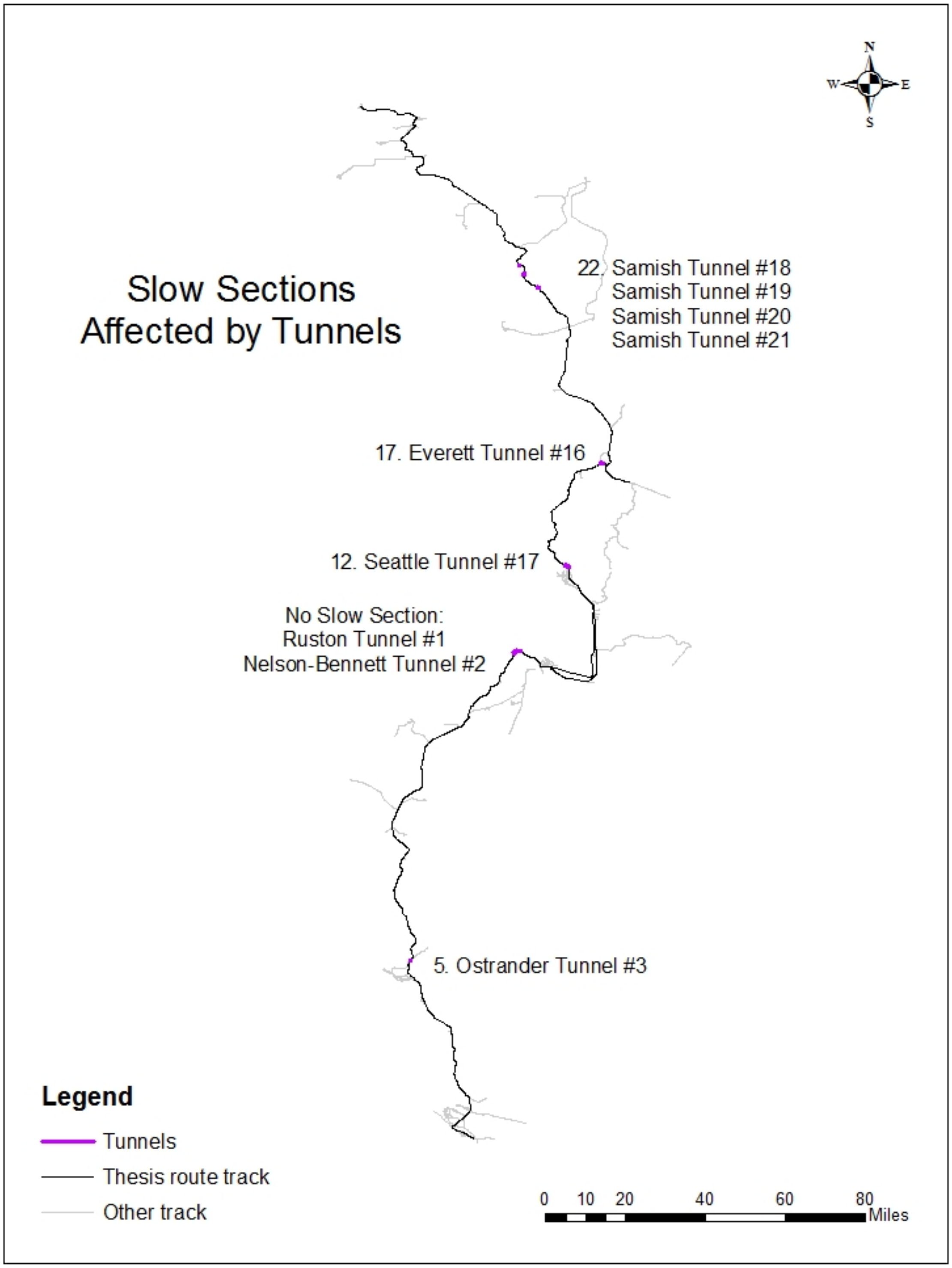


Figure 25. Map of slow sections affected by tunnels.

Other infrastructure problems

Six slow sections had problems other than curves, populated areas, bridges, or tunnels. These problems consisted of one section of track on a land berm in front of a lagoon, two sections on either side of the US-Canada border, two sections with steep inclines, and one section where I was unable to identify a clear infrastructure problem.

- Slow Section 7 consists of a section of partially curved track in front of a shoreline lagoon. The berm on which the track is located is the only barrier between the lagoon and Puget Sound. The track on the inside of the curve has a speed limit of 35 mph, and the outside of the track has a speed limit of 52 mph. If only the 3° curve was affecting the speed limit I would expect the speed limit to be 49-72 mph, so the 35 mph speed limit suggests that the berm location is also causing slower speeds. An aerial photo of the berm and track layout can be seen in Figure 26.

Figure 26. Berm in front of Titlow Lagoon (Slow Section 7). Photo from Google Earth.

- Slow Sections 22 and 29 both had short sections of steep inclines, either greater than +1.5% or less than -1.5%. In half a mile of Slow Section 22, in Bellingham, WA, the incline of the track shifts directly from -4.24% to +1.67%, or a steep downslope to a steep upslope, during which the speed limits are 40-46 mph. In Slow Section 29 in Vancouver, BC there is a similar situation where the track shifts from a -3.73% slope to a 2.64% slope over a mere 0.05 miles. The one final section with an incline over 1.5% has only a 1.52% incline and is located in a 79 mph section with no additional infrastructure problems.

- Slow Sections 24 and 25 are on either side of the US-Canada border, and both have a speed limit of 50 mph. While there are curves and the town of Blaine, WA on the United States side that could suggest slower speeds, the border is the only feature that would suggest slower speeds for this entire 2.7-mile long stretch.
- Finally for Slow Section 10 I had difficulty finding infrastructure problems that resulted in slower speeds. This section of track is a third mainline with speeds of 40-50 mph that parallels the two regular mainlines, both of which have speed limits of 79 mph. All three tracks share the same curves of up to 1.75° and the same three grade crossings. The third track even seems to be placed farthest away from the road and farthest away from the local industrial buildings. This leads me to the conclusion that some unstudied variable is causing the slower speed limits on this section of track.

Rails and ties

The rail and tie layers did not appear to have any major slowing effect for speeds under 79 mph, as far as the rail type, year, and weight or the tie type and year are concerned. Finer details about the rails and ties, such as the distance between the rails to less than an inch, the joints between sections of rails, and the number of ties in a given distance of rail can all affect the maximum speed limit, however these classifications tend to be constant for large stretches of mainline and result in higher maximum speeds than are currently on this route. (US GPO, March 13, 2014). When I compared the rail and tie layers to the speed layer, both overall and zoomed into the slow sections, I found few patterns, and none that directly suggested slower speeds. The two patterns I did notice were that lighter weight rails were usually the older rails, and that concrete ties were more likely to be found on curves. However there were 79 mph speed limits on everything from 115 lb/yd rail from the 1950s to 141 lb/yd rail built in the last five years. The ties had similarly little correlation with the speed, such as one section of track where age of the ties differed by twenty-two years between the two mainlines and both had a 45 mph speed limit.

DISCUSSION

Potential choke point locations

The causes of choke point locations can be considered in three different ways. They may be either the most problematic single infrastructure component along the entire study region, the stretch of track with the most problems, or the sections of track that if improved would immediately make longer sections above 60 mph. An example of this final situation would be a single infrastructure problem in an area of otherwise higher speeds. Some choke points are a combination of two or three of these situations.

Bridges were the most problematic single infrastructure component, as they caused the slowest speed limits. Six of the seven sections at 20 mph or below were due to a bridge, one example being the Ballard Bridge over Salmon Bay in Seattle, WA. Additionally there were a number of other slow sections that contained bridges, even if the speed limit was only reduced to 30-40 mph. The slowest speeds tended to be caused by the longest bridges. The bridges related to decreased speeds have previously been listed in Table 4, located in the results section.

The longest stretches of problematic track were the regions of Vancouver, BC, Bellingham, WA, Everett, WA, and Seattle, WA. Each of these areas had at least ten consecutive miles of slower speeds, which suggests that these areas might be the most in need of overall repair and upgrades. These four long slow sections are in heavily populated areas so they may be struggling with increased non-train traffic, such as busy grade crossings or pedestrians trespassing on the tracks. Vancouver, BC contains Slow Section 29, Bellingham contains Slow Section 22, Everett contains Slow Sections 17-19, and Seattle contains Slow Sections 10-13. Additionally they all have numerous problematic curves and at least one bridge that slowed a section of the speed limit to 20 mph or less. Vancouver, Everett, and Seattle all have rail yards, which may lead to slower speeds due to trains merging on and off of the mainlines.

The sections of track that if improved could lead to noticeably longer stretches of track over 60 mph are the slow sections due to individual curves. Along the project track there were five sections between 0.2 miles to 0.6 miles in length where the slow speed zone was located directly on top of a single curve, slowing the speed limit to 45-55 mph. These speeds are high enough that it may be less challenging to upgrade these sections enough to handle 60 mph or greater, which would mean the train could remain at higher speeds for a longer section of track.

Potential solutions to infrastructure-related choke points

Based on the results that curves, populated areas, bridges, and tunnels have the most noticeable effect on lowering speed limits, these would be the best infrastructure components to focus on for choke point remediation.

Curves could potentially be improved by redoing the curve alignment to be less sharp, increasing the superelevation, or possibly upgrading the ties. While there were no overall patterns between the ties and speed limits, I did notice some curves with speed limits over 60 mph have been upgraded in the last few years to have concrete ties, such as the one shown below in Figure 27. These curves tend to be in areas that otherwise have speed limits over 70 mph. Use of concrete ties might help increase speed limits, but it may also be related to the wear on the track caused by trains rounding curves at higher speeds. There could also be cost and maintenance issues that determine which type of tie is used where. Bridges and tunnels likewise could have engineering upgrades and retrofitting that allows trains to cross safely at higher speeds. One of the engineering challenges for bridges is that the train causes vibrations that increase with speed, which is one reason why some of the longest bridges may require the slowest speeds.

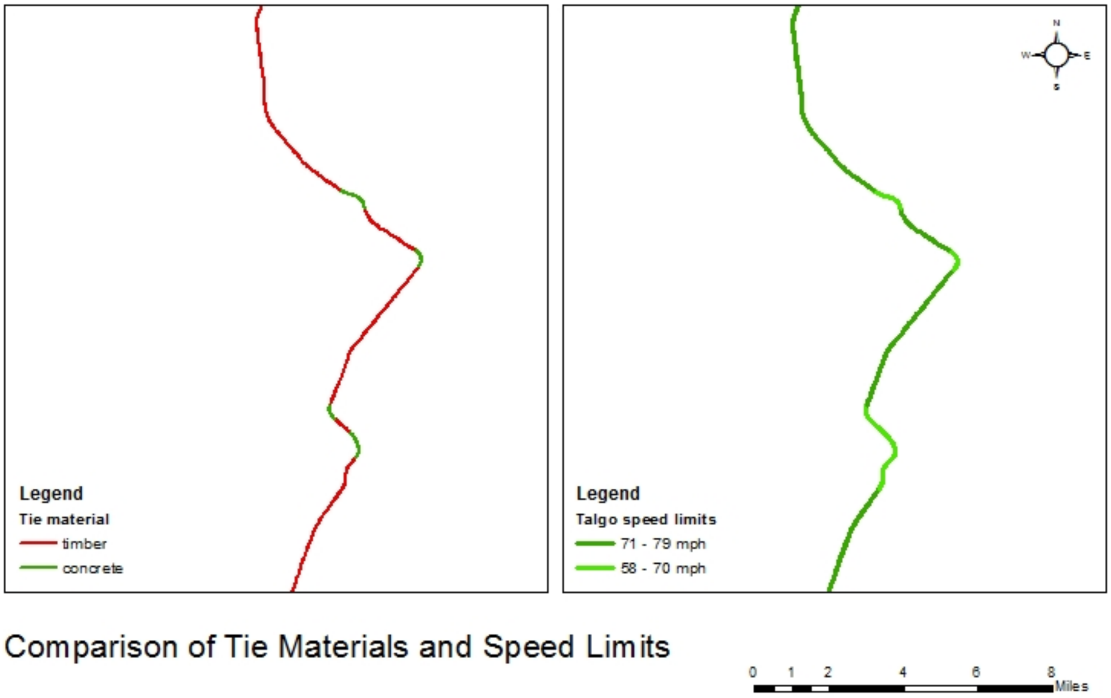


Figure 27. Comparison of curves with concrete ties and speed limit layer. This map shows recently replaced concrete ties on curves over 60 mph.

Populated areas are the most challenging issue to alleviate because of their complexity. Slow speeds in populated areas are related to actual and perceived safety concerns, as the more people there are in an area, the more opportunities there are for a person or a motor vehicle ending up on the tracks in front of a train. Railroads can work with local communities to improve the safety of the area by separating tracks from the surrounding area with fences or grade separation, upgrading crossing warning devices, restructuring crossings to have fewer grade level crossings, and making sure to maintain sightlines for both drivers and train engineers (Duncan-Cole, 2006). The can also wage public education campaigns about pedestrian and driver safety around railroads (WSDOT, no date). Currently, the Washington State Department of Transportation is working on implementing many of these solutions.

Connections with current rail improvement projects

My research only captures a portion of the infrastructure factors that influence train speeds, and focuses specifically on infrastructure components that are currently causing extremely low speed limits. The components that are currently causing major problems might be more or less of an issue in the future depending on upgrades along the route. The Washington State Department of Transportation and the many railroad companies and cities in the state are working on over one hundred rail projects, many of which are upgrades and replacements between Portland, OR and Vancouver, BC. The list of projects that are under construction or recently completed shows many similarities with the problems identified by this project, such as grade separation and bridge replacement. The projects that directly relate to the implementation of higher-speed rail can be seen in

Figure 28 below, but for a more complete list of projects statewide see Appendix 8 of the Washington State Freight Rail Plan. The current projects include at least four projects planned to upgrade bridges along the project route, including replacing the moveable span of the Ballard Bridge over Salmon Bay in Seattle. There are also numerous grade crossing separation projects under construction, which could help raise speeds in populated areas (WSDOT, 2009). Additionally there are infrastructure upgrades that involve component characteristics that this project did not take into account. Throughout Washington State BNSF Railway is upgrading and replacing rails and ties on the mainlines, as well as adding new track in the form of new or extended sidings and multiple mainlines (WSDOT, 2014). The effects of this project may be noticeable in my data, as the southern half of the project has both the most recently replaced track and most of the track running at over 70 mph. If the higher speeds between Portland and Seattle are a result of this partially completed project it could also be why I had a hard time detecting patterns between the speed and the rails and ties for the region as a whole. My project only focused on existing infrastructure; in contrast some of WSDOT and BNSF Railway's projects are the result of a recognized need for additional track due to rail lines currently being at or near capacity (WSDOT, 2013, Executive Summary p. x). In areas with single track if two trains need to pass each other one must pull over and wait at the nearest siding, which can lead to significant delay depending on train speeds and siding lengths and locations.

These 21 projects comprise WSDOT's federally funded corridor projects that will result in two additional round trips, 88 percent on-time performance, and a 10-minute reduction in travel time. The projects must be completed in 2017. The color coding represents the status of each of these capital projects.

Figure 28. Map of current infrastructure improvements along the Amtrak Cascades route. (WSDOT, no date, map).

Another point to consider is infrastructure components that may not slow the speed limit to less than 60 mph, but do prevent higher-speed rail. The most noticeable of these are grade crossings, combined with Positive Train Control (PTC). PTC systems are "integrated command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency" (USDOT FRA, no date). PTC systems help dispatch centers have more precise and up to date information about a train's location and speed, as well as giving the dispatch center some remote control over the train's speed. For example, PTC systems can be used to slow a train if it is speeding or if the crew becomes incapacitated. A law signed by President George W. Bush in the fall of 2008 states that all rail mainlines must be employing PTC systems by 2015 (WSDOT, 2008, Chapter 2 p. 5). Under current federal law, railroads must use PTC systems for trains to go over 79 mph, grade crossings are limited for speeds between 80-125mph and completely banned for speeds over 125mph (Gilleran, 2011, slides 6-8, 21). What the combination of these two rules means is that while grade crossings may not currently lower speeds they easily could in the next few years. There are many grade crossings along the entire stretch of project track, and they are located in a wide range of speed zones. Once PTC systems are in place in the next year or two, grade crossings could suddenly become an infrastructure component that prevents trains from going 110 mph or 125 mph.

Why do populated areas have slower speed limits?

Populated areas seem to have slower speeds due to safety concerns, both perceived and genuine. In a city or town there is a greater population density surrounding the track, leading to increased vehicle traffic at crossings and more opportunities for pedestrians to cross or walk along the tracks illegally. Residents of a town or city may file complaints about inadequate or malfunctioning warning devices at grade crossings. There may also be questions raised about the sightlines and visibility at crossings for both vehicle drivers and rail engineers (Duncan-Cole, 2006). Another thing unique to populated areas is that some cities and towns have designated sections of rail as “quiet zones”. These are sections that lessen the use of train horns when approaching grade crossings. Federal regulations do not mandate slower speeds within quiet zones, however maximum speed limits are one of many variables used to calculate risk levels when assessing whether or not an area can become a quiet zone. Federal regulations do mandate that all public grade crossings within quiet zones have active warning devices, advance warning signs, and automatic bells (US GPO, March 27, 2014).

CONCLUSION

Before high-speed rail in the United States can become a reality, there needs to be accurate knowledge of the existing rail infrastructure and rail choke points, as well as strong methods for analyzing infrastructure and choke points. This study focused on the use of GIS analysis to determine infrastructure-related choke points between Portland, OR and Vancouver, BC.

The decision to study infrastructure and choke point analysis using GIS evolved from the limited number of existing choke point analysis methods, and the recognition that GIS is a useful tool when studying spatial patterns. Currently, choke point analysis consists of using rail dispatch algorithms to simulate adding more and more trains to a route until traffic jams develop. These algorithms are supplemented by stakeholder input, such as day-to-day knowledge of where trains are frequently delayed. Infrastructure plays a key part in determining train speed limits, so it should be examined when doing choke point analysis. The location of infrastructure components and varying speed limits is a spatial problem, which suggested that GIS could be an effective new tool for choke point analysis because of the spatial visualization and manipulation it provides.

I started by collecting spatial data for the railroad main line between Portland, OR and Vancouver, BC. The data I used consisted of a geodatabase, track charts, and a timetable all provided by BNSF Railway, supplemented by a shape file of Amtrak stations downloaded from the United States Department of Transportation's Bureau of

Transportation Statistics. Through a combination of GIS attribute selection methods and manually extracting data from the track charts and timetable, I formatted all of the data into routes overlain with layers of infrastructure components. All of these routes were organized using linear referencing which allowed me to analyze the data using dynamic segmentation and vector reselection analysis. I compared the speed limits with each of the infrastructure components, looking for which components resulted in speed limits of less than 60 mph.

My research shows that the most common infrastructure-related causes of slow speed limits along the study route are curves, populated areas, and bridges. Most of the sections had two or three possible causes of slow speed limits, such as curves within a populated area. Of the twenty-nine sections with speeds below 60 mph, twenty-four sections had problems with curves, nineteen sections went through populated areas, and eleven sections were slowed by bridges. Tunnels only slowed four of the twenty-nine sections, however seven of the nine tunnels in the entire study area were included in these four slow sections. The remaining infrastructure problems consisted of two steep inclines and a handful of unique situations. The first steps to increasing the speed limits between Portland, OR and Vancouver, BC would be to upgrade some of the existing bridges, work on separation of track and the surrounding land in populated areas, and straighten curves. As much of the track follows its original right-of-way, along the waterfront and through the middle of cities, new right-of-ways may need to be considered for significant improvements in speed.

There is a lot of work to be done between the existing rail infrastructure and true high-speed rail at speeds of over 120 mph. Currently, passenger rail does not reach over 60 mph along 108.4 miles of the 341.73 miles of track, or nearly a third of the study area. On the rest of the track the highest speed limit is 79 mph due to a lack of positive train control (PTC). Although all passenger rail lines are supposed to use PTC by 2015, and use of PTC could raise speed limits in some areas above 79 mph, it will not automatically raise other slower infrastructure-related speed limits. As long as rail lines in the Cascadia region are shared with freight rail I see some form of higher-speed rail as the most likely future. Infrastructure improvements allowing for on schedule trips averaging speeds of 80-120 mph would be a great improvement over the existing system, and would provide a faster way to travel along the I-5 corridor than by automobile. The existing system provides a strong foundation for higher-speed rail, and WSDOT, BNSF Railway, and numerous other stakeholders, such as local cities and short-line railroads, have already begun investing in better rail infrastructure (WSDOT, 2009).

GIS is an effective tool for analyzing rail choke points, and provides a good compliment to track charts when trying to spatially analyze rail infrastructure. Track charts are formatted to be five-mile lengths of track drawn as a straight line, whereas in a GIS environment the user can see spatial patterns in their true shape, both for the overall region and in close detail. For example, in this project I was able to look at the speed limits overall and see that they correlated with the major urban areas in the region – Portland, OR, Seattle, Tacoma, Everett, and Bellingham, WA, and Vancouver, BC. A more focused view of the speed limits compared with the bridge layer allowed me to pinpoint the exact location of some of the longer bridges due to the extremely slow speed limits. Using only a track chart I might be able to see the correlation between bridges and speed limits, but it would be much harder to see the broader trends. I did find that one major advantage to using track charts is that they allow the user to see all of the infrastructure components at the same time. In comparison, when using GIS I had to keep switching back and forth between the different layers since they all share the same physical location.

A challenge to using GIS is the quality and availability of the data needed to make a detailed dataset for GIS analysis. While I was able to get some of my data already in a GIS format, namely the geodatabase, it did not contain very many infrastructure components, and was missing a few sections of track for the components it did contain. The result of this was that I had to manually extract data from the track charts to complete my GIS dataset. The milepost measuring tape on the track charts marks down to the tenth of a mile, which allowed me to estimate down to the hundredth of a mile, or roughly 50ft depending on the length of that milepost mile. The data in the geodatabase normally measures location to the hundredth or thousandth of a mile, so my manual measurements were reasonably precise. Another challenge I had when acquiring data was that the bridge locations in the track chart did not match up with actual locations, such as the bridge across the Columbia River in Portland, OR being listed as going from MP 9.6 to MP 10 when MP 9.8 is already past both the end of the bridge and the boundary with another subdivision. I ended up using an overlay of the tracks in Google Earth and Google Earth's measurement tool to calculate the locations of the bridges more accurately than the track charts allowed. Both the irregularities in bridge location and the need to manually extract data from the track charts meant that I had to revise my original plans for data acquisition and formatting. They also reinforced the fact that identification of choke points using GIS relies on the precision and detail of the inputted infrastructure data.

Overall GIS was a successful and novel tool to investigate infrastructure-related choke points on rail lines. I was able to pinpoint choke points and potential infrastructure causes for these slow speeds, and my results overlap with the current rail improvement projects that are currently being undertaken by WSDOT and BNSF Railway (WSDOT, 2009). Since my work identified many similar problems to those identified by traditional algorithmic techniques, I believe that GIS is correctly identifying choke points. An advantage of using GIS analysis along with the traditional methods of choke point identification, such as train scheduling algorithms and stakeholder reports, is that it does not depend on frequent interaction with the existing train traffic, allowing for a fresh perspective on areas of improvement. This means GIS could also be very useful when trying to rehabilitate lines that are currently underutilized, but which may have more train traffic in the near future, such as when a new market or shipping location gets connected to the rail system. An example of a shipping location with the potential for a massive increase in rail shipments is Port Prince Rupert in British Columbia. This region could see a major increase in rail shipments due to recent expansions and upgrades that allow it serve some of the biggest container ships in the world, combined with its strategic location between Asia and Canadian cities (A. Finkelstein, personal communication, January 1, 2014). Since this study only focused on a single region of track, there is potential for future research using GIS analysis for choke point identification in other regions of the world with varying levels of existing infrastructure. There is also potential for future research in this same region in a few years after the implementation of PTC and completion of current infrastructure improvement projects.

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