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a planning methodology for railway construction cost estimation in north america

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Abstract

The railroad industry is expected to see increased demand in the United States (U.S.) over the next 30 years. This demand will put a strain on the infrastructure and its ability to provide timely and efficient service. Various technologies are currently available to increase railroad capacity, but in time new trackage will either need to be added to existing routes, built as new routes, or existing routes be upgraded to a higher speed classification. Anticipating these costs is a challenge, since few railroad miles are constructed annually and there are various factors affecting costs. However, it is possible to calculate cost per mile (CPM) accounting for right-of-way (ROW), design and build, materials, communications and signaling, and electrification, where applicable. This thesis presents a methodology for estimating CPM of railroad construction in the U.S. as a function of design speed, geography, land use, number of tracks, and motive power. The proposed CPM estimates were compared to CPM estimates from feasibility studies, and resulted in the majority of costs being replicated by the methodology. The proposed methodology has been developed in an adaptable manner, where future project cost components may be included, creating a dynamic estimation methodology for analysis and planning activities, prior to feasibility study analyses.

Chapter 1 - Introduction

The railroad industry is expected to see increased demand in the United States (U.S.) over the next 30 years (Cambridge Systematics, 2005) (Cambridge Systematics, Inc, 2007) (CBO, 2006) (Weatherford, et al., 2008). This demand will put a strain on the railroad infrastructure and its ability to provide timely and efficient service. Various technologies are currently available to increase capacity, but in time new trackage will either need to be added to existing routes, built as new routes, or existing routes upgraded to a higher speed classification. Anticipating these costs is a challenge, since few railway miles are constructed annually and the numerous variables involved mean that each is different from another. However, it is possible to calculate cost per mile (CPM) estimates accounting for right-of-way, the design and build, materials, communications and signaling, and electrification, where applicable.

This thesis presents a methodology for estimating the CPM of railway construction in the U.S. for use in planning analysis and activities. These estimates make it possible to anticipate costs for current or future routes based on the top speed, terrain, land use, number of tracks, and motive power.

1.1 Research Objectives

The objective of this research is to develop a railway construction CPM estimation methodology that accounts for major factors affecting design, while being available in a simple and adaptable format. This research is meant to provide transportation planners and policy makers with a systematic process for estimating costs that are representative of the area and service in question, for analysis and decision making purposes. This methodology is not meant to replace the depth and detail of feasibility studies or professional railroad planning activities, but rather to be used as an intermediate tool to allow planners to more easily perform railroad analysis and planning activities on their own, prior to contracting out feasibility studies.

1.2 Anticipated Benefits

Predicting the exact costs of railway construction is very difficult, if not impossible. But being able to determine realistic and representative estimates based on influencing factors that will factor into the cost of the railway, will allow a wider range of analysis to be performed by planning personnel and therefore shorter time to satisfy decision making deadlines concerning network and service demands. The proposed CPM estimation methodology would be used as one of the first steps in the planning process. Due to the capital intensiveness of a railroad construction project, preliminary estimates of project costs can help to determine whether planning for such a project would be beneficial. The CPM methodology is not intended to replace the use of feasibility studies that provide the accurate cost estimates as well as ridership and economic impacts. But rather, the CPM methodology could be used as a qualifier for project advancement in the planning process, and may help the planning entity utilize resources and funds more efficiently.

1.3 Organization of this Thesis

This thesis is organized as follows: Chapter 2 includes a literature review documenting the need for capacity enhancements from freight and passenger traffic, capacity improvements currently available, as well as current methods of cost estimation and their associated benefits and challenges. Chapter 3 discusses the factors that influence the cost of railway construction and the resulting cost components defined as design criteria used to capture those influences. Chapter 4 discusses the results of the methodology, including trends and patterns as exhibited by select design criteria. Chapter 5 includes a comparison, validation, and discussion of the estimation methodology with individual and categorized study costs. Lastly Chapter 6 offers the conclusions and limitations of this research, as well as recommendations for further research.

Chapter 2 - Literature Review

2.1 Overview of the Railroad Industry

The current railroad network in the United States (U.S.) is the product of 180 years of development (Armstrong, 2008). Specifically, today's network is the result of an industry-wide contraction in the last 60 years, where mergers, abandonments, and consolidations have taken a former network of some 250,000 route miles in 1916 to roughly 120,000 as of 2010 (Armstrong, 2008). As a result the industry has tailored operations for efficient transportation of the current levels of demand, but may not be capable of supplying the capacity to meet future demand. It is common to encounter different descriptions of the structure upon which rail operations are performed, the most common being a railroad or railway. To simplify the use of these terms, the American Railway Engineering and Maintenance of Way Association differentiation will be used, where "railway" describes the track and other integral items upon which rail operations can be performed. Use of the term "railroad" will describe the company or industry that owns and/or operates the sum of railway assets (American Railway Engineering and Maintenance of Way Association, 2003).

2.2 Freight Demand: Past, Current, and Future Trends

Four reports have been published since 2005 that highlight the state of the current U.S. railroad network, and discuss how future demand will require significant investment as capacity to fulfill that demand is not currently in place. In 2005 Cambridge Systematics Inc. documented how the economics of railroading do not provide adequate income for railroads to expand their infrastructure to handle increasing business for even the normal growth of their market share. As a result the railroad network might not be able to handle the estimated 44% increase in demand by 2020 (Cambridge Systematics, 2005). In 2006 the Congressional Budget Office documented the railroad industry's inability to fund capacity improvements that would result in the need for public funds and highway capacity to satisfy anticipated increase in demand of 55% by 2020 (CBO, 2006). In 2008 Cambridge Systematics in association with the Association of American Railroads outlined the current capacity conditions of the US rail network as woefully prepared for anticipated 88% increase in demand for 2035 traffic levels (Cambridge Systematics, Inc, 2007). And in 2008 The RAND Supply Chain Policy Center anticipated the doubling of freight volumes in the next 30 years, on a network that is wholly unprepared to handle such volumes (Weatherford, et al., 2008).

While the estimates of freight demand in the future vary by report, all reports lead to the same conclusion: without infrastructure and capacity improvements, the ability of the U.S. railroad network to provide satisfactory service in the future is questionable. Each report in turn recommends different technologies and investments that would bring an acceptable level of service (excess capacity compared to demand) to the railroad industry given the predicted increase in freight demand, including the addition of railways to the current network.

To further discern how the national railway system came to this position, a review of its history is necessary. The history of the railroads in the past 50 years is one of economic survival. Up until the Staggers Act of 1980, railroads were subject to greater regulation of services and prices. Because of this regulation, along with factors such as mode shift, economic conditions, and railroad crises (for example the Penn Central & Rock Island Bankruptcies), market share for railroads was lost to other modes, as shown in Figure 2-1 (Saunders Jr., 2003).

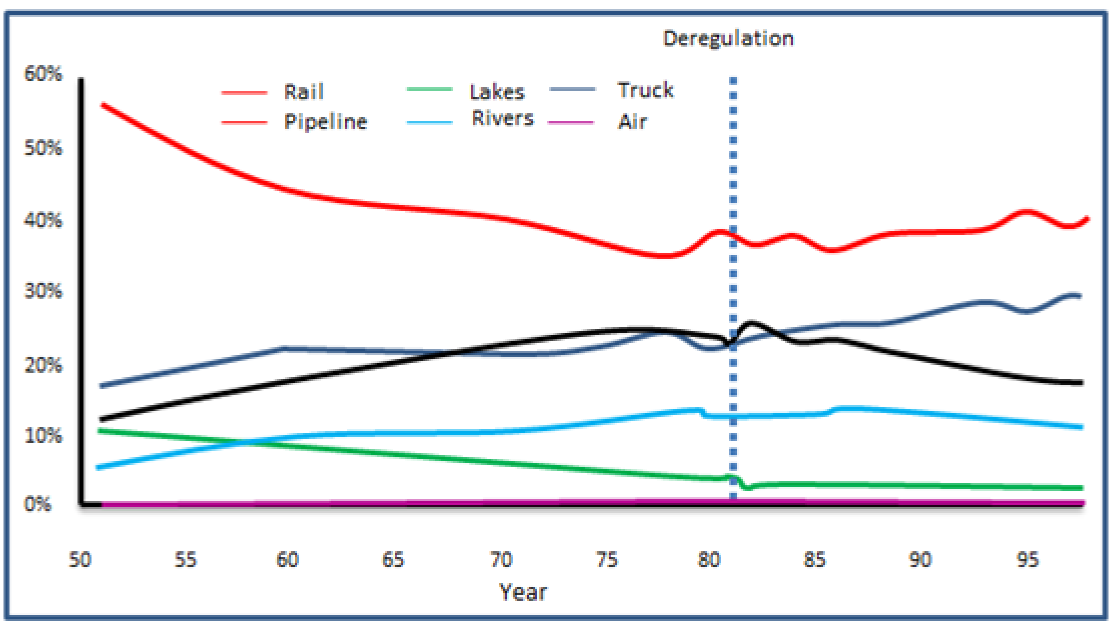

Figure 2-1: Mode Market Share as a Percentage of Intercity Ton-Miles (adapted from (Cambridge Systematics, 2005))

To survive, railroads abandoned track, merged or were acquired, and eliminated labor and services that were deemed antiquated. The Staggers Rail Act of 1980 removed many regulatory restraints, which allowed business practices and rate changes that brought about the first upswing in traffic in decades and a new era of economic strength for the railroads (Federal Railroad Administration, 2010). In that era, capacity was not the concern it is today, where railroads typically had excess capacity due to a shrinking market share, from 737 billion revenue ton-miles (RTM) in 1944 to 572 billion RTM in 1960 and a slow recovery from that figure until the 1980's (Murray, 2006). Since this time period, deregulation and increases in traffic has caused the industry's freight traffic to increase. Figure 2-2 shows the timing and relationship of total mileage and tons originated. Around 1990, 1,500 tons were originated and by 2005 grew to 1,900 tons, a 21% increase.

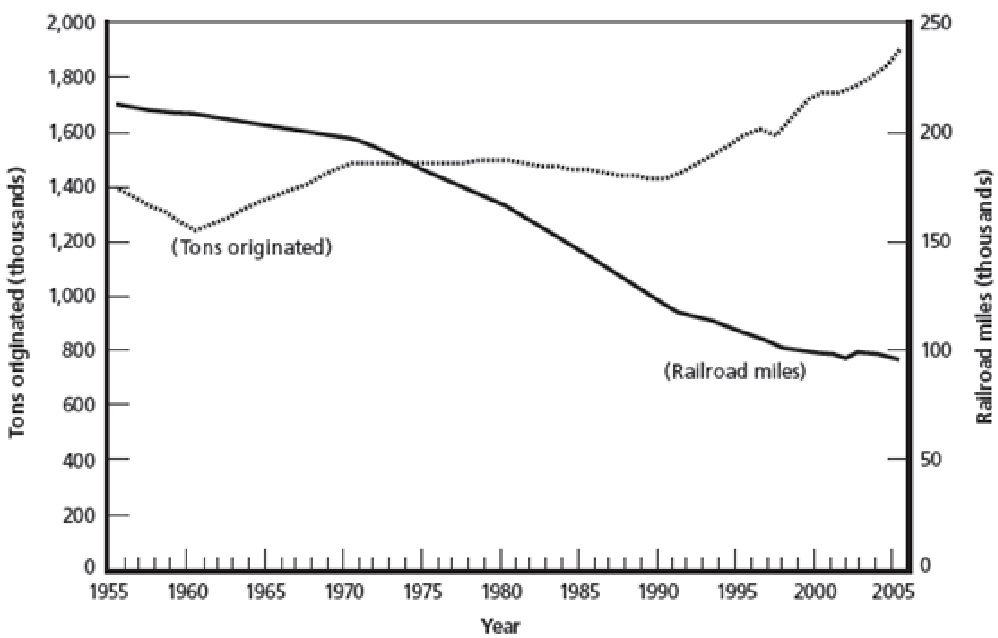

Figure 2-2: Miles of Railroad and Tons Originated (1955-2005) (Weatherford, et al., 2008)

Similarly, train miles, which are the total miles traveled by all trains upon the total track network available for travel, more than doubled from the time of deregulation to 2004 as shown in Figure 2-3.

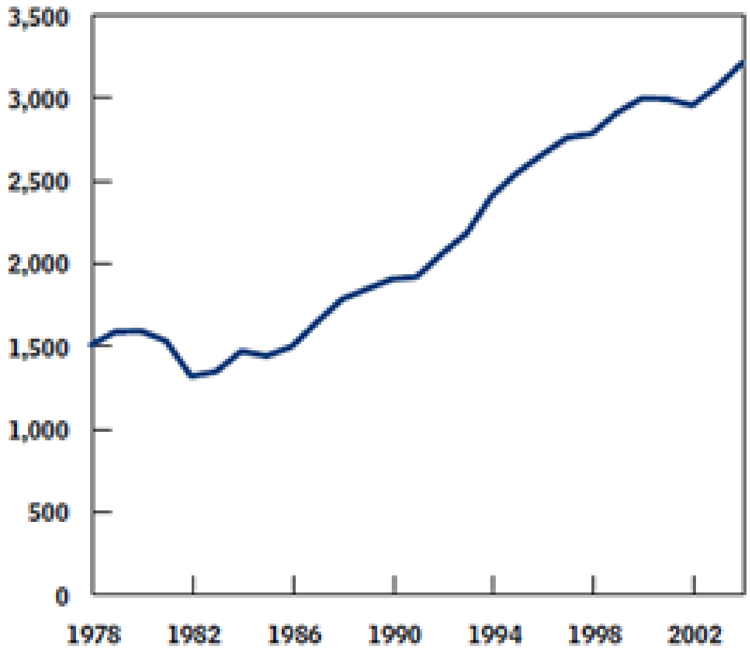

Figure 2-3: Trains-Miles per Track-Mile for Class I Railroads, 1978 to 2004 (CBO, 2006)

These figures clearly show the boom of the railroad industry in the last 30 years. Table 2-1 gives an indication of the increases in business where the US railroads may experience a lack of capacity on the aggregate national system. For example a 47.4% increase in rail tonnage on average may be seen from 1998 to 2020 (CBO, 2006). This increase represents a segment of demand that may become more of an operational burden than an economic benefit to the railroad industry.

Table 2-1: Freight Rail Traffic, 1998 and 2020 (adapted from (CBO, 2006))

Commodity Group	Freight Rail Traffic in 1998 (Millions of tons)	Freight Rail Traffic Projected for 2020 (Millions of tons)	Growth, 1998-2020 (Percent)	Growth, 1998-2020 (Millions of tons)
Clay/Concrete/Glass/Stone	53.2	121.8	128.9	68.6
Food and Kindred Products	103.5	228.1	120.3	124.6
Freight All Kind	96.4	187.3	84.3	90.9
Lumber/Wood	62.3	119.5	91.9	57.2
Waste/Scrap Materials	43.3	76.9	77.7	33.6
Chemicals/Allied	153.2	268.9	75.5	115.6
Pulp/Paper/Allied	46.7	79.1	69.3	32.4
Primary Metal	62.7	101.2	61.5	38.6
Transportation Equipment	45.5	63.7	40.1	18.3
Petroleum/Coal	45.4	63.3	39.4	17.9
Farm	153.9	208.4	35.4	54.5
Coal	829.6	1,065.7	28.5	236.1
Nonmetallic Minerals	151.1	192.9	27.7	41.8
Metallic Ores	76.0	57.0	(25.0)	(19.0)

The “ill-effects” of freight demand constraints that are expected to occur, can be examined in an analysis by Cambridge Systematics Inc. (Cambridge Systematics, Inc, 2007). Figure 2-4 shows the 2005 levels of service (LOS) on the primary rail freight corridors, with the majority of the network being capable of handling traffic satisfactorily. Only a few lines suffer from demand that exceeds capacity (Levels E and F). The majority of these problem locations may be attended to in a reasonable amount of time by the home railroads, with investment in capacity-enhancing technologies. It is beyond this base line LOS that attention to future demand be given.

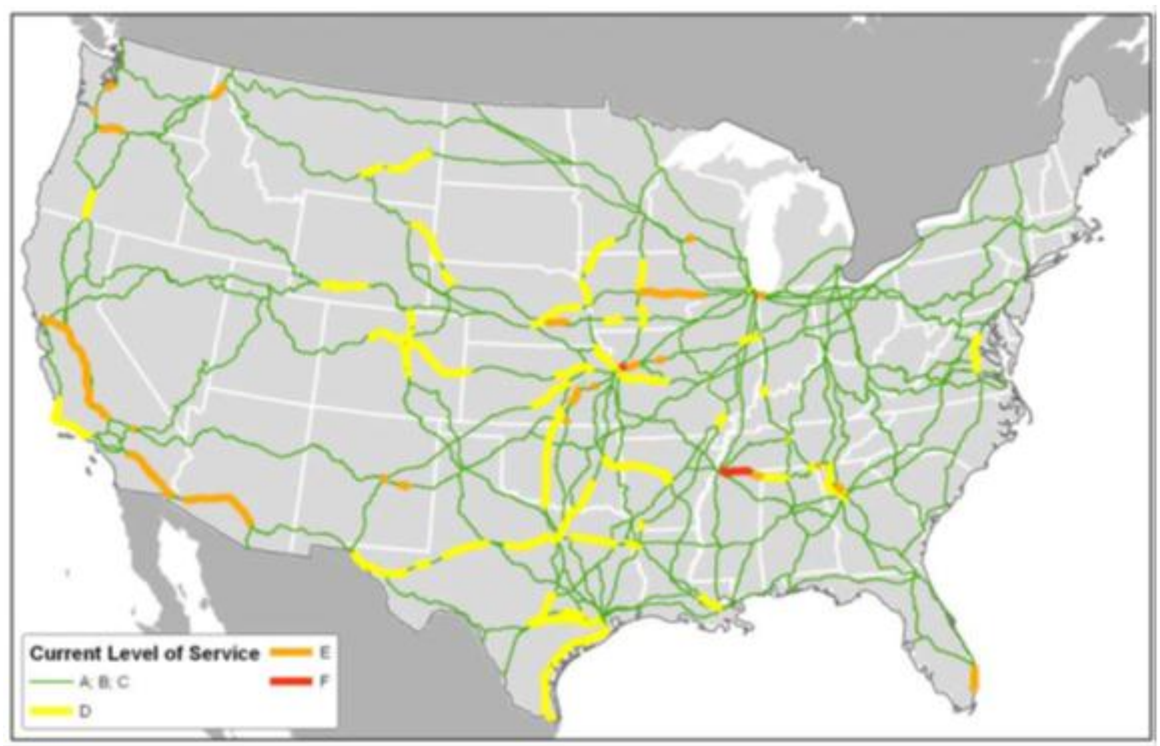

Figure 2-4: 2005 Level of Service (Base Line) (Cambridge Systematics, Inc, 2007)

Figure 2-5 represents the primary rail freight corridors in 2035 without any capacity enhancing investment. Results show that the majority of the network will be operating at a poor LOS and as a result, freight may either be shifted from the railroads to the national highway and interstate network, or transit time will increase. These changes may result in negative effects to the economy and general public, as monetary and travel time costs would affect the transportation and manufacturing of nearly every commodity, due to the current time critical business practices such as:

lean manufacturing, Six Sigma, just-in-time delivery, and warehouse inventory controls.

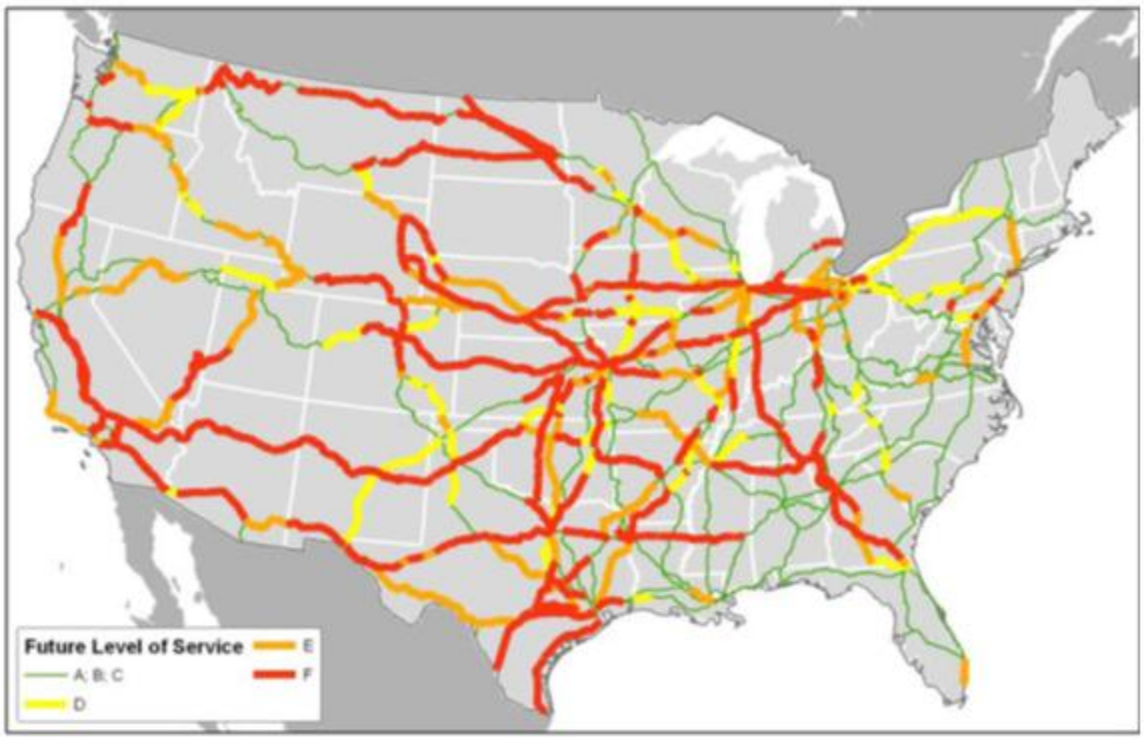

Figure 2-5: 2035 Level of Service (without investment) (Cambridge Systematics, Inc, 2007)

Whereas Figure 2-5 represents the effects of no investment, Figure 2-6 represents the level of service possible in 2035, if appropriate investment is allocated to the national network. Similar to 2005 LOS, Figure 2-6 shows how the investment of $148 billion in 2007 money would keep the national network up to acceptable service standards. The investment package recommended by Cambridge Systematics Inc. includes a combination of communications, railway, and support facilities enhancements to handle the increases in demand. Most important of all is the recognition that the private railroads may not be able to handle these capacity improvements themselves, so public money may be needed to ensure that demand does not have a negative effect on the general well-being of the country. This demand satisfaction by a private-public effort will require tools such as a reasoned railway construction estimation methodology. Preliminary analysis and cost estimation may need to be conducted outside of typical cost-estimation strategies in-order to provide some of the necessary planning estimates, before feasibility or engineering studies are performed.

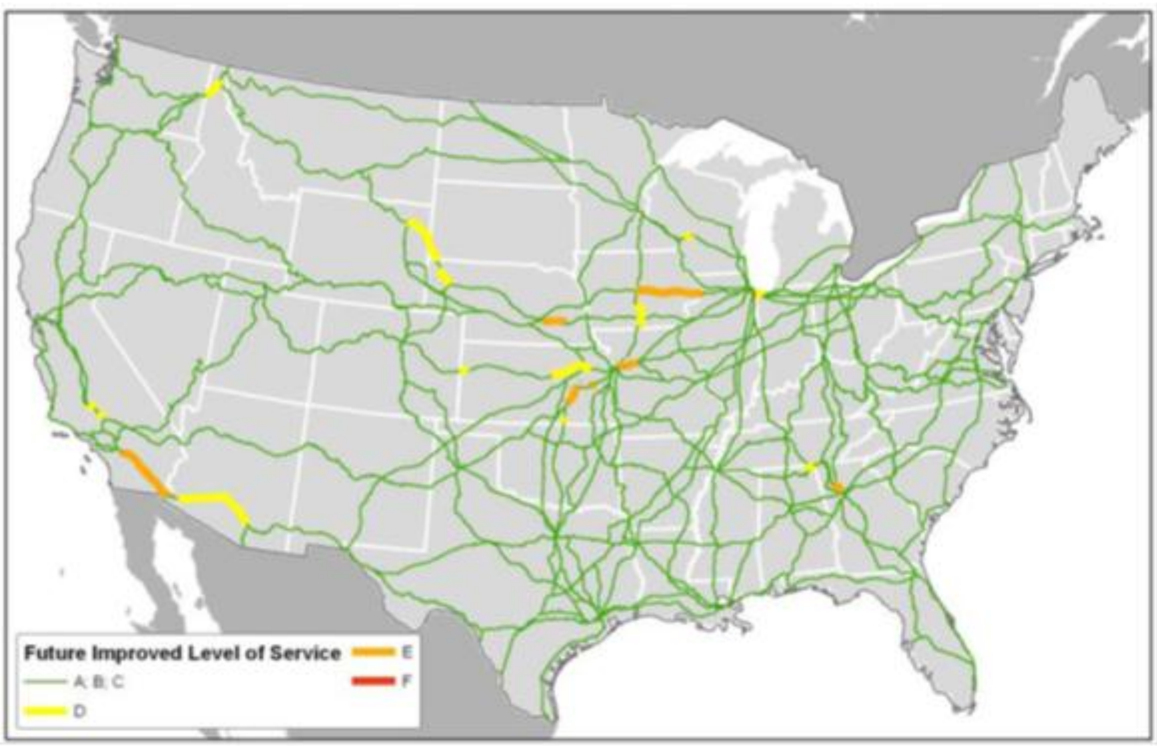

Figure 2-6: 2035 Level of Service (with investment) (Cambridge Systematics, Inc, 2007)

2.3 Passenger Demand: Future Trends

Passenger traffic increases may also result in the need for additional capacity and railways construction. Passenger services include high-speed-rail (HSR), long distance, and commuter-train operations. Increasing population density in major population areas, coupled with current capacity constraints on traditional transportation infrastructures (such as highway), and increased interest in renewable fuels, may make travel by rail a necessary and sustainable mode choice (Federal Railroad Administration, 2011). Figure 2-7 exhibits the emerging mega regions of the U.S. and the areas that influence the anticipated activity in each (Hagler, et al., 2009).

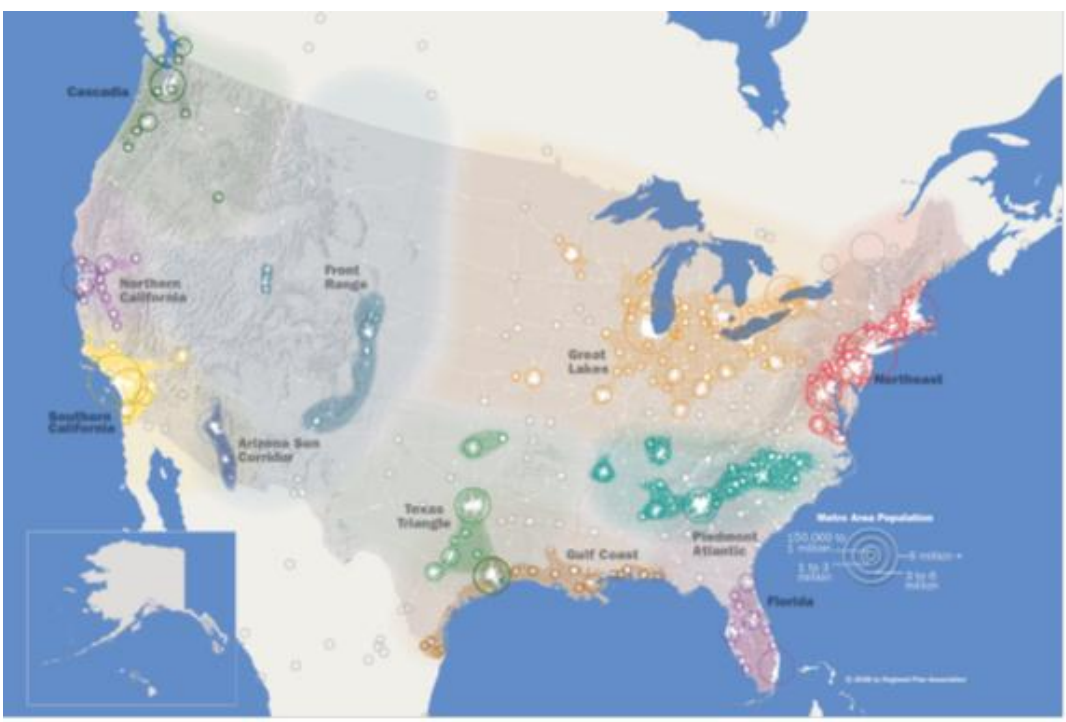

Figure 2-7: Emerging Mega Regions of the U.S. (Hagler, et al., 2009)

These regions are currently connected via road, air, conventional rail, and 150mph HSR (Amtrak's Northeast Corridor). In the future, additional HSR is seen as an essential mode to allow connectivity in an efficient manner. As a result, the Federal Railroad Administration (FRA) has identified multiple candidate corridors for HSR, as exhibited in Figure 2-8. The FRA's vision involves corridors of current traffic that would either benefit from additional mode choices or where anticipated growth trends suggest that proactive planning will help to serve demand at its source (Federal Railroad Administration, 2011). As of the summer of 2011, federal funding has been allocated to the selected corridors, but represents only the initial funds needed to complete the projects. Current budgetary contractions may cause the next round of funds to be reallocated and result in a delay of the services. But the factors that make HSR attractive will only continue to attract attention, making the vision all the more justifiable (Federal Railroad Administration, 2011). With the delay in funding, the planning period for such services will be pushed back. When funding begins again, analytical and planning activities would likely happen within a short time frame as the immediate and looming demand to be served would call for a faster planning period than before.

Figure 2-8: Designated HSR and other passenger rail routes (Federal Railroad Administration, 2011)

2.4 High Speed Rail Systems

Within the general concept of HSR, there are multiple maximum speeds that require differentiation. Each speed is able to offer certain benefits for associated costs, allowing a mix of service options to best fit the need of the area in question. Classifications of service by speed have been done by agencies such as the FRA, which defined them as Emerging (up to 90mph), Regional (90 –125mph) and Core Express (125 - 250mph) (Administration, 2011). This classification may be appropriate for distinguishing the service as expected by the ridership, but in terms of railway construction, a new set of classifications is necessary. The classification used in this research includes; Conventional (79 - 90mph), Incremental (110mph), Higher-Speed (125mph), High-Speed (150mph), and Very High Speed (220mph). This reclassification allows the planner to analyze an individual service, rather than grouping of services as denoted by the FRA definitions (Federal Railroad Administration, 2011).

Conventional - represent passenger operations at 79mph to 90mph on existing infrastructure alongside freight services. In most instances, these conventional services are operated upon the private freight railroad right-of-way (ROW) as a tenant. Therefore, improvements in capacity will be provided by the freight railroads. Nearly all commuter and Amtrak services are considered conventional (Peterman, et al., 2009), (SunRail, 2011), (Morlock, et al, 2004).

Incremental - represent projects that operate at 110mph maximum speed on existing track along with existing freight services or alone. The maximum speeds attained are low enough that safe operation with the appropriate communications and signaling (C&S) system allows mixing of services. Above this speed level, the speed differential is too great to justify the mixing of services and a dedicated and separate infrastructure is needed (White, 2000). Incremental HSR will be found in secondary markets where the benefits from ridership demand are not great enough to warrant the expenses incurred with faster service speeds. An example of incremental HSR is the Chicago to St. Louis corridor service that is currently being upgraded to handle 110 - mph passenger service on Union Pacific infrastructure

(TransSystems, Parsons, 2009).This case shows that incremental HSR can be planned as a stepping stone to full right-of-way construction and greater service speeds. Political wrangling and public concern may delay plans or studies of higher speed systems as, the technology may be too unfamiliar to the legislators and general public.

Higher-Speed and High-Speed - represent projects that operate at 125mph and 150mph. The speed differential with freight services is too great at this speed, requiring a separate infrastructure to operate above conventional passenger service speeds. Amtrak's North East Corridor is the only example of High-Speed service in the United States, with only portions of the Washington DC to Boston line allowing the maximum designed speed of 150mph to be reached (Amtrak, 2010). These service levels may comprise a great share of the services necessary for the emerging mega regions as shown in Figure 2-7. In these regions, the potential ridership and service characteristics will require something faster than 110mph, but the region may lack the characteristics and ridership pool for which a 220 - mph service is warranted.

Very High-Speed - represent projects that are designed for 220 - mph maximum speed. There are currently no examples of this service speed in the U.S., but several proposals are being developed. The California High Speed Rail Authority has a master plan that includes a 220 - mph service connecting Los Angeles to San Francisco and Sacramento and San Diego (California High-Speed Rail Authority, 2009). At this time the project has begun preliminary construction, but lack of the total funds and questions on the accuracy of the ridership estimates have generated public and private concerns (Cox, et al., 2008). Amtrak has also released a plan to design a new North East Corridor with 220mph service between Washington D.C. and Boston, totally independent of the current route (Amtrak, 2010). An ambitious plan from the US High Speed Rail Association, promotes the vision of a national system of primary 220 - mph and secondary 110 - mph networks, as shown in Figure 2-9 (US High Speed Rail Association, 2011). It is debatable whether a vision of this nature may occur, but significant changes in social, economic, and environmental considerations may result in significant national transportation policy changes such as this.

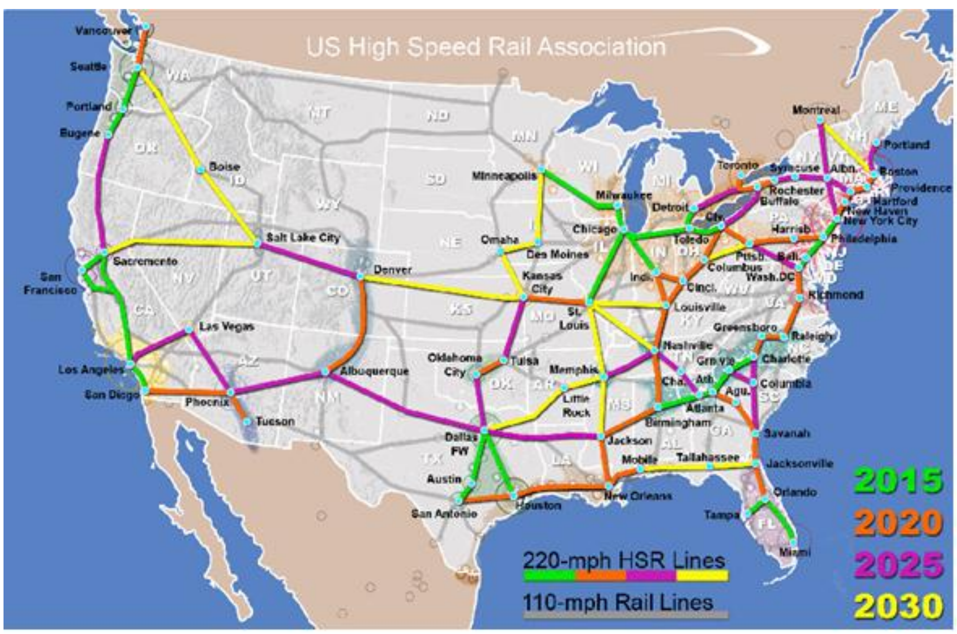

Figure 2-9: US High Speed Rail Association 4 Phase National HSR Rail System (US High Speed Rail Association, 2011)

2.5 Railroad Network Capacity Enhancements

Increasing railroad network capacity can be achieved without the construction of new rail lines. In fact there are cheaper options that can help to gain efficiencies that maximize the existing track configuration and train control technologies. However at a certain point these improvements will no longer be able to cope with demand and therefore new construction may be warranted. This section discusses some of the enhancements that railroads may implement before considering new rail line construction.

Communications & Signaling [C&S] – For simplification, the C&S systems include Warrant Control, Automatic Block Signaling (ABS), and Centralized Traffic Control (CTC) (Cambridge Systematics, Inc, 2007). Each system offers increased capacity, albeit with increasing costs. Installation of new C&S systems would be one of the first options for capacity improvements, as it will decrease the degradation of the weakest infrastructure elements, at a lower cost than other technologies such as train or car specific technologies. Upgrading CTC from Warrant Control for one track would cost $700,000 per mile, while upgrading the system from ABS to CTC for one track would cost $500,000 per mile (Cambridge Systematics, Inc, 2007).

Rail car capacity – This involves the introduction of a rail car that is capable of hauling greater loads as rated per axle. This increased capacity per car, would allow more product for the same number of cars, but would result in operational changes or improvements, such as additional locomotives to haul the train and rail hardware upgrades to handle the increased weight. As a result, the cost for the increased capacity rail cars, together with the cost of new rail hardware (tracks and ties) may result in a considerable investment. In 2009, the average cost for a new freight car on a Class I railroad was $98,090. If capacity were to increase, this would result in a higher cost of the new car, as well as the potentially higher cost of increase maintenance and replacement components (Association of American Railroads, 2010).

Electrification – This is the replacement of diesel-electric locomotives with locomotives operating via an electrically-fed infrastructure parallel to the railway. Some of the benefits of electrification include;

- Increased performance of acceleration and deceleration
- Closer headways
- Greater horsepower per locomotive
- Regenerative braking that results in energy normally lost as heat transferred back into the electrical system
- Fewer moving parts resulting in fewer and less costly routine maintenance inspections.

Operationally, electrification may result in more or longer trains per a given distance, thereby enhancing the efficiency and capacity of the operation on current as well as on an expanded capacity railway. However, electrification will pose a significant load on the national electrical grid to feed such an operation while serving all other energy demands at the same time.

The cost of an electrification project is very capital intensive, requiring a considerable amount of continuous track, new locomotives, power stations, and catenary systems. Installation of an electrified infrastructure would require a significant short term investment, with a slow return on investment (ROI) in the form of energy savings that may take years or even decades to recoup.

Structures – These are the elements of a railway that allow it to traverse its path over or through natural or manmade obstructions. Typical structures include bridges, tunnels, and culverts. The cost of structure improvements can vary depending on many variables, but once completed may result in a benefit for every train that operates on that railway.

Facilities – These are the yards, sidings, maintenance, and facilities that allow trains to navigate freight from origin to destination with minimal dwell time, and efficient equipment utilization, thereby allowing reliable service. Investments in facilities can include expanded and enlarged facilities, or even the construction of new facilities. Both could be done strategically to allow the greatest utilization of the investment. Examples of such facilities include the Union Pacific's Bailey yard in Nebraska and Global III Intermodal Terminal in Illinois, where optimization of operations within and between railroads is done both tactically and strategically (Union Pacific).

Electronically controlled pneumatic brakes [ECPB] – This is a braking system on each train car that is electronically controlled by the locomotive and results in faster brake applications (Mandelbaum, 2009). The current method is controlled by the locomotive and rather than waiting for the change in air pressure from one end of the train to the other to start the application of brakes, ECPB simultaneously applies brakes. The capacity (number of trains on a railway) would increase as trains would respond faster and have the ability to operate with smaller headways. The use of ECPB would require any ECPB-equipped car to only run with other ECPB cars, possibly reducing the positive impacts due to limited applications. Expected costs vary as the technology is being developed. Estimates for the Powder River Basin operations of the Union Pacific and BNSF suggest that these costs would be $432 million for 2,800 locomotives and 80,000 freight cars, with an annual benefit of $157 million (Federal Railroad Administration, 2007).

Positive Train Control [PTC] – This locomotive computer monitoring allows verification of current place, performance and adherence to train orders. This monitoring results in a failsafe that may prevent accidents and offer greater control of each train on the network, possibly resulting in smaller headway and increased use of track (Federal Railroad Administration). The cost for PTC is estimated at $13.2 billion and is being federally mandated on all locomotives by 2015 (Association of American Railroads). Even though capacity enhancements may result, one concern is that for railroads to finance PTC systems on all locomotives, it may result in a technology that limits the ability of the railroads to invest in other projects with a greater capacity improvement effect. It may also result in railroads being unable to introduce any other technology to help serve future demand, as well as the need for public funds to supply the capital needed at locations where PTC capacity enhancements do not improve services to acceptable levels.

Track realignment – This involves the redesigning of the route that a railway follows. Whether it is rerouting for geographical or land use reasons, removing restrictive curves, or decreasing grades, the potential benefit would be more consistent speeds with less power requirements to haul the same train. The cost for track realignment projects depends on numerous factors and therefore is difficult to estimate. Any realignment would bring a benefit to only those trains that traversed the railway in question. Therefore high density corridors would see the biggest benefit.

2.6 Review of Cost Estimation Methods

Capacity improvements including railway construction are planned at several levels of analysis. At the planning level strategic decisions are developed that determine the likely benefits and costs of a project, before further resources are utilized for more in-depth investigation. At the project level actual location specific studies are conducted to determine the overall costs of the project. It is at the planning level that the proposed CPM estimation methodology may be of use, where several forms of estimation are typically made. A review of available CPM methods is provided next.

Cost estimation can be simply obtained by comparison. This method lies on the assumption that another project's cost can be similar to the study costs due to the similarities of actual projects. This form of estimation requires minimal devotion of resources, but the likelihood of accuracy is low, as one project will likely be different from another. In addition the assumed study cost may or may not include all of the applicable cost categories to the proposed project, leaving even greater chance for an inaccurate estimation due to assumptions.

Challenges do exist when making decisions based on comparisons. First, utilizing another project's feasibility study costs to generalize one's own, makes the assumption that the project being analyzed is similar in every way to the project under study. This challenge is illustrated in Figure 2-10, where the cost for a 125 – mph non-electric railway ranges from $1 million to $7 million (Federal Railroad Administration, 1997). Selecting a study cost by the means of comparison may lead to large discrepancies, if dissimilar location/service specific information is not acknowledged. Second, the proprietary nature of construction costs incurred by the predominately private railroads makes the sharing of costs rare. Third, very few miles of railway are constructed each year, making it unlikely that any available costs are representative of other projects or locales. Finally, many of the new railway projects and studies focusing on HSR in North America have yet to be built. While they have produced some cost estimates, these were not verified with actual construction and are open to certain levels of error due to unforeseen impacts that change the study assumptions.

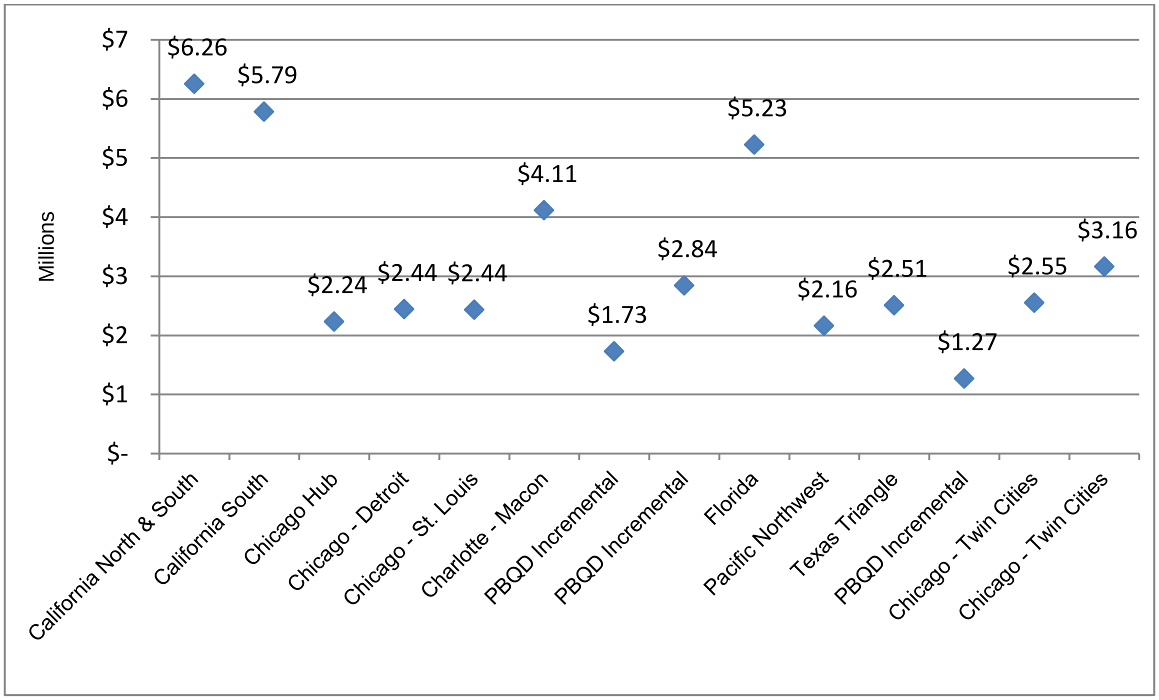

Figure 2-10: 110 - mph Non-Electric Study Cost Distribution

Feasibility studies are also used for cost estimation, where the viability of a project is examined in greater detail. Within a feasibility study a team of professionals perform a site-specific analysis to determine the final costs and benefits. Use of a feasibility study may provide a cost estimate that is more accurate than the one obtained from comparison, but the result can only be validated after a project has been completed. Therefore, the feasibility study estimates may not be as accurate as desired. Feasibility studies are very time and resource-intensive, and as such only the most promising projects are studied while other plans that may in all actuality be just as promising are discarded or shelved.

Due to the increasing interest in railway construction and the difficulty in determining the costs, a CPM estimation methodology is proposed herein to serve as a planning tool for estimating expected construction costs based on the location and service characteristics of the intended project. The proposed methodology can provide reasonable and representative estimates at the planning level and can provide the groundwork for determining whether such a project would be financially feasible to study.

Chapter 3 - Methodology Overview

3.1 Methodology Components

The proposed CPM estimation methodology is based on examples of modern and representative railway construction costs and estimates, and, with the use of multipliers, it is possible to determine further cost estimates based on different location or service characteristics. The methodology is based on five components of railway construction:

1. The right of way the track is built upon (ROW)
2. The design and construction of the railway (Design & Build)
3. Raw materials and finished goods required (Materials)
4. Train control and communications systems (C&S)
5. Catenary/grid components for electrified service (if applicable) (Electric Infrastructure)

These components are deemed representative of those needed to install a fully operational railway infrastructure. Note that, maintenance, control, station, or rolling stock expenses are not included, as these expenses mainly depend on anticipated ridership, an analysis that is separate from the railway cost estimation. Table 3-1 provides a list of the existing studies and their corresponding cost components that are considered in the CPM methodology.

Table 3-1: Summary of Existing CPM Studies

Study	Location	Used for	Notes
(Mid Region Council of Governments, New Mexico Department of Transportation, 2008)	Albuquerque to Santa Fe, NM	Design & Build, materials	18 - mile construction of new railway
(California High-Speed Rail Authority, 2009)	Los Angeles to San Francisco/Sacramento	Design & Build, electric infrastructure, C&S, materials	Projections for a 220 - mph HSR system
(Schwarm, et al., 1977)	Not specified	Electric infrastructure	Cost for catenary, substation share per mile
(Barton-Aschman Associates, Inc., et al, 1986)	Tampa to Orlando to Miami	ROW, study comparison	Florida Overland Express project that was canceled in 1999
(TransSystems, Parsons, 2009)	Chicago to St. Louis	Design & Build, electric infrastructure, C&S, materials, study comparison	Projections for a 322 - mile 220 - mph HSR system
(Illinois Department of Transportation, 2011)	Chicago to St. Louis	C&S	Projection for 110 – mph C&S costs
(Federal Railroad Administration, 1997)	Corridor-specific cost projections	Study comparison	Projections for 11 projects at various operating speeds
(Tanaka, et al., 2010)	Corridor-specific cost projections	Study comparison	Projections for 11 projects at 220 - mph

Table 3-1: Summary of Existing CPM Studies (Continued)

Study	Location	Used for	Notes
(TMS/Benesch High Speed Rail Consultants, 1991)	Chicago to Twin Cities	Study comparison	Projection for a Chicago to Twin Cities system at various operating speeds
(Transportation Economics & Management Systems, Inc., 2000)	Chicago to Twin Cities	Study comparison	Projection for a Chicago to Twin Cities system at various operating speeds
(Transportation Economics & Mangement Systems, Inc, 2009)	Chicago to Twin Cities	Study comparison	Projection for a Chicago to Twin Cities system at various speeds
(Texas Turnpike Authority, et al, 1989)	Dallas/Fort Worth to San Antonio and Houston	Study comparison	Projection for a network between said locations at various speeds
(Parsons Brinckerhoff Quade and Douglas, Inc., 1991)	Land use-specific, but not location-specific	Study comparison, C&S	Projections based on speed and land use specific requirements
(Volpe National Transportation Systems Center, 2008)	Charlotte NC to Macon GA	Study comparison	Projection for 110, 125, and 150 - mph HSR scenarios
(Ontario / Québec Rapid Train Task Force, 1991)	Quebec City QC to Windsor ON	Study comparison	Projection for 125 - mph HSR service

These cost components are also influenced by factors related to the type of location or service to be instituted. These factors are shown in Figure 3-1 and include:

- Construction (adding to existing, building new, or upgrading existing railways)
- Service (passenger, freight, or mixed use)
- Speed (maximum intended speed: 79, 110, 125, 150, or 220mph)
- Motive power (electric or non-electric)
- Trackage (single, double, or other)
- Terrain (plains, hills, or mountains)
- Land Use (urban, suburban, or rural)

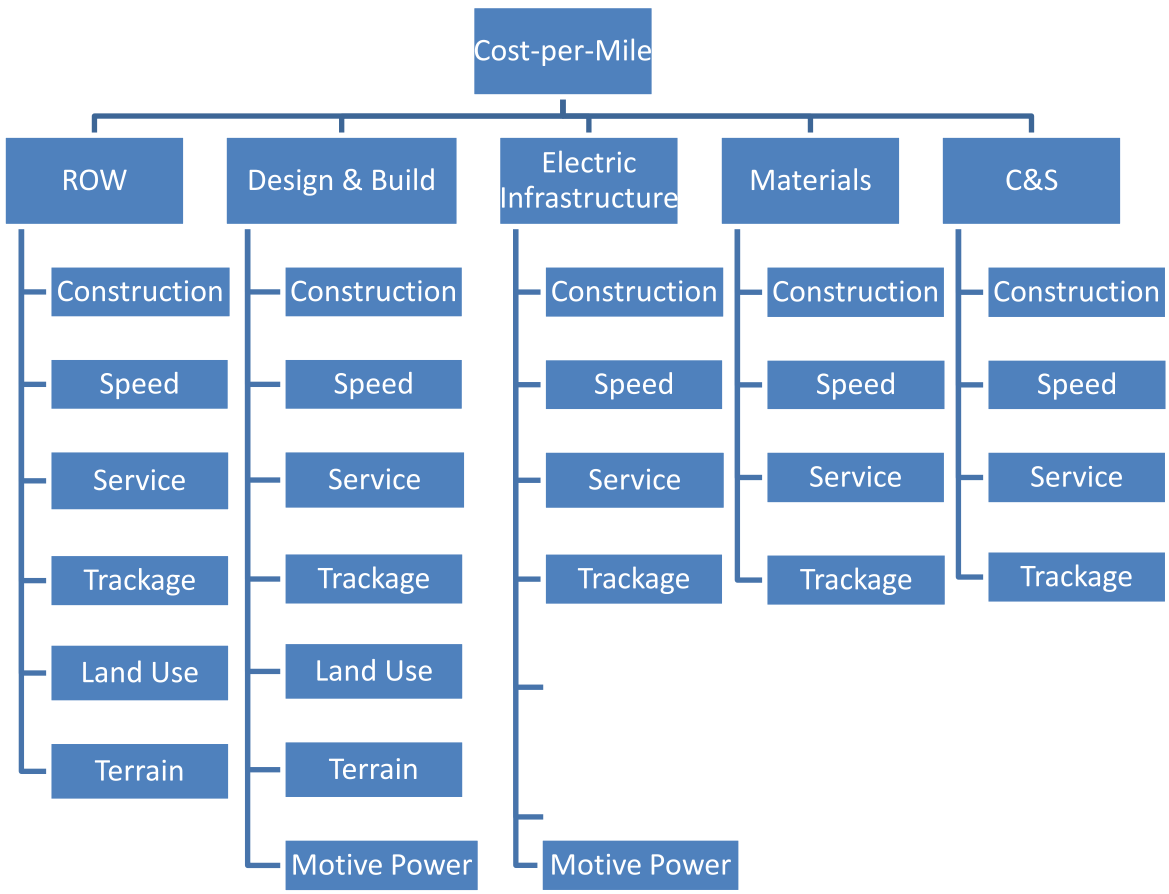

Figure 3-1: CPM components and corresponding influencing factors

3.2 Influencing Factors

Railway construction costs are influenced by various factors that make it difficult to create an estimate that is applicable to every site. These factors can be grouped in two categories: location characteristics and service characteristics. Location characteristics, such as land use and terrain of the area, can have considerable influence on costs. Service characteristics include the speed and the level of service, which also have a great influence on cost. These influencing factors are considered in the CPM components presented in Figure 3-1 and help account for differences that may be encountered in railway construction. Note that other influencing factors such as an abnormally high frequency of structures or environmentally sensitive land are not included in the proposed methodology. These types of factors are considered the exception to the rule, as their inclusion would increase the complexity of the data requirements and conflict with the mission to create a simple, but representative estimate methodology.

3.2.1 Location Characteristics

Terrain reflects the engineering costs associated with the design of the railway dependent on the maximum ruling grade, length of grade, and occurrence of special structures. Due to the variability of terrain that might occur at a state or regional basis, the terrain characteristic has been assigned as the geographic features most likely to be encountered depending on the speed. Figure 3-2, a hillshade, or hypothetical illumination of the ground surface, shows the potential impact terrain variability may have when determining locational influences (U.S. Geological Survey) (ESRI Press, 2008).

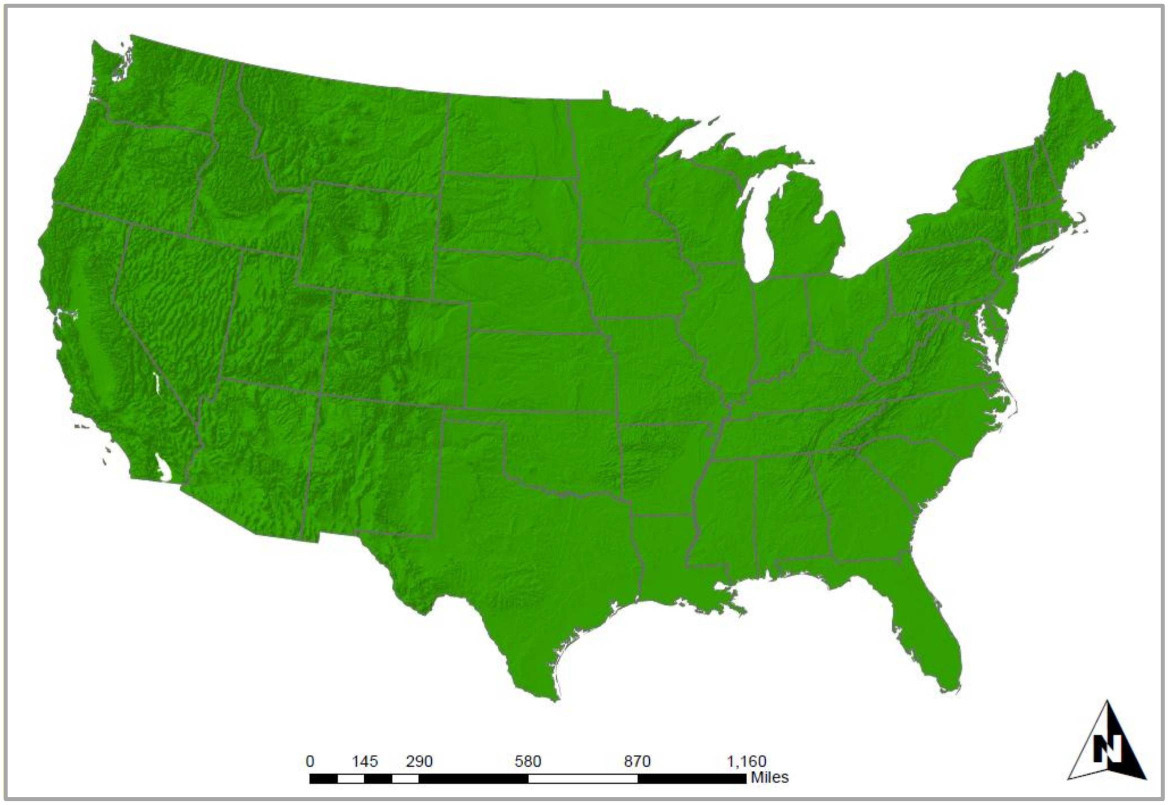

Figure 3-2: Terrain distribution by state ((U.S. Geological Survey) (ESRI Press, 2008))

Despite the variability, two methods can be used to establish the appropriate terrain type (plains, rolling hills, or mountains) for cost estimation:

- For a known location, Figure 3-2 can be used to determine the predominant terrain characteristic of that specific location.
- For preliminary engineering studies or estimations where the alignment of the railway is not known, Figure 3-3 and Table 3-2 can be used to

determine the terrain type most likely encountered by a railway for different speed services. For example, Colorado is classified as mountainous terrain for a 79 to 110mph service according to Figure 3-2, as the majority of freight traffic flows east-west and capacity improvements would most likely occur in the Rocky Mountains (consisting of 2/3rd of the state). Rolling hills classifies Colorado for 125mph and above, as high population density only occurs on the Front Range. The Front Range consisting of a corridor between Albuquerque, NM and Cheyenne, WY is recognized as an emerging region for HSR service (Hagler, et al., 2009).

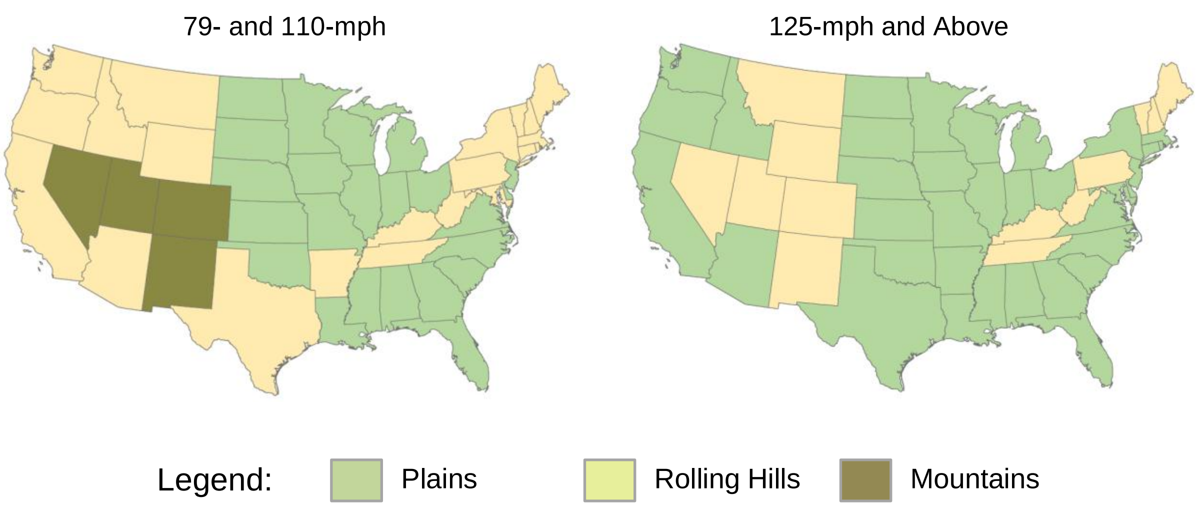

Figure 3-3: Terrain distribution by state

Table 3-2: State Terrain Classification Table

Speed Level	Plains	Hills	Mountains
79mph to 110mph	ND, SD, NE, KS, OK, MN, IA, MO, WI, IL, IN, MI, OH, LA, MS, AL, GA, FL, SC, NC, VA, NJ, DE	WA, OR, CA, ID, MT, WY, AZ, TX, AR, TN, KY, WV, PA, MD, NY, NH, VT, ME, RI, CT, MA	CO, NM, UT, NV
125mph and above	WA, OR, CA, AZ, ID, ND, SD, NE, KS, OK, TX, MN, IA, MO, AR, LA, WI, MI, IL, IN, OH, MS, AL, GA, FL, SC, NC, VA, MD, DE, NJ, NY, CT, RI, MA	ME, NH, VT, PA, WV, KY, TN, NM, CO, WY, MT, UT, NV	

The influence of terrain type is based on multipliers that are applied to the appropriate base cost scenario. For example, the costs in rolling hills terrain are assumed to be 1.5 times those in plains, while the costs in mountainous terrain are assumed to be 1.5 times those in rolling hills terrain. These multipliers were based on freeway factors for truck and bus passenger car equivalent units (Transportation Research Board, 2000)

Land use is also a factor that affects the CPM of railway construction. The land use characteristics reflect the most likely value of land encountered to build a railway. Land use is based on the costs associated with different land use types from the proposed Florida Overland Express HSR system of the 1990s (Barton-Aschman Associates, Inc., et al, 1986). Each state, as shown in

Figure **3-4** and Table 3-3, has been categorized as one of three land-use types: urban, suburban, or rural. The aforementioned project also included a cost classified as "core" to represent the city center; this categorization has not been used for land use specification, but has been included in the actual ROW cost estimation (shown in Section 3.3). Each speed category represents the most common costs encountered for the prescribed railway ROW. An example is a 79 - mph railway, which may serve industrial and rural areas, whereas 125 mph and higher speed services will be offered in areas with higher population density to maximize the ridership and value of service.

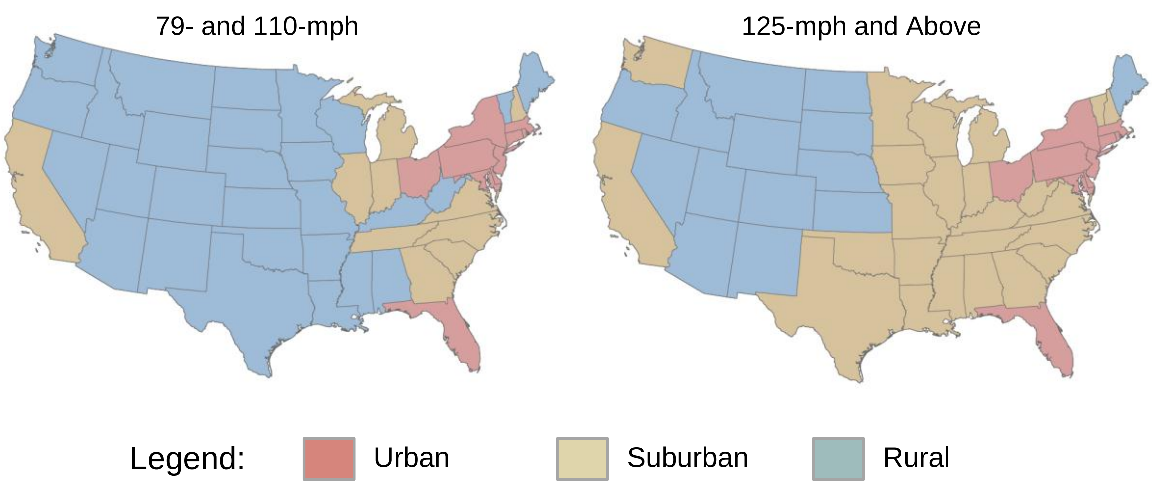

Figure 3-4: Land use distribution by state

Table 3-3: State Land Use Classification Table

Speed Level	Urban	Suburban	Rural
79mph to 110mph	MA, RI, CT, NY, NJ, DE, PA, MD, OH, FL	NH, MI, IN, IL, VA, NC, SC, GA, TN, CA	WA, OR, ID, MT, WY, UT, CO, AZ, NM, TX, OK, KS, NE, SD, ND, MN, IA, MO, AR, LA, MS, AL, WI, KY, WV, VT, ME
125mph and above	MA, RI, CT, NY, NJ, DE, MD, PA, NY, OH, FL	NH, VT, WV, VA, NC, SC, GA, AL, MS, KY, TN, IN, MI, IL, WI, MN, IA, MO, AR, LA, TX, OK, CA, WA	ME, OR, ID, MT, WY, NV, CO, UT, AZ, NM

The land-use effect is determined at the state level using the 2010 U.S. Census data on population density per square mile, shown in Figure 3.5 (U.S. Census Bureau, 2011). It was assumed that, for a 79 to 110 - mph railway, population density per square mile of 1 - 125 designates rural areas; 125 - 250 designates suburban areas, and a value of over 250 designates urban areas. For 125 - mph and higher speed railway, population density per square mile of 1 - 50 designates rural areas; 50 - 250 designates suburban areas, and a value of over 250 designates urban areas (U.S. Census Bureau, 2011).

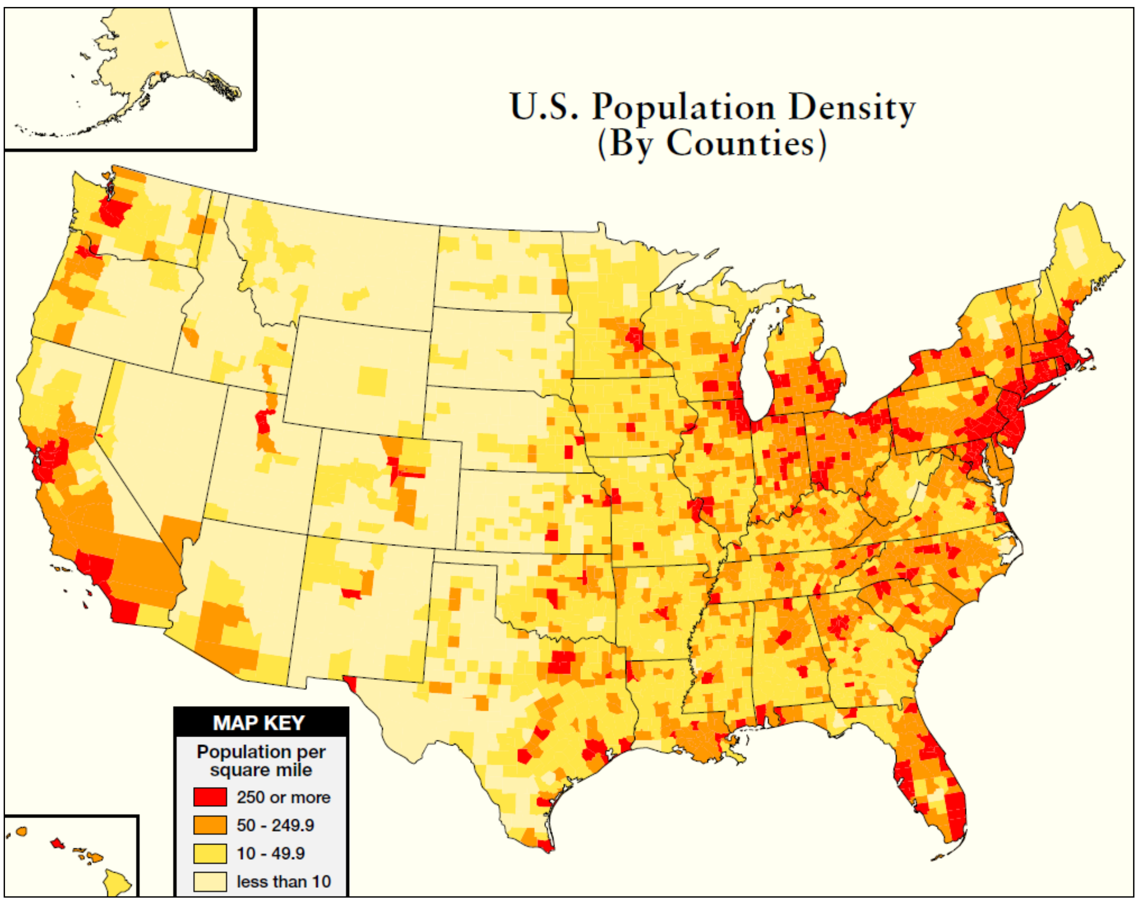

Figure 3-5: Original U.S. Census population density for influencing factor (U.S. Census Bureau, 2011)

3.2.2 Service Characteristics

Construction type reflects the type of project to be built, whether adding a track ("cost to add"), upgrading a current infrastructure ("cost to upgrade"), or building a new infrastructure ("cost to build").

The "cost to build" represents the cost for constructing an entirely new railway. Common application of this cost would be for high-speed-rail (HSR) projects like the California HSR, or the Amtrak Next Generation HSR, where purpose built railways are required (Amtrak, 2010) (California High-Speed Rail Authority, 2009).

The "cost to upgrade" refers to the cost that would occur if an existing railway were upgraded to a different maximum speed level. This application is possibly the most common today, as it allows cost savings by using existing ROW. The North East Corridor is such an example and has undergone upgrades to increase the service speeds of Amtrak on multiple occasions (Federal Railroad Administration, 2011). In addition, incremental HSR is based on upgrading existing routes as a way to increase service offerings without the extensive costs related to full construction (de Cerreno, et al., 1991). Cost to upgrade represents one-third of the total cost to build, because of economies of scale in the existing railway. Additionally, for speeds of 125mph and above additional ROW is required to accommodate the broader curves and removal of intermodal crossings to ensure safe and comfortable travel. For 79 and 110mph, it is assumed that no new ROW is required, as reengineering of the railway and use of tilt trains equipment can help to gain some increases in service speed, without major work on the infrastructure itself.

The "cost to add" represents the costs to add one track to an existing railway. Costs are represented as the portion of all cost components that are required to add the additional track, typically a fraction of the costs needed for an entire railway construction project (design and build as well as ROW are thirty percent of the total cost). Railways that are targeted as added capacity candidates would most likely follow the same route to reduce costs and benefit from the existing traffic. Lower costs for adding a railway is represented by requiring only one-third of the ROW and Design & Build associated with a similar new cost to build project.

Service defines the role of a railway project. Passenger, freight, and mixed use are the possible service types for a railway, where the intended service will determine the types of speed levels that are allowable.

Mixed use service represents a railway that is designed to operate both freight and passenger services. The speeds for this service type are typically 79mph and in some cases, 110mph, and represent the national network almost in its entirety (Peterman, et al., 2009). Projects related to mixed use service types include increasing capacity by adding additional tracks to an existing railway, or upgrading a railway to a maximum of 110mph to establish an "incremental HSR" service.

Passenger service represents a railway designed to operate only passenger services. Projects related to passenger service include commuter services at 79mph (Transportation Economics & Management Systems, Inc., 2000) (de Cerreno, et al., 1991) (Peterman, et al., 2009) (Transportation Economics & Management Systems, Inc & HNTB, 2004), incremental HSR services at 110mph (Illinois Department of

Transportation, 2011) (Midwest High Speed Rail Association, 2011) and true HSR projects of dedicated infrastructures at 125, 150, and 220mph (Texas Turnpike Authority, Lichliter/Jameson & Associates, Inc, Wilbur Smith Associates, Inc, Morrison-Knudsen, M.Ray Perryman Consultants, Inc, Underwood, Neuhaus & Co. Incorporated, Sylva Engineering Corportation, Andrews & Kurth, 1989) (TransSystems, Parsons, 2009) (Federal Railroad Administration, 1997) (Transportation Economics & Management Systems, Inc., 2000) (de Cerreno, et al., 1991).

Freight service is limited to 79mph and, in most cases; trains operate at much lower speeds (Peterman, et al., 2009). In the case of freight service, additional tracks would be most likely constructed, due to existing auxiliary infrastructure, such as C&S, yards, and maintenance facilities, allowing economies of scale.

<u>Speed</u> is a factor in all cost categories involved in the CPM methodology. The maximum intended speed will dictate how the railway is designed, either by rules of law or physics (Transportation Economics & Management Systems, Inc & HNTB, 2004). Examples of rules of physics include the minimization of the degree of curvature and the minimization of the ruling grade, both of which affect how the train is able to perform at the design speed without discomfort or danger to the passenger, cargo, or equipment (Lindahl, 2001) (Transportation Economics & Management Systems, Inc., 2000). An example of a rule of law relates to the C&S system employed for HSR services where computer integration and reporting of information is relayed to the engineer in the locomotive, as trackside signals are not

easily interpreted by the engineer and reduced headway is often practiced, resulting in greater service frequency but a smaller margin for error (TransSystems, Parsons, 2009) (Parsons Brinckerhoff Quade and Douglas, Inc., 1991) (TGVweb, 1998).

Motive power pertains to the fuel source which the locomotive will draw upon. As of 2011, multiple sources of fuel are available, but for the purposes of the CPM methodology, the only motive power source that requires consideration is electric. Electric locomotives use electricity to power the traction motors and ancillary machinery via overhead or third-rail powered transmission. Electrification requires considerable installation costs, and therefore requires justification by volume and/or need. Conversely, more traditional means of motive power, such as diesel, do not typically require any additional physical infrastructure to be constructed, and thus no power specific costs are considered in the CPM estimates. Depending on the use of the railway, electric motive power offers benefits as well as costs, and can be utilized on any of the service types: freight, passenger, or mixed use. For speeds at and above 150mph, modern diesel-electric or turbine-electric locomotives do not operate efficiently and therefore, electric motive power is the single source (TMS/Benesch High Speed Rail Consultants, 1991). Example pictures of modern locomotives for diesel-electric and electric railways are shown in Figure 3-6 and Figure 3-7.

Figure 3-6: Modern General Electric locomotive (General Electric)

Figure 3-7: Modern Siemens AG electric locomotive (Buczynski, 2010)

Trackage or the number of tracks also affects the CPM of railway construction. When more than a single track is required, larger space and more materials will be required, thereby increasing the cost. The computation for the effects of additional tracks is formulated with a multiplier applied on each of the five cost components, which are discussed in the next section. A multiplier of 1.5 (instead of 2.0) is applied that reflects the additional work needed to build a single additional track, as only a portion of the required elements are needed for the additional track, such as sub-grade, C&S, and electronic components.

3.3 CPM Components

The five CPM component cost categories have been designated as “Design & Build”, “ROW”, “Materials”, “C&S”, and “Electric Infrastructure”. Each cost is based on a finished project, proposed project, or study cost. Since most of the cost sources pertained to a particular project or state, it was necessary to adjust these cost estimates for the influence of the state. To achieve this, the US Army Corps of Engineers “Civil Works Construction Cost Index System (CWCCIS)” was applied (U.S. Army Corps of Engineers, 2000). The index is used to “…escalate or inflate various project cost features to current or future price levels…” along with adjusting for the influence of a state on construction costs. Therefore, the CWCCIS was also used to escalate costs into 2009 dollars for all five cost categories. The CWCCIS is especially suited for the escalation of costs as railroad work has a specific “Civil work Breakdown Structure (CWBS) Feature Code” This specific code allows a different rate of escalation compared to other civil works projects.

To remove the influence of a state the following calculation (equation 3-1) was used. Based on 1.0 as the uninfluenced adjustment factor, the original state’s adjustment factor is subtracted from 2 and then multiplied on the original state’s cost, resulting in a cost without a state influence included.

$$\textit{Base Cost without influence} = (2 - \textit{State Adjustment Factor}) \times (\textit{State Influenced Cost}) \tag{3-1}$$

The adjustment factors used to remove state influences are available in Table 3-4.

Table 3-4: CWCCIS State Adjustment Factors (adapted from (U.S. Army Corps of Engineers, 2000))

State	Factor	State	Factor
Alabama	0.90	Montana	0.97
Alaska	1.21	Nebraska	0.98
Arizona	0.96	Nevada	1.08
Arkansas	0.88	New Hampshire	1.04
California	1.18	New Jersey	1.20
Colorado	0.99	New Mexico	0.95
Connecticut	1.18	New York	1.16
Delaware	1.11	North Carolina	0.83
Florida	0.94	North Dakota	0.92
Georgia	0.90	Ohio	1.02
Hawaii	1.18	Oklahoma	0.86
Idaho	0.95	Oregon	1.07
Illinois	1.14	Pennsylvania	1.09
Indiana	1.00	Rhode Island	1.15
Iowa	0.99	South Carolina	0.84
Kansas	0.95	South Dakota	0.89
Kentucky	0.98	Tennessee	0.90
Louisiana	0.89	Texas	0.87
Maine	1.00	Utah	0.95
Maryland	0.99	Vermont	0.94
Massachusetts	1.19	Virginia	0.94
Michigan	1.05	Washington	1.07

Table 3-4: CWCCIS State Adjustment Factors (adapted from ((U.S. Army Corps of Engineers, 2000)) (Continued)

State	Factor	State	Factor
Minnesota	1.16	West Virginia	1.03
Mississippi	0.90	Wisconsin	1.07
Missouri	1.04	Wyoming	0.90
		Washington D.C.	1.05

To escalate a cost into future dollars, the following calculation was made;

$$Future\ year\ specific\ cost = Base\ year\ specific\ cost \times \frac{Future\ year\ specifc\ Feature\ Code}{Base\ year\ specific\ Feature\ Code} \tag{3-2}$$

The feature codes used to escalate costs are shown in Table 3-5.

Table 3-5: CWCCIS Feature Code and yearly cost indexes (adapted from (U.S. Army Corps of Engineers, 2000)

Feature Code Year	Feature Code Index
1978	239.50
1979	260.37
1980	280.18
1981	306.16
1982	327.4
1983	340.86
1984	349.51
1985	355.43

Table 3-5: CWCCIS Feature Code and yearly cost indexes (adapted from (U.S. Army Corps of Engineers, 2000)) (Continued

Feature Code Year	Feature Code Index
1986	358.36
1987	366.32
1988	380.42
1989	394.57
1990	402.95
1991	411.27
1992	422.37
1993	440.44
1994	454.26
1995	463.84
1996	473.27
1997	486.24
1998	490.26
1999	501.14
2000	507.97
2001	513.30
2002	529.95
2003	541.73
2004	586.53
2005	618.63
2006	646.72
2007	676.51
2008	710.58
2009	705.61

Design & Build captures the cost to engineer a railway, including the building of the grade, substructures, and structures (like bridges and tunnels) before any track or additional hardware is installed. The basis of this component comes from two studies and project costs. The first is from Phase II of the New Mexico Rail Runner Express commuter service (Mid Region Council of Governments, New Mexico Department of Transportation, 2008), which required eighteen miles of new railway construction and is used for the 79 - mph service level baseline cost estimation. The project cost was modified, due to the high occurrence of structures to accommodate its inclusion in the median of interstate I-25. Therefore, half the CPM value was used for a more representative new railway construction cost. Despite the adjustments to the CPM value, the New Mexico cost is used with confidence, as it represents one of the few completely new build projects of significant length, to have occurred in the last ten years. The design and build elements of the 2009 Chicago to St. Louis and California High-Speed-Rail Authority costs were considered for 220 - mph services level, but the former was deemed more representative of cost due to the smaller variations in geographic conditions incurred compared to the latter (TransSystems, Parsons, 2009), (California High-Speed Rail Authority, 2009).

For speeds other than those planned for in these studies, the authors used Figure 3-8 to estimate the differences in cost by speed in conjunction with the New Mexico Rail Runner Express CPM values. Figure 3-8 shows track maintenance cost as a function of speed (Thompson, 1986). As speed increases, the cost to build and maintain a railway increases (Peterman, et al., 2009) . Therefore, the graphic is used to represent the percent change in cost from one speed level to the next. Multipliers were calculated from Figure 3-8 as the change in cost by speed from 79-mph and include 1.67 for 110 - mph, 2.47 for 125 - mph, and 3.33 for 150 - mph rail service.

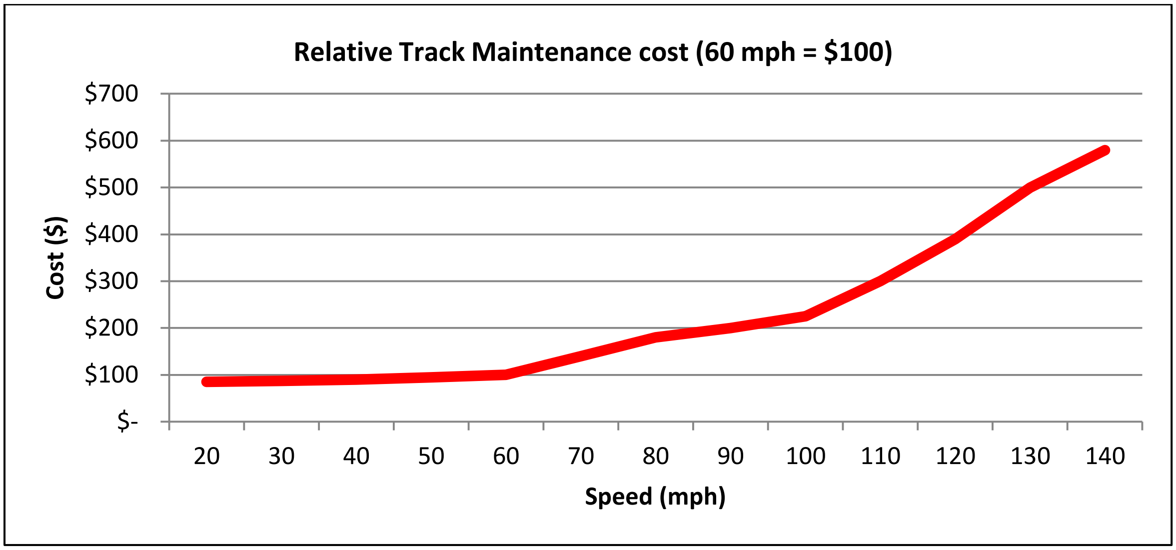

Figure 3-8: Railway track maintenance cost as a function of speed (Adapted from (Thompson, 1986))

It must be noted that Design & Build is based on four assumptions in lieu of actual and quantifiable figures that may be replaced when actual railway costs become available.

- The costs associated with a double-track construction would be 1.5 times the costs of a single-track project in the same location. This assumption was made since the existing grade, geometry, and structures offer existing work and economies of scale to be built alongside of.
- CPM increases by 1.1 from rural to suburban and 1.2 from rural to urban areas. This assumption represents the increased presence of intersections

and structures that affect optimal railway placement. While the number of intersections will increase with more densely populated areas, it was determined that a less obtrusive railway would accordingly be built to avoid unnecessary interactions with surface traffic or built-up areas. For central business districts, no multiplier has been included due to the small proportion that this land use represents of the whole. In addition, some projects may utilize current conventional rail infrastructure for built-up areas, therefore cost estimation was deemed too variable to determine.

- CPM increases by 1.5 from plains to hills and 1.5 from hills to mountains. This assumption was made as the slope, length of slope, maximum curvature, and additional structures encountered result in greater engineering work to Design & Build the railway. This information is based on the effect of terrain on passenger car equivalents for truck traffic with regards to highway capacity (Transportation Research Board, 2000).
- The cost to upgrade a railway is one-third of the corresponding cost to build. This assumption was made as all or a portion of the grade, structures, and necessary geometry is already in place, requiring adaptation or partial building, rather than complete rebuilding.

ROW is the land that the railway is built on, as well as the corridor of land immediately surrounding the track infrastructure. The total width of land allows for the movement of traffic and railway maintenance to minimize service disruptions. The ROW figures are based on cost estimates for ROW procurement in the proposed Florida Overland Express HSR System from the 1980s and have been adapted to reflect the land most likely encountered, accounting for land use, terrain, and speed (Parsons Brinckerhoff Quade and Douglas, Inc., 1991).

An example of the ROW calculation is shown in Table 3-6, where the ROW cost is based on the proportion of land use types likely to be encountered as a function of the speed and land use. All ROW calculations are shown in Appendix A.

Table 3-6: ROW Calculation: 79 & 110 – mph Single Track Urban

ROW Calculation: 79 & 110 - mph Single Track Urban					
Land Use Type	Land Use Type Cost		Proportion		ROW Cost
Core	$42,905,286	x	3%	->	$3,228,906 (Plains)
Urban	$4,291,155		15%		
Suburban	$3,218,366		32%		
Rural	$536,394		50%		

Additional examples for ROW costs in an urban area are shown in Table 3-7.

Table 3-7: ROW Costs: Urban Land Use (Adjusted for state influence)

Terrain	Trackage	79mph, 110mph	125mph	150mph	220mph
Plains	Single	$3,228,906	$4,398,121	$4,827,236	$5,524,549
	Double	$4,197,578	$5,717,557	$6,275,407	$7,181,913
Hills	Single	$3,551,797	$4,837,933	$5,309,960	$6,077,004
	Double	$4,617,336	$6,289,312	$6,902,947	$7,900,105
Mountains	Single	$4,197,578	$5,717,557	$6,275,407	$7,181,913
	Double	$5,456,851	$7,432,824	$8,158,029	$9,336,487

Materials include the costs of supplying the needed hardware and components for construction and are derived from the New Mexico Rail Runner Express project costs, and adjusted by the same multipliers for 110 through 150 mph services as shown in Figure 3-8 (Mid Region Council of Governments, New Mexico Department of Transportation, 2008) (Parsons Brinckerhoff Quade and Douglas, Inc., 1991) (Thompson, 1986).

The multipliers reflect an increase in material costs by speed. The 220mph related costs represent an average of the costs associated with the California HSR and Transystems Chicago to St. Louis study costs (TransSystems, Parsons, 2009) (California High-Speed Rail Authority, 2009). The use of baseline costs was deemed appropriate for materials as the associated costs are assumed to vary little by location for the same speed category. The variation in structures is accounted for in the design and build cost category. Geographical variation in the costs due to material origin may be a factor influencing costs; however, due to data unavailability, it was not possible to take into account in the analysis. The average material costs by speed level and trackage are shown in Table 3-8.

Table 3-8: Material Cost Categories

Speed	Single Cost	Double Cost	Additional Cost
79 - mph	$304,456	$608,911	$304,456
110 - mph	$508,441	$1,016,882	$508,441
125 - mph	$752,055	$1,504,010	$752,005
150 - mph	$1,013,837	$2,027,674	$1,013,837
220 - mph	$2,185,016	$4,370,032	$2,185,016

C&S involve the train-control systems and signals required to operate a railway network. As speeds increase, the ability of the system to display information is crucial, especially when higher speeds make regular trackside signals difficult to read (Nash, 2003). C&S costs are shown in Table 3-9 where 79 to 110mph, the Illinois Department of Transportation, Chicago to St. Louis 110 - mph service estimate was used (Illinois Department of Transportation, 2011) (Midwest High Speed Rail Association, 2011). The costs for 125 - and 150 - mph C&S systems were adopted from the proposed Florida Overland Express system of the 1990s (Parsons Brinckerhoff Quade and Douglas, Inc., 1991). The same value was used for both speed types, due to the similar requirements, as assumed in (Parsons Brinckerhoff Quade and Douglas, Inc., 1991). The costs for 220 - mph C&S systems were estimated from (TransSystems, Parsons, 2009) (California High-Speed Rail Authority, 2009).

Table 3-9: C&S Infrastructure Information

Speed	Single Track	Double Track	Additional Track
79 – mph	$419,390	$634,536	$209,695
110 – mph	$419,390	$634,536	$209,695
125 - mph	$922,932	$1,398,382	$461,466
150 - mph	$922,932	$1,398,382	$461,466
220 - mph	$1,516,953	$2,298,413	$758,476

Electric infrastructure refers to the overhead power lines or catenary and substations that provide the energy for electric locomotive operations. Typically, only HSR or heavy density freight lines require or justify electric operations. Therefore, electric infrastructure is considered to be an optional component for speeds lower than 150mph. For speeds at and above 150mph, all services are electric operations only, as current diesel-electric or turbine-electric technologies limit cost-effective use to speeds 125mph and lower (Transportation Economics & Management Systems, Inc., 2000). Two sources were used for electric infrastructure costs related to 79 through 150 - mph rail service (Schwarm, et al., 1977) (TGVweb, 1998). With the costs for a 220 - mph electric infrastructure estimated from an average of two modern feasibility studies (TransSystems, Parsons, 2009) (California High-Speed Rail Authority, 2009). The inputs for the analysis are included in Table 3-10.

Table 3-10: Electric Infrastructure Information

Speed	Single Track	Double Track	Additional Track
79mph	$593,655	$1,064,706	$296,827
110mph	$593,655	$1,064,706	$296,827
125mph	$1,152,355	$1,728,532	$576,177
150mph	$1,152,355	$1,728,532	$576,177
220mph	$2,281,267	$3,421,901	$1,140,634

3.5 Demonstration of the CPM Methodology

The estimation methodology includes multiple influences and cost categories, and relies on numerous sources of information. To demonstrate the application of the methodology the equation is shown below.

$$\begin{aligned} \textit{Scenario CPM} = {} & (\textit{Design \& Build base cost} \times TE \times LU \times SP \times TR \times UP \times AD) \\ & + (\textit{ROW base cost} \times TE \times LU \times SP \times TR) \\ & + (\textit{Materials base cost} \times TR) \\ & + (\textit{C\&S base cost} \times TR) \\ & + (\textit{Electric Infrastructure base cost} \times TR) \end{aligned} \tag{3-3}$$

Where:

TE = Terrain multiplier
LU = Land Use multiplier
SP = Speed multiplier
TR = Track multiplier
UP = Upgrade multiplier
AD = Additional multiplier

The methodology is also demonstrated through two examples as shown in Table 3-11 and Table 3-12.

Table 3-11: 110 – mph Upgraded Single-Track Non-Electric railway in Suburban Hills

Design & Build Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	Scenario Design & Build Cost
$3,733,333		1.00		1.10		1.67		1.00		0.33		$2,263,184
						+						
ROW Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
N/A		1.00		1.00		1.00		1.00		1.00		$0.00
						+						
Materials Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
$508,441		1.00		1.00		1.00		1.00		1.00		$508,441
						+						
C&S Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
$419,390		1.00		1.00		1.00		1.00		1.00		$419,390
						+						
Electric Infrastructure Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
N/A		1.00		1.00		1.00		1.00		1.00		$0.00
					Total:							$3,191,014

Table 3-12: 150 – mph Built Double-Track Electric railway in Suburban Plains

Design & Build Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	Scenario Design & Build Cost
$3,733,333		0.67		1.10		3.33		1.50		1.00		$13,682,038
						+						
ROW Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
$1,697,625		1.00		1.00		1.00		1.30		1.00		$2,206,913
						+						
Materials Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
$1,013,837		1.00		1.00		2.00		1.00		1.00		$2,027,674
						+						
C&S Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
$922,932		1.00		1.00		1.00		1.52		1.00		$1,398,382
						+						
Electric Infrastructure Base Cost	x	Terrain	x	Land Use	x	Speed	x	Track	x	Upgrade	=	ROW Build Cost
$1,152,355		1.00		1.00		1.00		1.50		1.00		$1,728,532
					Total:							$21,043,539

3.6 Methodology Notes

Certain assumptions and limitations of this analysis are worth mentioning. First, all figures—either components of the methodology or comparative study costs—have been converted into 2009 dollars (U.S. Army Corps of Engineers, 2000), (Friedman, 2010). Second, the influencing factors are characterized at the state level, and it is assumed that the costs of a specific project type and for a certain terrain type will be similar regardless of geographic location. For example, upgrading a 79mph service to 110mph in a suburban plains location will require the same types of building requirements regardless of locale, resulting in the same cost.

Chapter 4 - CPM Estimation Results

4.1 Results Overview

The CPM methodology (presented in Chapter 3, and summarized in Equation 3-3) was applied for different combinations of influencing factors such as speed, land use, terrain, and number of tracks. The resulting CPM estimates for building a single railway track are shown in Table 4-1 The CPM estimates for other speed categories are available in Appendix A.

Table 4-1: “To Build” Single Track Plains CPM Estimates

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Plains	$6,940,911	$4,321,223	$3,495,585
79 - mph Electric		$7,534,566	$4,914,877	$4,089,240
110 - mph Non-Electric		$9,146,964	$6,360,436	$5,367,960
110 - mph Electric		$9,740,618	$6,954,091	$5,961,614
125 - mph Non-Electric		$13,453,813	$9,843,238	$8,187,633
125 - mph Electric		$14,606,168	$10,995,593	$9,339,988
150 - mph Electric		$17,866,933	$13,908,108	$11,857,318
220 - mph Electric		$25,287,768	$20,476,316	$17,928,161

Table 4-2: "To Build" Single Track Hills CPM Estimates

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Hills	$8,755,642	$5,774,566	$4,766,946
79 - mph Electric		$9,349,296	$6,368,220	$5,360,601
110 - mph Non-Electric		$11,961,227	$8,730,018	$7,472,265
110 - mph Electric		$12,554,881	$9,323,672	$8,065,919
125 - mph Non-Electric		$17,578,470	$13,361,274	$11,294,544
125 - mph Electric		$18,730,825	$14,513,629	$12,446,899
150 - mph Electric		$23,317,484	$18,631,712	$16,044,779
220 - mph Electric		$32,730,215	$26,936,527	$23,678,020

Table 4-3: "To Build" Single Track Mountains CPM Estimates

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Mountains	$11,641,423	$7,999,545	$6,689,934
79 - mph Electric		$12,235,077	$8,593,200	$7,283,589
110 - mph Non-Electric		$16,347,808	$12,330,731	$10,645,919
110 - mph Electric		$12,554,881	$9,323,672	$8,065,919
125 - mph Non-Electric		$23,990,894	$18,713,529	$15,977,623
125 - mph Electric		$25,143,249	$19,865,884	$17,129,978
150 - mph Electric		$31,742,131	$25,808,837	$22,355,989
220 - mph Electric		$44,170,112	$36,725,135	$32,330,634

Figure 4-1 illustrates the variation of CPM estimates for 220-mph HSR service by terrain and land use. As planned, the CPM estimates are higher for HSR service in urban versus suburban and rural areas, as well as on mountainous versus plains or hills.

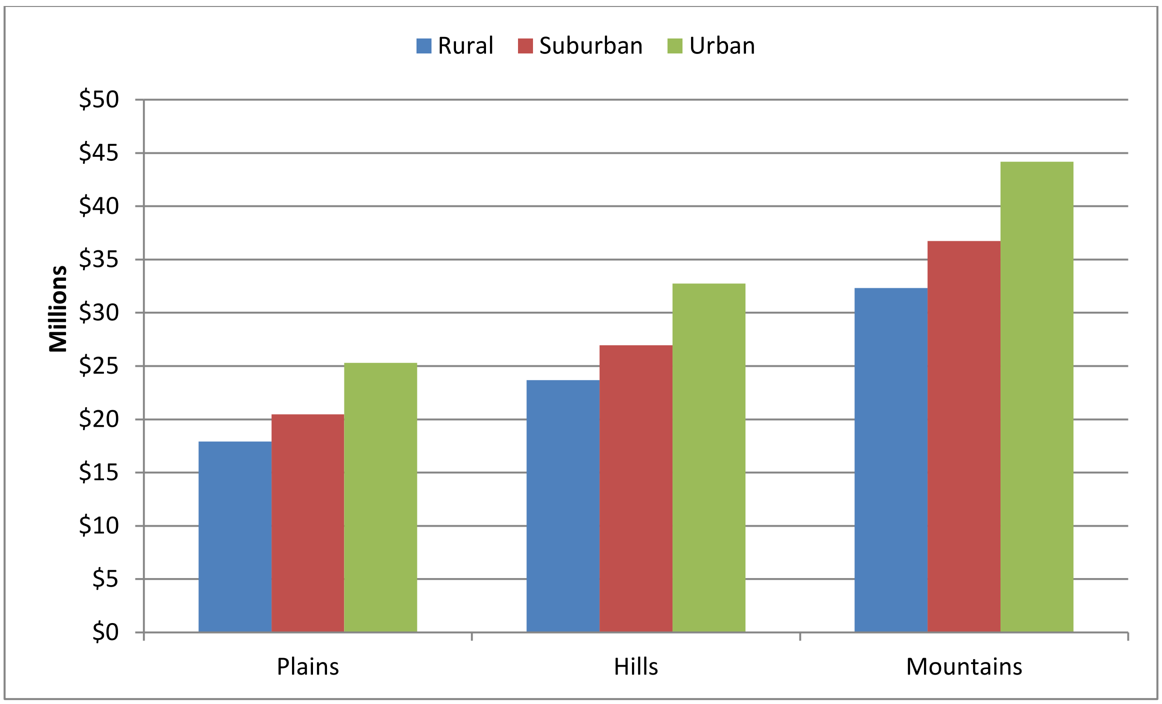

Figure 4-1: Summary of “Build” 220-mph Single Track

Figure 4-2, shows similar trends by speed and land use. As it can be observed, the higher-speed categories reflect considerable increases in cost that are typically associated with such projects.

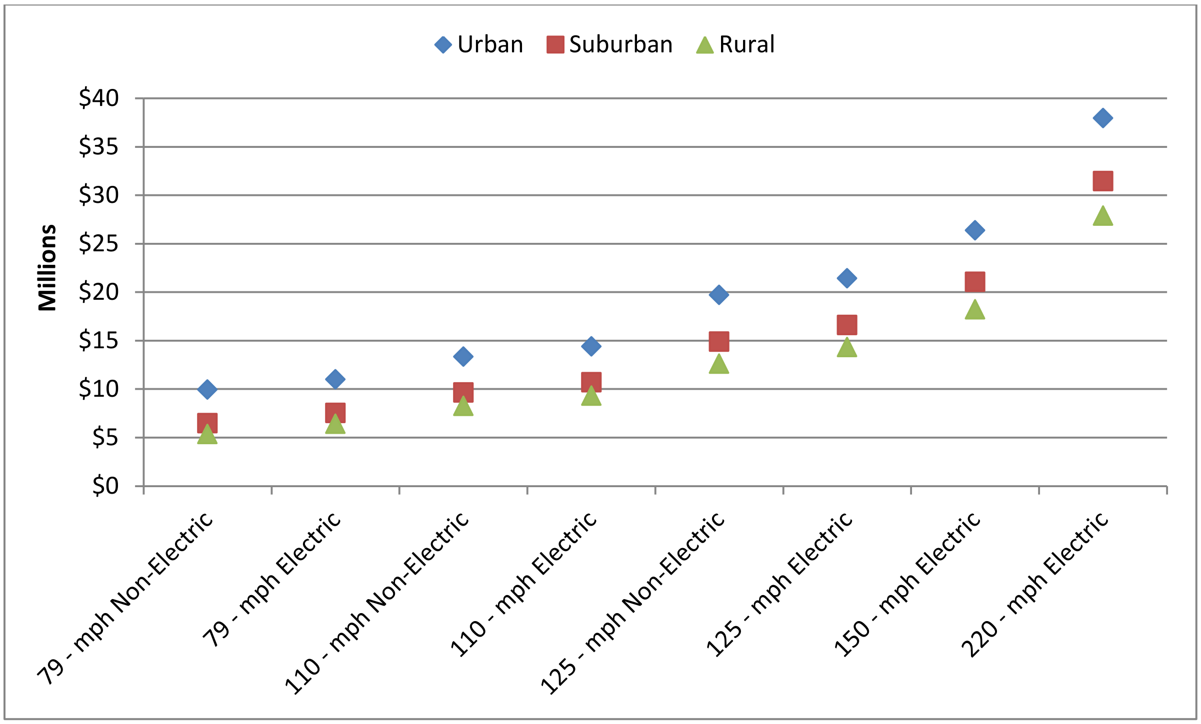

Figure 4-2: Double Track CPM Estimates by Service Type

Figure 4-3 shows that adding new tracks, or upgrading existing tracks, is more cost-effective than building a new railway. Similar increases in costs as terrain changes from plains to mountains, and land use from rural to urban are observed. Note that these trends to apply to a 220-mph HSR service.

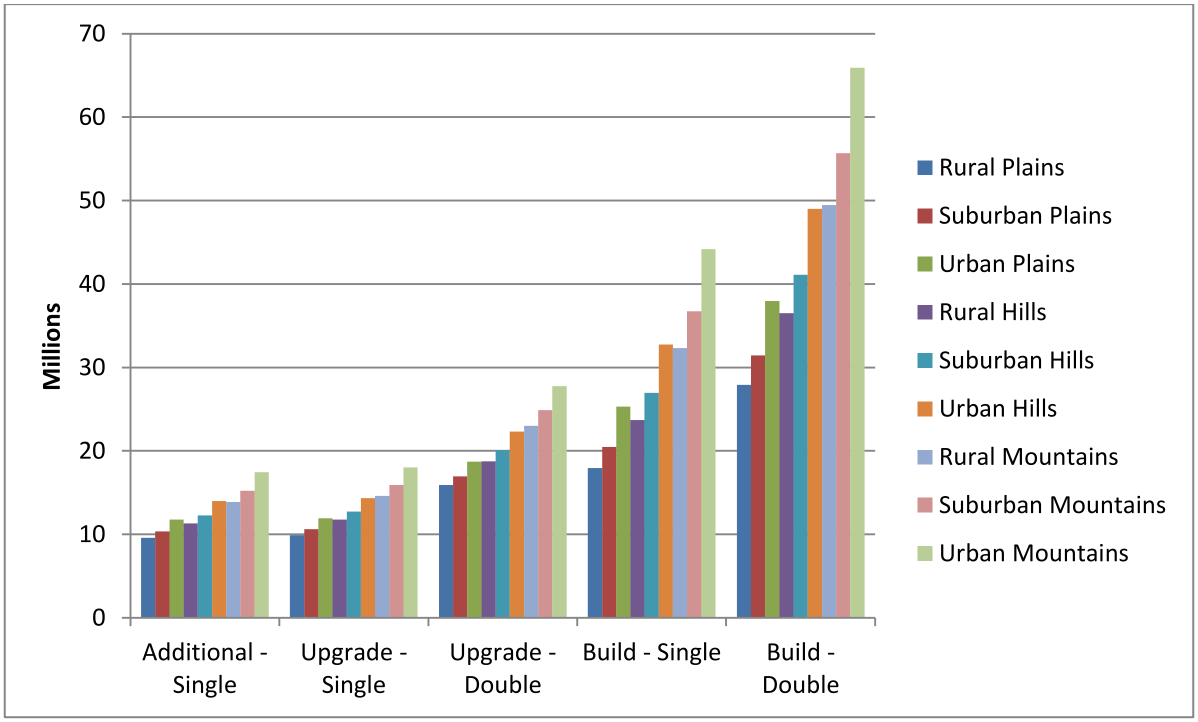

Figure 4-3: Example of 220-mph Categorical Cost Changes

The overall pattern of the estimates is as anticipated, where speed, land, and terrain have a significant effect on CPM estimates. An effort to validate the proposed CPM methodology and corresponding results is presented in the next Section.

4.2 Validation of the CPM methodology

Validation of the CPM methodology included the following comparisons: 1) a comparison between existing feasibility study costs per mile and proposed CPM estimates ("individual comparison"); 2) a comparison between the average cost of all similar study costs and a range of the proposed CPM estimates ("categorical comparison").

4.2.1 Individual CPM Comparison

The individual cost comparison was performed by matching each study cost with their equivalent CPM cost, according to the proposed methodology. Costs from feasibility studies, are listed in Table 3-1, and were gathered and converted into 2009 dollars utilizing the CWCCIS index (U.S. Army Corps of Engineers, 2000). Once the appropriate CPM cost was identified, it was then adjusted to account for the study cost state influence by a state adjustment factor (U.S. Army Corps of Engineers, 2000). If a non-location specific study cost was being compared, no adjustment was made, and if multiple states were involved in the corridor, then an equally weighted average of the state adjustment factors was utilized.

The study costs were then categorized according to the influencing factors described in Chapter 3. This included specifying the land use, terrain, speed, trackage, and motive power for each study cost. In some cases, the characteristics of the study cost were not clear and the cost amount had to be used as an indicator of influences, such as number of tracks. The result included 77 study costs over several speed categories from 110 to 220mph, as well as a range of land and terrain types. A summary of the study costs are available in Table 4-4.

Table 4-4: Summary Statistics of Study Costs (n = 77)

Variables	Count	Percentage
Track		
Single	48	62.3%
Double	29	37.7%
Motive Power		
Non-Electric	25	32.5%
Electric	52	67.5%
Construction		
Upgrade	26	33.8%
Build	51	66.2%
Additional	0	0.0%
Speed		
79mph	0	0.0%
110mph	15	19.5%
125mph	23	29.9%
150mph	12	15.6%
220mph	27	35.1%
Terrain		
Plains	72	93.5%
Hills	5	6.5%
Mountains	0	0.0%

Table 4-4: Summary Statistics of Study Costs (n = 77) (Continued)

Land Use		
Rural	8	10.4%
Suburban	56	72.7%
Urban	13	16.9%

Figure 4-1 shows the comparison of 110 – mph non-electric feasibility study costs (A-O) and the proposed CPM estimates. The costs include 15 studies representing 6 different categories. Overall, 60% of the estimates are within +/- 50% of the study costs. The large discrepancy between study and methodology costs for "A," "B," and "I" could be due to unaccounted regional variability. They are based on studies in California (A and B) and Florida (I) where population density is likely higher in the areas most likely to be served, rather than the statewide population density classification assumed (shown in Figure 3-4).

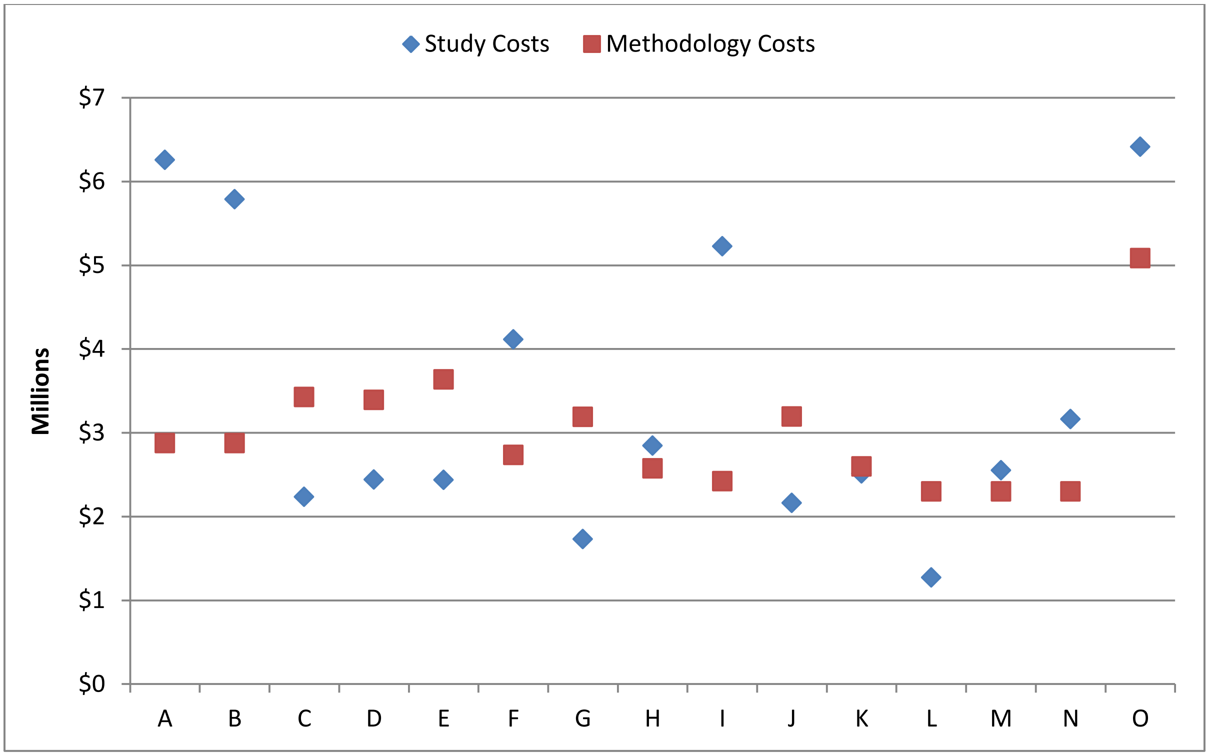

Figure 4-4: Individual Cost Comparison: 110 - mph Non-Electric

Figure 4-5 shows the comparison for 125 – mph non-electric service costs (A-J). These results represent 10 costs of 3 different categories. The results are noticeably more accurate, with 80% of the estimates within +/- 50% of the study costs. Overall, the methodology has been able to replicate the associated study costs. The outlier, "A," represents a study cost estimate for a corresponding service in California.

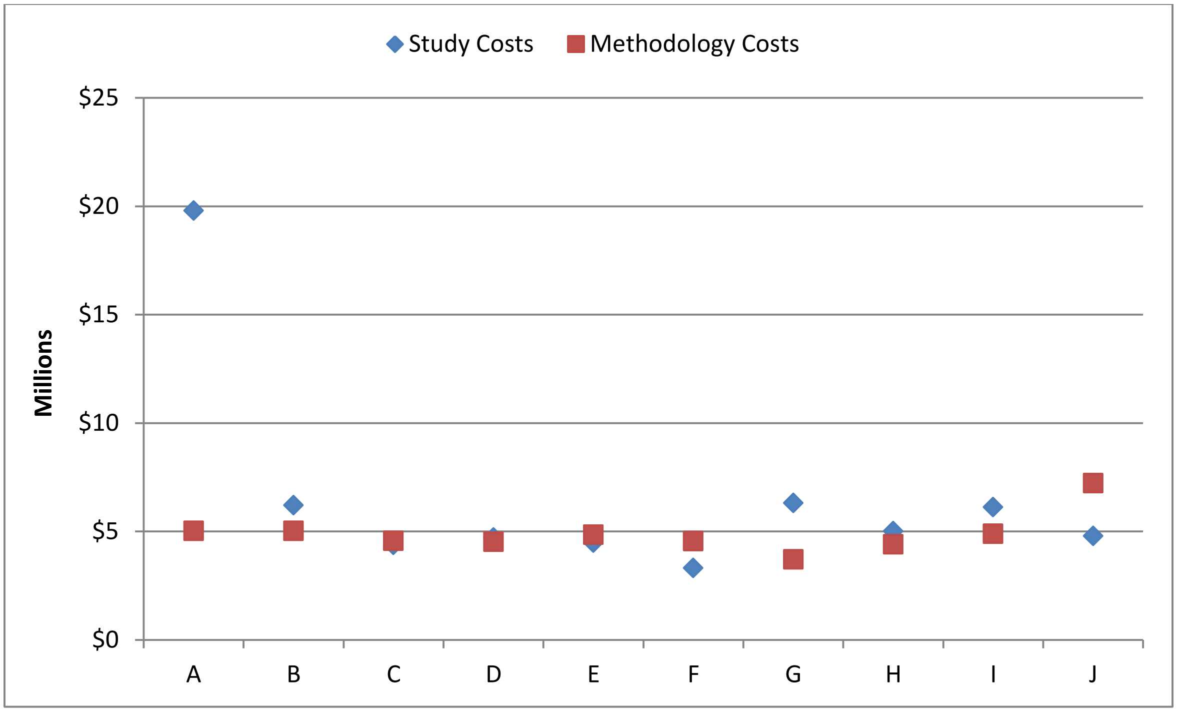

Figure 4-5: Individual Cost Comparison: 125 - mph Non-Electric

Figure 4-6 shows the comparison for 125 – mph electric service costs (A-M). These results represent 13 costs of 5 different categories. The results include 46% of the estimates within +/- 50% of the study costs. The majority of the methodology cost estimates is higher than the corresponding study costs. Cost “F”, again represents an under estimation of cost associated with service in California.

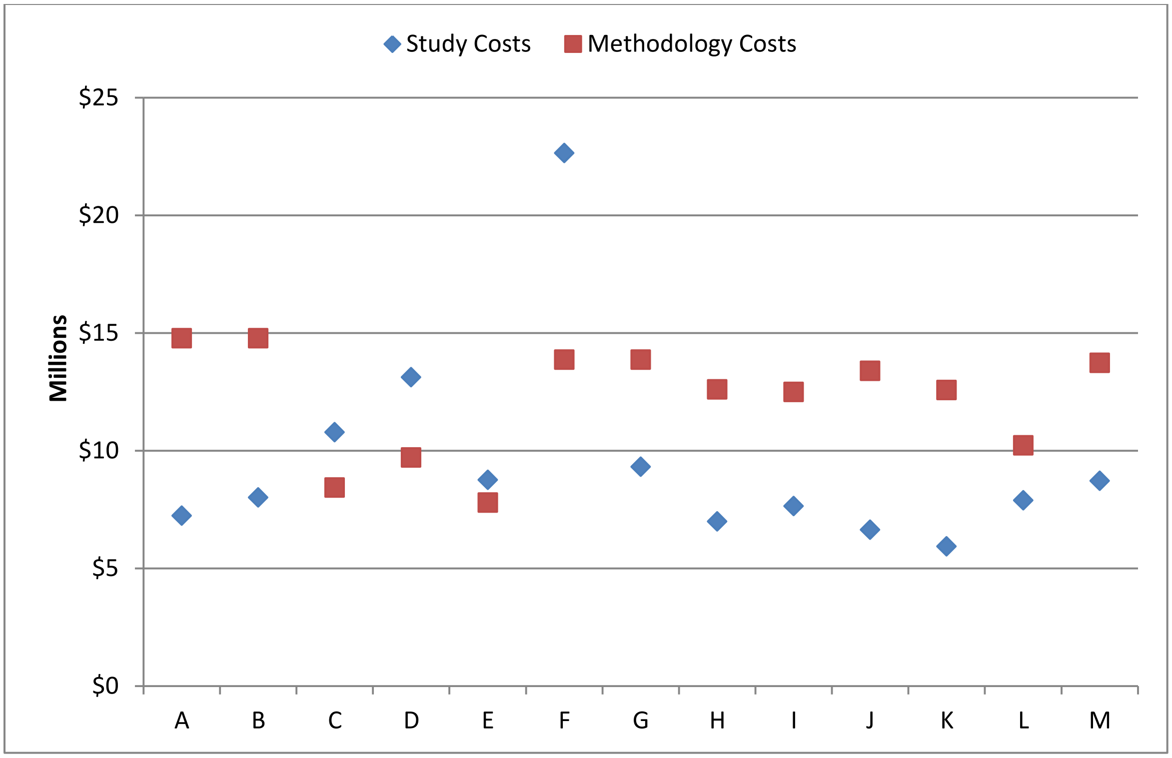

Figure 4-6: Individual Cost Comparison 125 - mph Electric

Figure 4-7 shows the comparison for 150 – mph electric service costs (A-L). These results represent 12 costs of 4 different categories; with 42% of the estimations are within +/- 50% of the study costs. As was seen with the 125 – mph electric comparison, the majority of methodology costs are higher than the study costs. These overestimations include specific regions, which may indicate incorrect spatial assumptions including; Texas “A” and “B”, and Chicago “G”-“I” and “K”.

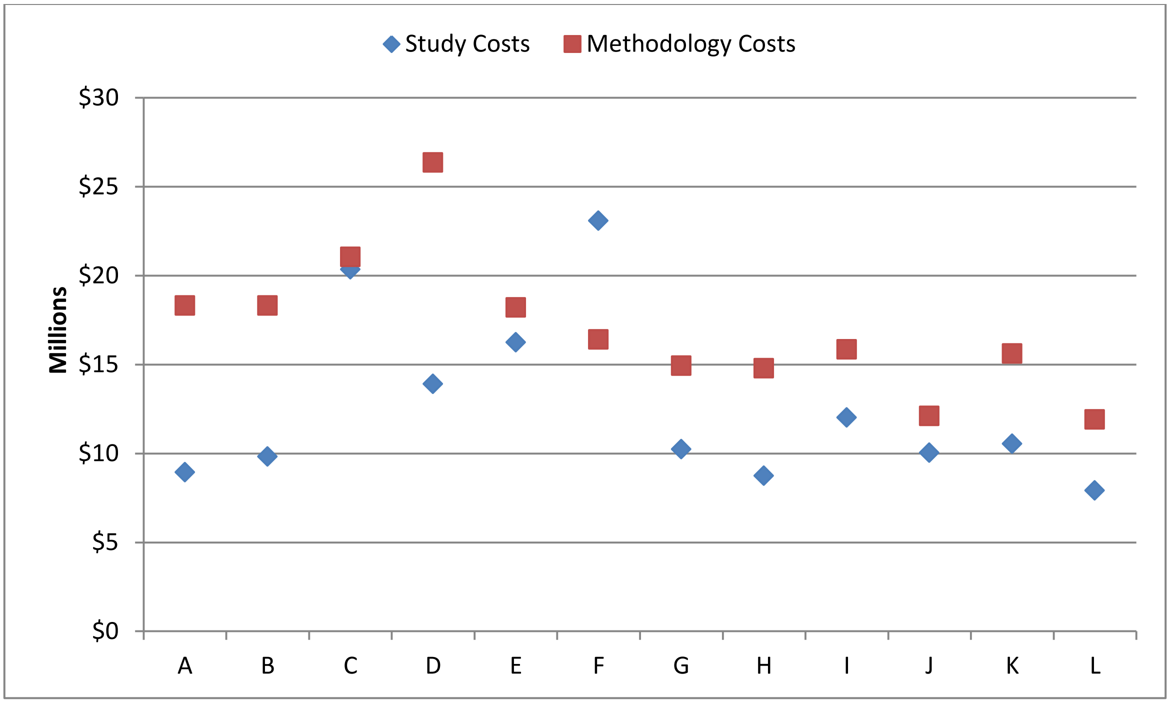

Figure 4-7: Individual Cost Comparison 150 - mph Electric

Figure 4-8 shows the comparison for 220 – mph electric service costs (A-AA). These results represent 27 costs of 5 different categories, with 74% of the estimations within +/- 50% of the study costs. Overall, the methodology and study costs estimates are close and there are no outlying observations. The highest difference applies for costs in the Northeast including: New England “I”, Chicago to the Twin Cities “M” and “N”, Keystone Corridor “O”, and the Empire Corridor “S”.

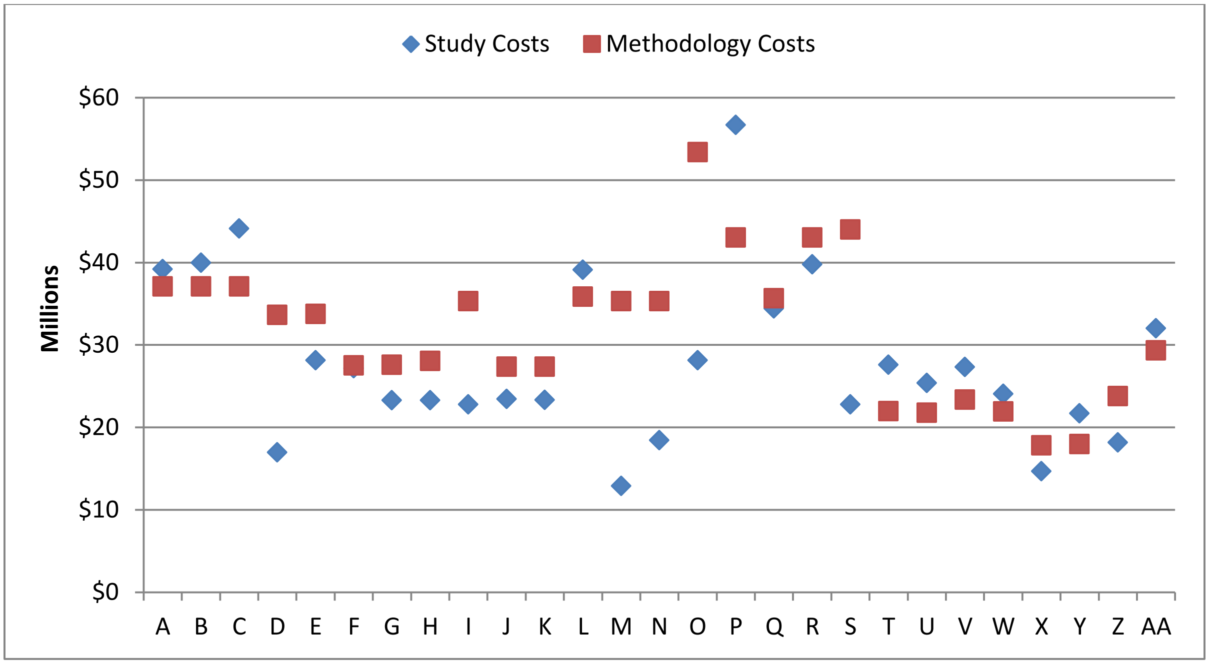

Figure 4-8: Individual Cost Comparison 220 - mph Electric

Table 4-5 summarizes the results of the individual cost comparison. 69% of CPM estimates were within +/- 50% of the study costs.

Table 4-5: Individual Cost Comparison: Statistics (n = 77)

Individual Comparison	Count	%
Within 10%	15	19%
Within 30%	39	51%
Within 50%	50	69%
Within 80%	63	82%
Over 100%	5	6%

Upon review of the five individual comparisons, certain trends are evident. For 110 – mph Non-Electric, 125 - mph Non-Electric, and 125 - mph Electric (Tables 4.4, 4.5, and 4.6), the results show underestimated study costs for California. Upon review, the likely cause for the undervalued estimation lies with the land use and terrain classification of the state. Due to the size of the state and location of intended services (roughly 800 miles from San Diego to Sacramento/San Francisco), all terrain and land use types are encountered. Therefore the lack of a distinct terrain or land use influencing factor may require classifying California as multiple geographic areas rather than one. While not all estimations for California were underestimated (the 220-mph estimates were within 10% of the study costs), the aforementioned costs came from the same source, therefore methodological differences may exist (Federal Railroad Administration, 1997).

Estimations for Texas in the125 - mph Electric and 150 – mph Electric (Figure 4-6 and Figure 4-7) comparisons show similar amounts of overestimation. Upon review it was determined that the size of Texas may preclude the use of one land use factor (as shown in Figure 3-5), as a varying mix of all land use types are encountered between the destination combinations of Dallas/Fort Worth, San Antonio, and Houston. Other instances of error over 50% were investigated, but no discernible pattern was determined.

With regards to successful estimation of particular studies or influences, no overwhelming evidence was found. Possible instances of close estimation of study costs were identified for two sources, where nearly half of the estimates were within

+/- 20% of the study costs ((Tanaka, et al., 2010), (Parsons Brinckerhoff Quade and Douglas, Inc., 1991).

Note that true validation may not be possible as the study costs do not represent completed railway projects, but rather feasibility study estimates. In addition each project is influenced by local factors (such as Figure 4-4) that may not be captured in the methodology.

4.2.2 Categorical CPM Comparison

Based on the variability of study costs and the possible error in comparing average estimates of individual study costs, it was decided to perform a sensitivity analysis. The sensitivity analysis is intended to better represent a CPM cost, by taking into account potential variability in the cost components of the methodology.

Table 4-6 shows the contribution of each cost component to the total cost for two example services (also shown Table 3-11and Table 3-12).

Table 4-6: Cost Category Comparison Example

Cost Component	110 – mph Upgrade Single Non-Electric Suburban Hills		150 – mph Build Double Electric Suburban Plains	
	Cost	% of Total	Cost	% of Total
Design & Build	$2,263,184	71%	$13,682,038	65%
Right-of-way	$0	0%	$2,206,913.12	10%
Materials	$508,441	16%	$2,027,674	10%
Communications & Signals	$419,390	13%	$1,398,382	7%
Electric Infrastructure	$0	0%	$1,728,532	8%
Total	$3,191,014	100%	$22,312,871	100%

It can be observed that the Design & Build category is found to be the most influential to the overall cost. As discussed in Section 3.3, the costs associated with this category was estimated based on four assumptions pertaining to the number of tracks, terrain, and land multipliers, as well as the build type (upgrade or build)

Of these four assumptions, the land and terrain multipliers were selected as the most prone to error, as the estimates for material and engineering costs for upgrades or adding tracks were deemed more realistic. As such, the sensitivity of the Design & Build cost estimates was examined by changing the terrain multiplier by +25% (from 1.5 to 1.875 for use when computing hills to mountains, and from 0.667 to 0.833 when computing hills to plains).and -25% (from 1.5 to 1.125 and 0.667 to 0.5, respectively) compared to the base cost. A second test was performed where the land use multiplier was changed by +25% (from 1.1 to 1.375 for rural to suburban and 1.2 to 1.5 for rural to urban), and -25% (for 1.1 to 0.83 and 1.2 to 0.90, respectively).

Table 4-7 and Table 4-8 present a summary of the sensitivity analysis results, that is the lower and upper bounds of CPM estimates, for 150 - mph electric and 220 - mph electric railways respectively. The corresponding results for the other speed categories are listed in Appendix B (Table C-1, Table C-2, and Table C-3).

Table 4-7: Sensitivity Analysis Results – 150-mph Electric

	Terrain Multiplier (+/- 25%)			Land Use Multiplier (+/- 25%)		
Category	Lower Bound	Upper Bound	Difference	Lower Bound	Upper Bound	Difference
150 – mph Build Electric Double Suburban Plains	$10,256,400	$17,087,162	$6,830,762	$13,820,240	$17,102,547	$3,282,307
150 – mph Build Electric Double Urban Plains	$11,188,800	$18,640,541	$7,451,741	$14,985,802	$18,657,324	$3,671,522
150 – mph Build Electric Double Rural Plains	$9,324,000	$15,533,784	$6,209,784	$12,438,216	$12,438,216	$0
150 – mph Build Electric Single Suburban Plains	$6,837,600	$11,391,442	$4,553,842	$9,213,493	$11,401,698	$2,188,205
Totals			$25,046,129			$9,142,033

Table 4-8: Parameter Sensitivity Analysis Comparison – 220-mph Electric

	Terrain Multiplier (+/- 25%)			Land Use Multiplier (+/- 25%)		
Category	Lower Bound	Upper Bound	Difference	Lower Bound	Upper Bound	Difference
220 – mph Build Electric Double Suburban Plains	$18,790,886	$18,790,886	$0	$18,790,886	$18,790,886	$0
220 – mph Build Electric Double Urban Hills	$23,253,722	$38,756,203	$15,502,481	$33,959,433	$38,756,203	$4,796,770
220 – mph Build Electric Double Urban Plains	$20,669,975	$20,669,975	$18,086,228	$22,639,622	$25,837,469	$3,197,847
220 – mph Build Electric Single Suburban Plains	$12,527,258	$12,527,258	$0	$12,527,258	$12,527,258	$0
220 – mph Build Electric Single Urban Plains	$13,779,983	$13,779,983	$0	$15,093,081	$17,224,979	$2,131,898
	Totals		$33,588,709			$10,126,514

The sensitivity analysis results show that the CPM estimates were more sensitive to the assumptions used to characterize the terrain. Because of this, a range of CPM estimates is considered instead of a single estimate and is the basis of the comparison that is discussed next.

4.2.2.1 Categorical Cost Comparison Results

The range of CPM estimates obtained from the sensitivity analysis was compared against a one-standard deviation range of the average study costs. For a study bound that is not a range, only one study cost was available, and no range was calculated. For a methodology bound that is not a range, the category terrain is the same as the base cost and therefore does not have a multiplier. The results of this comparison are shown below in Table 4-9.

Table 4-9: Comparison of Categorical CPM Estimates

Label	Category	Overlap Count	Study Bounds	Methodology Bounds	Overlap
A	220 – mph Build Electric Double Suburban Plains	14	$18.4 - $33.9	$31.4	Yes
B	220 – mph Build Electric Double Urban Hills	1	$25.8	$41.2 - $56.7	No
C	220 – mph Build Electric Double Urban Plains	4	$22.9 - $47.8	$37.9 - $56.0	Yes
D	220 – mph Build Electric Single Suburban Plains	6	$19.8 - $26.1	$20.5	Yes
E	220 – mph Build Electric Single Urban Plains	2	$17.6 - $29.3	$25.3	Yes

Table 4-10: Comparison of Categorical CPM Estimates (Continued)

Label	Category	Overlap Count	Study Bounds	Methodology Bounds	Overlap
F	150 – mph Build Electric Double Suburban Plains	3	$8.4 - $19.5	$17.6 - $24.4	Yes
G	150 – mph Build Electric Double Urban Plains	1	$13.9	$22.6 - $30.1	No
H	150 – mph Build Electric Double Rural Plains	1	$16.2	$15.1 - $21.3	Yes
I	150 - mph Build Electric Single Suburban Plains	7	$7.3 - $15.0	$11.6 - $16.2	Yes
J	125 – mph Build Electric Double Suburban Plains	2	$8.1 -$9.4	$14.4 - $19.5	No
K	125 – mph Upgrade Electric Double Suburban Plains	1	$9.4	$7.6 - $9.3	No
L	125 – mph Upgrade Electric Double Urban Plains	1	$9.2	$8.8 - $10.6	Yes
M	125 – mph Upgrade Electric Double Rural Plains	1	$8.80	$7.0 - $8.6	No
N	125 – mph Build Electric Single Suburban Plains	7	$4.0 - $13.5	$10.0 - $13.4	Yes
O	125 – mph Build Electric Single Urban Plains	1	$9.30	$12.8 - $16.4	No
P	125 – mph Upgrade Non-Electric Single Suburban Plains	8	$1.8 - $10.6	$3.7 - $4.8	Yes
Q	125 – mph Upgrade Non-Electric Single Urban Plains	1	$6.5	$4.6 - $5.8	No
R	125 – mph Build Non-Electric Single Suburban Plains	1	$5.6	$8.1 - $11.5	No
S	110 – mph Upgrade Non-Electric Single Suburban Hills	2	$4.8 - $5.4	$3.2	No
T	110 – mph Upgrade Non-Electric Single Suburban Plains	5	$1.4 - $3.9	$2.0 - $2.8	Yes
U	110 – mph Upgrade Non-Electric Single Urban Plains	2	$2.3 - $6.1	$2.2 - $3.0	Yes

Table 4-10: Comparison of Categorical CPM Estimates (Continued)

Label	Category	Overlap Count	Study Bounds	Methodology Bounds	Overlap
V	110 – mph Upgrade Non-Electric Single Rural Hills	2	$1.8 - $3.1	$3.0	Yes
W	110 – mph Upgrade Non-Electric Single Rural Plains	3	$1.3	$2.0 - $2.6	No
X	110 – mph Build Non-Electric Single Rural Plains	1	$6.40	$4.0 - $6.1	No

The categorical cost comparison results are more satisfactory than those of the individual cost comparison, where 54% or 13 out of 24 cost categories overlap, consisting of 81% of all individual study costs. It should be noted that while there were some instances of large differences, only 3 of the categories that did not overlap consisted of more than 1 observation. If all single observation categories were eliminated, 79% or 11 of 14 cost categories overlap, consisting of 90% of all individual study costs. While true validation may not be possible for the reasons mentioned previously, a range of likely costs by cost category seems to be a better predictor of anticipated construction costs. The CPM estimation methodology can assist transportation planners in determining preliminary or pre-feasibility study costs and for project ranking.

Chapter 5 – Conclusions, Limitations and Recommendations

5.1 Conclusions

This thesis presented a methodology for estimating the CPM of railway construction as a function of location and service characteristics such as Figure 4-8. Five cost components were considered: design and build; ROW; materials; C&S; and electric infrastructure. A sensitivity analysis was conducted that produced a range of CPM estimates depending on the assumptions for the influence of terrain and land use on CPM. While true validation may not be possible as the study costs do not represent actual railway construction costs but rather feasibility study estimates, the author conducted the following comparisons: 1) a comparison between existing feasibility study costs per mile and proposed CPM estimates ("individual" comparison); 2) a comparison between the average cost of all similar study costs and a range of the proposed CPM estimates ("categorical comparison"). It was found that the proposed methodology can predict practical estimates for the majority of the study costs; over half of the individual study costs can be anticipated within 50% of their comparable study costs and nearly 80% of the costs by category being anticipated within the estimated cost ranges. The analysis also showed that the CPM estimates associated with speed levels (such as Table 4-9) are close to those estimated in the feasibility studies.

This methodology can be used to produce CPM estimates that are representative of average values for similar projects at a low cost. It is not meant to replace the need for feasibility studies, but it is an intermediate tool to help determine the likely project costs based on the service and location of the study project, and enable further decision by transportation planning professionals. Users of the CPM methodology can interact with the process in two ways. First, by simply reviewing the results and second, by interacting with the data to allow revision of the inputs as more valid and representational information becomes available. It can be updated with recent information on costs or by including site-specific considerations, if they are known.

5.2 Limitations and Recommendations

Because of these promising results, continued validation and comparison may be worthwhile. The limitations of this research as well as recommendations for future work are discussed below:

- Determine if the six base cost sources (New Mexico Rail Runner Express, California High-Speed-Rail Authority, etc.) are truly representative of railway construction. For example, utilizing the Florida ROW information (Barton-Aschman Associates, Inc., et al, 1986) as a representative basis for other areas may not be as accurate as state or region specific data.
- Identify whether the categorization of study costs for comparison has led to an incorrect classification, where an incorrect interpretation of the source may result in comparing two dissimilar projects. An example of this may be a study cost that is not explicit in the number of tracks, resulting in an assumption by the author.

- Investigate the use of assumptions which were adopted due to the lack of appropriate information. For example, the use of statewide classifications for terrain and land use may not accurately represent the actual conditions, as there might be variations in terrain and land use within a state. Studies not identified or projects that are completed will help to replace some of these assumptions.
- Identify whether the study costs used for comparison are representative of the technology and location analyzed. This point is of great interest, as each of the 77 costs represents estimates only and no actual project costs. None of these projects advanced beyond the planning stage. Therefore, it could be assumed that certain assumptions and calculations were based on parameters that no longer hold true, and would require reevaluation to be determined representative. For example, the only HSR project that has been completed during the period that the studies were published was the upgrading of the New York to Boston Northeast Corridor segment in 2000 (TGVweb, 2001). Of the studies, 22% were conducted prior to 1995, 55% were conducted between 1996 and 2000, and the remaining 23% were conducted between 2009 and 2010. Although all figures have been escalated into 2009 dollars, adjustments for specific cost inputs, such as the change in the price of steel were not possible and are almost certainly worthy of examination when determining the validity of the study data. Future data collection on detailed CPM figures of completed railway projects is a promising avenue for validation of this work.
- Determine how the range of possible error and its impact might be negated. Each comparison shows a varying amount of error and determining systematic

improvements to limit error may prove unrealistic. By quantifying what is an acceptable amount of error may help determine the representative nature of the methodology and its use as a planning tool.

Based on these points, further analysis is recommended to investigate these potential issues and determine whether the nature of the methodology has been compromised, or due to lack of completed projects in North America, the results of the methodology are just as potentially valid as those suggested previously.

Despite these limitations, the CPM estimation methodology shows potential to allow for pre-feasibility study cost estimation based on characteristics of the service and location of a project. Increasing demand on the nation's railroad infrastructure will necessitate more projects to be carried out that would provide updated information for potential revisions to the methodology.

Appendix A

Right-of-Way cost calculation information as discussed in section 3.3 Cost Components.

Below is an example of the ROW calculation, including the use of the “Land Use Type Cost” and multipliers.

Table A-1: ROW Calculation: 79 & 110 – mph Single Track Urban

Land Use Type	Land Use Type Cost		Proportion	ROW Cost: Single Track					
Core	$42,905,286		3%						
Urban	$4,291,155	x	15%	=	$3,228,906 (Plains)	X 1.1	$3,551,797 (Hills)	X 1.2	$4,197,578 (Mountains)
Suburban	$3,218,366		32%						
Rural	$536,394		50%						

Land Use Type	Land Use Type Cost		Proportion	ROW Cost: Double Track					
Core	$42,905,286		3%						
Urban	$4,291,155	x	15%	X 1.3	$4,197,578 (Plains)	X 1.1	$4,617,336 (Hills)	X 1.2	$5,456,851 (Mountains)
Suburban	$3,218,366		32%						
Rural	$536,394		50%						

Below are the tables of ROW proportions, for Suburban and Rural.

Table A-2: ROW Proportion Calculations: Urban

Land Use Type	Land Use Type Cost (2009)	79 - mph, 110 - mph	125 - mph	150 - mph	220 - mph
		Urban	Urban	Urban	Urban
Core	$42,905,286	3%	5%	5%	5%
Urban	$4,291,155	15%	25%	40%	55%
Suburban	$3,218,366	32%	30%	25%	30%
Rural	$536,394	50%	40%	30%	10%

Table A-3: ROW Proportion Calculations: Suburban

Land Use Type	Land Use Type Cost		Cost Adjusted for Rural	79 - mph, 110 - mph	125 - mph	150 - mph	220 - mph
				Rural	Rural	Rural	Rural
Core	$42,905,286		$33,791,378	0%	2%	2%	2%
Urban	$4,291,155	X 0.5 =	$3,379,631	10%	20%	30%	30%
Suburban	$3,218,366		$2,534,723	30%	25%	33%	53%
Rural	$536,394		$422,454	60%	53%	35%	15%

Table A-4: ROW Proportion Calculations: Rural

Land Use Type	Land Use Type Cost		Cost Adjusted for Rural	79 - mph, 110 - mph Rural	125 - mph Rural	150 - mph Rural	220 - mph Rural
Core	$42,905,286		$16,895,689	0%	0%	0%	0%
Urban	$4,291,155	X .25 =	$1,689,815	5%	10%	15%	20%
Suburban	$3,218,366		$1,267,362	15%	20%	30%	35%
Rural	$536,394		$211,227	80%	70%	55%	45%

Below are tables with each ROW cost after the state influence has been removed

Table A-5: ROW Costs: Urban Land Use (Adjusted for state influence)

Terrain	Trackage	79 mph, 110 mph	125 mph	150 mph	220 mph
Plains	Single	$3,228,906	$4,398,121	$4,827,236	$5,524,549
	Double	$4,197,578	$5,717,557	$6,275,407	$7,181,913
Hills	Single	$3,551,797	$4,837,933	$5,309,960	$6,077,004
	Double	$4,617,336	$6,289,312	$6,902,947	$7,900,105
Mountains	Single	$4,197,578	$5,717,557	$6,275,407	$7,181,913
	Double	$5,456,851	$7,432,824	$8,158,029	$9,336,487

Table A-6: ROW Costs: Suburban Land Use (Adjusted for state influence)

Terrain	Trackage	79 mph, 110 mph	125 mph	150 mph	220 mph
Plains	Single	$858,231	$1,402,609	$1,697,625	$1,965,823
	Double	$1,115,700	$1,823,391	$2,206,913	$2,555,569
Hills	Single	$944,054	$1,542,869	$1,867,388	$2,162,405
	Double	$1,227,270	$2,005,730	$2,427,604	$2,811,126
Mountains	Single	$1,115,700	$1,823,391	$2,206,913	$2,555,569
	Double	$1,450,410	$2,370,409	$2,868,987	$3,322,240

Table A-7: ROW Costs: Rural Land Use (Adjusted for state influence)

Terrain	Trackage	79 mph, 110 mph	125 mph	150 mph	220 mph
Plains	Single	$281,607	$362,066	$476,050	$556,509
	Double	$366,089	$470,686	$618,865	$723,462
Hills	Single	$309,768	$398,273	$523,655	$612,160
	Double	$402,698	$517,755	$680,751	$795,808
Mountains	Single	$366,089	$470,686	$618,865	$723,462
	Double	$475,916	$611,892	$804,524	$940,500

Appendix B

Appendix B contains the Individual CPM Comparisons

Table B-1: CPM to Build Single Track Plains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Plains	$6,940,911	$4,321,223	$3,495,585
79 - mph Electric		$7,534,566	$4,914,877	$4,089,240
110 - mph Non-Electric		$9,146,964	$6,360,436	$5,367,960
110 - mph Electric		$9,740,618	$6,954,091	$5,961,614
125 - mph Non-Electric		$13,453,813	$9,843,238	$8,187,633
125 - mph Electric		$14,606,168	$10,995,593	$9,339,988
150 - mph Electric		$17,866,933	$13,908,108	$11,857,318
220 - mph Electric		$25,287,768	$20,476,316	$17,928,161

Table B-2: CPM to Build Single Track Hills

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Hills	$8,755,642	$5,774,566	$4,766,946
79 - mph Electric		$9,349,296	$6,368,220	$5,360,601
110 - mph Non-Electric		$11,961,227	$8,730,018	$7,472,265
110 - mph Electric		$12,554,881	$9,323,672	$8,065,919
125 - mph Non-Electric		$17,578,470	$13,361,274	$11,294,544
125 - mph Electric		$18,730,825	$14,513,629	$12,446,899
150 - mph Electric		$23,317,484	$18,631,712	$16,044,779
220 - mph Electric		$32,730,215	$26,936,527	$23,678,020

Table B-3: CPM to Build Single Track Mountains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Mountains	$11,641,423	$7,999,545	$6,689,934
79 - mph Electric		$12,235,077	$8,593,200	$7,283,589
110 - mph Non-Electric		$16,347,808	$12,330,731	$10,645,919
110 - mph Electric		$12,554,881	$9,323,672	$8,065,919
125 - mph Non-Electric		$23,990,894	$18,713,529	$15,977,623
125 - mph Electric		$25,143,249	$19,865,884	$17,129,978
150 - mph Electric		$31,742,131	$25,808,837	$22,355,989
220 - mph Electric		$44,170,112	$36,725,135	$32,330,634

Table B-4: CPM to Build Double Track Plains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Plains	$9,923,265	$6,467,868	$5,344,737
79 - mph Electric		$10,987,972	$7,532,574	$6,409,443
110 - mph Non-Electric		$13,334,337	$9,628,681	$8,255,291
110 - mph Electric		$14,399,043	$10,693,387	$9,319,997
125 - mph Non-Electric		$19,691,082	$14,874,322	$12,599,023
125 - mph Electric		$21,419,615	$16,602,855	$14,327,555
150 - mph Electric		$26,355,855	$21,043,539	$18,211,670
220 - mph Electric		$37,942,235	$31,436,802	$27,896,432

Table B-5: CPM to Build Double Track Hills

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Hills	$12,580,783	$8,630,718	$7,246,145
79 - mph Electric		$13,645,490	$9,695,424	$8,310,852
110 - mph Non-Electric		$17,491,154	$13,165,888	$11,406,116
110 - mph Electric		$18,555,860	$14,230,595	$12,470,822
125 - mph Non-Electric		$25,790,105	$20,123,323	$17,252,147
125 - mph Electric		$27,518,637	$21,851,855	$18,980,680
150 - mph Electric		$34,435,136	$28,094,993	$24,483,340
220 - mph Electric		$48,995,414	$41,087,802	$36,510,091

Table B-6: CPM to Build Double Track Mountains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Mountains	$16,780,299	$11,933,858	$10,119,363
79 - mph Electric		$17,845,005	$12,998,564	$11,184,070
110 - mph Non-Electric		$23,941,869	$18,532,628	$16,155,334
110 - mph Electric		$25,006,576	$19,597,335	$17,220,040
125 - mph Non-Electric		$35,232,816	$28,095,601	$24,262,284
125 - mph Electric		$35,157,716	$28,020,501	$24,187,184
150 - mph Electric		$46,879,017	$38,792,776	$33,931,113
220 - mph Electric		$65,934,278	$55,692,081	$49,466,751

Table B-7: CPM to Build Additional Track Plains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Plains	$2,588,965	$1,803,058	$1,555,367
79 - mph Electric		$3,182,619	$2,396,713	$2,149,022
110 - mph Non-Electric		$3,393,570	$2,557,612	$2,259,869
110 - mph Electric		$3,987,225	$3,151,267	$2,853,524
125 - mph Non-Electric		$5,208,600	$4,125,428	$3,628,746
125 - mph Electric		$5,643,797	$5,277,783	$4,222,401
150 - mph Electric		$7,522,467	$6,334,819	$5,719,582
220 - mph Electric		$11,774,596	$10,331,160	$9,566,714

Table B-8: CPM to Build Additional Track Hills

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Hills	$3,133,384	$2,239,061	$1,936,775
79 - mph Electric		$3,727,039	$2,832,716	$2,530,430
110 - mph Non-Electric		$4,237,849	$3,268,486	$2,891,161
110 - mph Electric		$4,831,504	$3,862,141	$3,484,815
125 - mph Non-Electric		$6,445,997	$5,180,838	$2,891,161
125 - mph Electric		$7,598,352	$6,333,193	$5,713,174
150 - mph Electric		$9,157,632	$7,751,901	$6,975,821
220 - mph Electric		$14,007,330	$12,269,224	$11,291,671

Table B-9: CPM to Build Additional Track Mountains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Mountains	$3,999,118	$2,906,555	$2,513,672
79 - mph Electric		$4,592,773	$3,500,210	$3,107,326
110 - mph Non-Electric		$5,553,824	$4,348,700	$3,843,257
110 - mph Electric		$6,147,478	$4,942,355	$4,436,912
125 - mph Non-Electric		$8,369,724	$6,786,515	$3,843,257
125 - mph Electric		$9,522,079	$7,938,870	$7,118,098
150 - mph Electric		$11,685,026	$9,905,038	$8,869,184
220 - mph Electric		$17,439,299	$15,205,806	$13,887,456

Table B-10: CPM to Upgrade Single Track Plains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Plains	$1,709,938	$1,627,763	$1,241,134
79 - mph Electric		$2,303,592	$2,221,418	$2,139,244
110 - mph Non-Electric		$2,574,605	$2,437,374	$2,300,143
110 - mph Electric		$3,168,260	$3,031,029	$2,893,797
125 - mph Non-Electric		$5,210,117	$4,258,268	$3,795,162
125 - mph Electric		$6,362,472	$5,410,623	$4,947,517
150 - mph Electric		$7,579,622	$6,523,579	$5,944,544
220 - mph Electric		$11,911,768	$10,608,687	$9,880,541

Table B-11: CPM to Upgrade Single Track Hills

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Hills	$3,090,194	$2,315,059	$2,033,287
79 - mph Electric		$3,683,849	$2,908,713	$2,626,941
110 - mph Non-Electric		$4,284,707	$3,427,028	$3,062,712
110 - mph Electric		$4,878,362	$4,020,682	$3,656,367
125 - mph Non-Electric		$6,536,069	$5,407,999	$4,817,546
125 - mph Electric		$7,688,424	$6,560,354	$5,969,901
150 - mph Electric		$9,339,686	$8,068,787	$7,322,598
220 - mph Electric		$14,323,579	$12,724,830	$11,773,542

Table B-12: CPM to Upgrade Single Track Mountains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Mountains	$3,990,840	$3,035,570	$2,663,367
79 - mph Electric		$3,990,840	$3,035,570	$2,663,367
110 - mph Non-Electric		$5,680,617	$4,601,531	$4,105,513
110 - mph Electric		$5,680,617	$4,601,531	$4,105,513
125 - mph Non-Electric		$8,581,799	$7,151,801	$6,357,169
125 - mph Electric		$8,581,799	$7,151,801	$6,357,169
150 - mph Electric		$12,042,584	$10,410,076	$9,397,680
220 - mph Electric		$18,010,352	$15,923,617	$14,620,001

Table B-13: CPM to Upgrade Double Track Plains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Plains	$2,722,587	$2,599,325	$2,476,063
79 - mph Electric		$3,787,293	$3,664,031	$2,460,807
110 - mph Non-Electric		$4,121,580	$3,915,733	$3,709,887
110 - mph Electric		$4,715,235	$4,509,388	$4,774,593
125 - mph Non-Electric		$7,985,256	$6,707,258	$6,064,626
125 - mph Electric		$9,137,611	$7,859,613	$7,793,158
150 - mph Electric		$11,648,974	$10,221,389	$9,413,916
220 - mph Electric		$18,706,917	$16,930,231	$15,908,478

Table B-14: CPM to Upgrade Double Track Hills

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Hills	$4,615,381	$3,583,065	$3,192,122
79 - mph Electric		$5,680,088	$4,647,771	$3,785,776
110 - mph Non-Electric		$6,509,144	$5,353,011	$4,838,252
110 - mph Electric		$7,102,798	$5,946,666	$5,902,959
125 - mph Non-Electric		$9,809,254	$8,379,256	$7,596,391
125 - mph Electric		$11,104,548	$9,577,196	$9,324,924
150 - mph Electric		$14,264,933	$12,530,714	$11,478,616
220 - mph Electric		$22,297,010	$20,094,617	$18,745,197

Table B-15: CPM to Upgrade Double Track Mountains

Speed	Terrain	Land Use: Urban	Land Use: Suburban	Land Use: Rural
79 - mph Non-Electric	Mountains	$5,934,060	$4,655,250	$4,134,426
79 - mph Electric		$6,998,767	$5,719,956	$4,728,081
110 - mph Non-Electric		$8,570,719	$7,106,184	$6,399,637
110 - mph Electric		$9,164,373	$7,699,839	$7,464,343
125 - mph Non-Electric		$12,690,929	$10,935,349	$9,902,206
125 - mph Electric		$14,129,161	$12,178,874	$11,630,738
150 - mph Electric		$18,271,008	$16,025,671	$14,586,480
220 - mph Electric		$27,771,925	$24,873,140	$23,009,320

Appendix C

Appendix C includes the remainder of the speed category specific parameter sensitivity analysis from Chapter 5.

Table C-1: Parameter Sensitivity Analysis Comparison – 110-mph

Category	Terrain Method Lower Bound	Terrain Method Upper Bound	Terrain Diff	Land Use Method Lower Bound	Land Use Method Upper Bound	Land Use Diff
Upgrade Non-Electric Single Suburban Hills	$2,263,184	$2,263,184	$0	$2,286,044	$2,828,980	$542,936
Upgrade Non-Electric Single Suburban Plains	$1,131,592	$1,885,232	$753,640	$1,524,792	$1,886,930	$362,138
Upgrade Non-Electric Single Urban Plains	$1,234,464	$2,056,617	$822,153	$1,653,389	$2,058,469	$405,080
Upgrade Non-Electric Single Rural Hills	$2,057,440	$2,057,440	$0	$2,057,440	$2,057,440	$0
Upgrade Non-Electric Single Rural Plains	$1,028,720	$1,713,848	$685,128	$1,372,312	$1,372,312	$0
Build Non-Electric Single Rural Plains	$3,117,333	$5,193,477	$2,076,144	$4,158,523	$4,158,523	$0
	Totals		$4,337,065			$1,310,154

Table C-2: Parameter Sensitivity Analysis Comparison – 125-mph

Category	Terrain Method Lower Bound	Terrain Method Upper Bound	Terrain Diff	Land Use Method Lower Bound	Land Use Method Upper Bound	Land Use Diff
Upgrade Non-Electric Single Suburban Plains	$1,673,672	$2,788,338	$1,114,666	$2,255,231	$2,790,848	$535,617
Upgrade Non-Electric Single Urban Plains	$1,825,824	$3,041,823	$1,215,999	$2,445,431	$3,044,562	$599,131
Build Non-Electric Single Suburban Plains	$5,071,733	$5,071,733	$0	$6,834,033	$8,457,115	$1,623,083
	Totals		$2,330,664			$2,757,831

Table C-3: Parameter Sensitivity Analysis Comparison – 125-mph Electric

Category	Terrain Method Lower Bound	Terrain Method Upper Bound	Terrain Diff	Land Use Method Lower Bound	Land Use Method Upper Bound	Land Use Diff
Build Electric Double Suburban Plains	$7,607,600	$12,674,262	$5,066,662	$10,251,049	$12,685,673	$2,434,624
Upgrade Electric Double Suburban Plains	$2,510,508	$4,182,506	$1,671,998	$3,382,846	$4,186,272	$803,426
Upgrade Electric Double Urban Plains	$2,738,736	$4,562,734	$1,823,998	$3,668,146	$4,566,842	$898,696
Upgrade Electric Double Rural Plains	$2,282,280	$3,802,278	$1,519,998	$3,044,562	$3,044,562	$0
Build Electric Single Suburban Plains	$5,071,733	$8,449,508	$3,377,774	$6,834,033	$8,457,115	$1,623,083
Build Electric Single Urban Plains	$5,532,800	$9,217,645	$3,684,845	$7,410,397	$9,225,944	$1,815,547
Totals			$17,145,276			$7,575,376

Table C-4: Parameter Sensitivity Analysis Comparison – 150-mph Electric

Category	Terrain Method Lower Bound	Terrain Method Upper Bound	Terrain Diff	Land Use Method Lower Bound	Land Use Method Upper Bound	Land Use Diff
Build Electric Double Suburban Plains	$10,256,400	$17,087,162	$6,830,762	$13,820,240	$17,102,547	$3,282,307
150 – mph Build Electric Double Urban Plains	$11,188,800	$18,640,541	$7,451,741	$14,985,802	$18,657,324	$3,671,522
Build Electric Double Rural Plains	$9,324,000	$15,533,784	$6,209,784	$12,438,216	$12,438,216	$0
Build Electric Single Suburban Plains	$6,837,600	$11,391,442	$4,553,842	$9,213,493	$11,401,698	$2,188,205
Totals			$25,046,129			$9,142,033

Table C-5: Parameter Sensitivity Analysis Comparison – 220-mph Electric

Category	Terrain Method Lower Bound	Terrain Method Upper Bound	Terrain Diff	Land Use Method Lower Bound	Land Use Method Upper Bound	Land Use Diff
Build Electric Double Suburban Plains	$18,790,886	$18,790,886	$0	$18,790,886	$18,790,886	$0
Build Electric Double Urban Hills	$23,253,722	$38,756,203	$15,502,481	$33,959,433	$38,756,203	$4,796,770
220 –mph Build Electric Double Urban Plains	$20,669,975	$20,669,975	$0	$22,639,622	$25,837,469	$3,197,847
Build Electric Single Suburban Plains	$12,527,258	$12,527,258	$0	$12,527,258	$12,527,258	$0
Build Electric Single Urban Plains	$13,779,983	$13,779,983	$0	$15,093,081	$17,224,979	$2,131,898
Totals			$15,502,481			$10,126,514

Appendix D

Individual cost comparisons as referred to in Chapter 5.

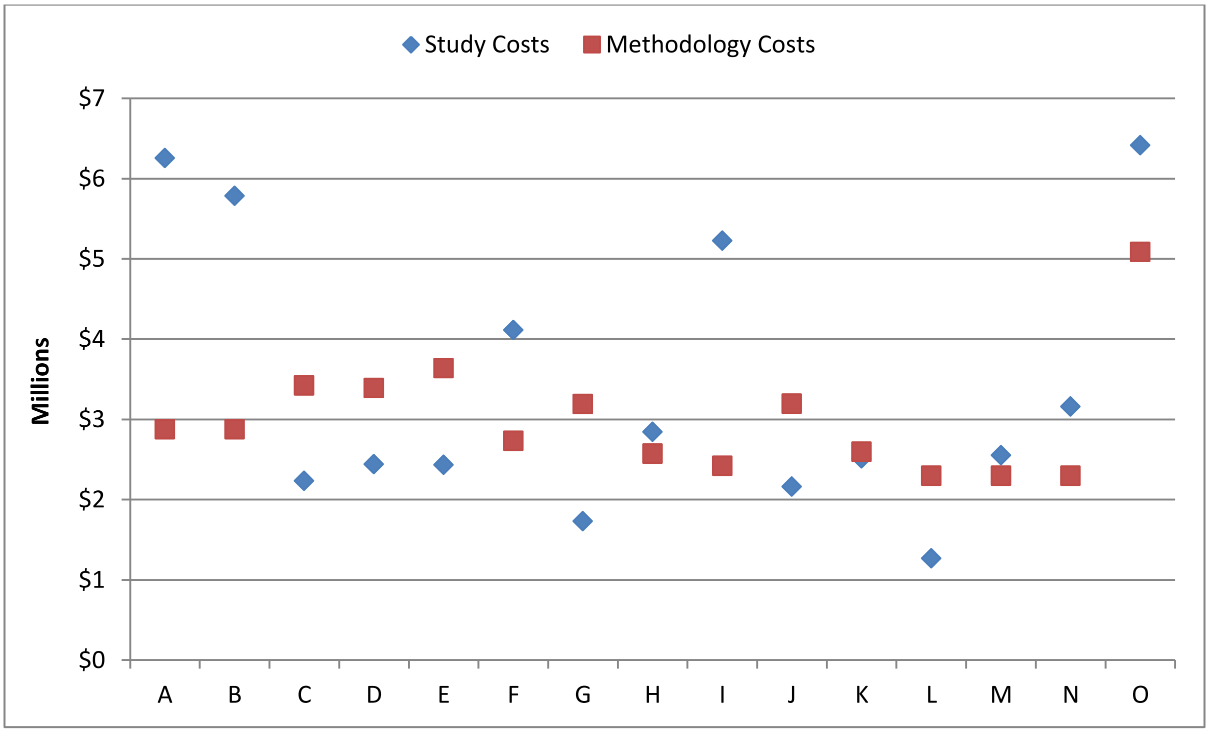

Figure D-1: Individual Cost Comparison 110 - mph Non-Electric – Graph

Table D-1: Individual Cost Comparison Statistics: 110 - mph Non-Electric

Individual Cost Comparison Statistics: 110 - mph Non-Electric		
Individual Comparison	Count	%
Within 10%	3	20%
Within 30%	5	33%
Within 50%	9	60%
Within 80%	13	87%
Over 100%	0	0%

Table D-2: Individual Cost Comparison 110 - mph Non-Electric Data

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
California North & South	A	Upgrade Single Non-Electric Suburban Hills	$6,256,335	$2,876,101	-$3,380,233	-54.0%
California South	B	Upgrade Single Non-Electric Suburban Hills	$5,785,953	$2,876,101	-$2,909,852	-50.3%
Chicago Hub	C	Upgrade Single Non-Electric Suburban Plains	$2,235,358	$3,425,022	$1,189,664	53.2%
Chicago to Detroit	D	Upgrade Single Non-Electric Suburban Plains	$2,441,762	$3,393,112	$951,350	39.0%
Chicago to St. Louis	E	Upgrade Single Non-Electric Suburban Plains	$2,435,601	$3,637,756	$1,202,155	49.4%
Charlotte to Macon	F	Upgrade Single Non-Electric Suburban Plains	$4,114,790	$2,733,636	-$1,381,155	-33.6%
PBD&Q Suburban	G	Upgrade Single Non-Electric Suburban Plains	$1,731,007	$3,191,014	$1,460,008	84.3%
PBD&Q Urban	H	Upgrade Single Non-Electric Urban Plains	$2,844,483	$2,574,605	-$269,878	-9.5%
Florida	I	Upgrade Single Non-Electric Urban Plains	$5,226,155	$2,420,129	-$2,806,026	-53.7%
Pacific Northwest	J	Upgrade Single Non-Electric Rural Hills	$2,162,814	$3,194,239	$1,031,425	47.7%
Texas Triangle	K	Upgrade Single Non-Electric Rural Hills	$2,511,828	$2,597,185	$85,357	3.4%
PBD&Q Rural	L	Upgrade Single Non-Electric Rural Plains	$1,270,784	$2,300,143	$1,029,358	81.0%

Table D-2: Individual Cost Comparison 110 – mph Non-Electric Data (Continued)

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
Chicago to Twin Cities	M	Upgrade Single Non-Electric Rural Plains	$2,551,755	$2,300,143	-$251,612	-9.9%
Chicago to Twin Cities	N	Upgrade Single Non-Electric Rural Plains	$3,162,180	$2,300,143	-$862,037	-27.3%
Chicago to Twin Cities	O	Build Single Non-Electric Rural Plains	$6,415,385	$5,086,353	-$1,329,032	-20.7%

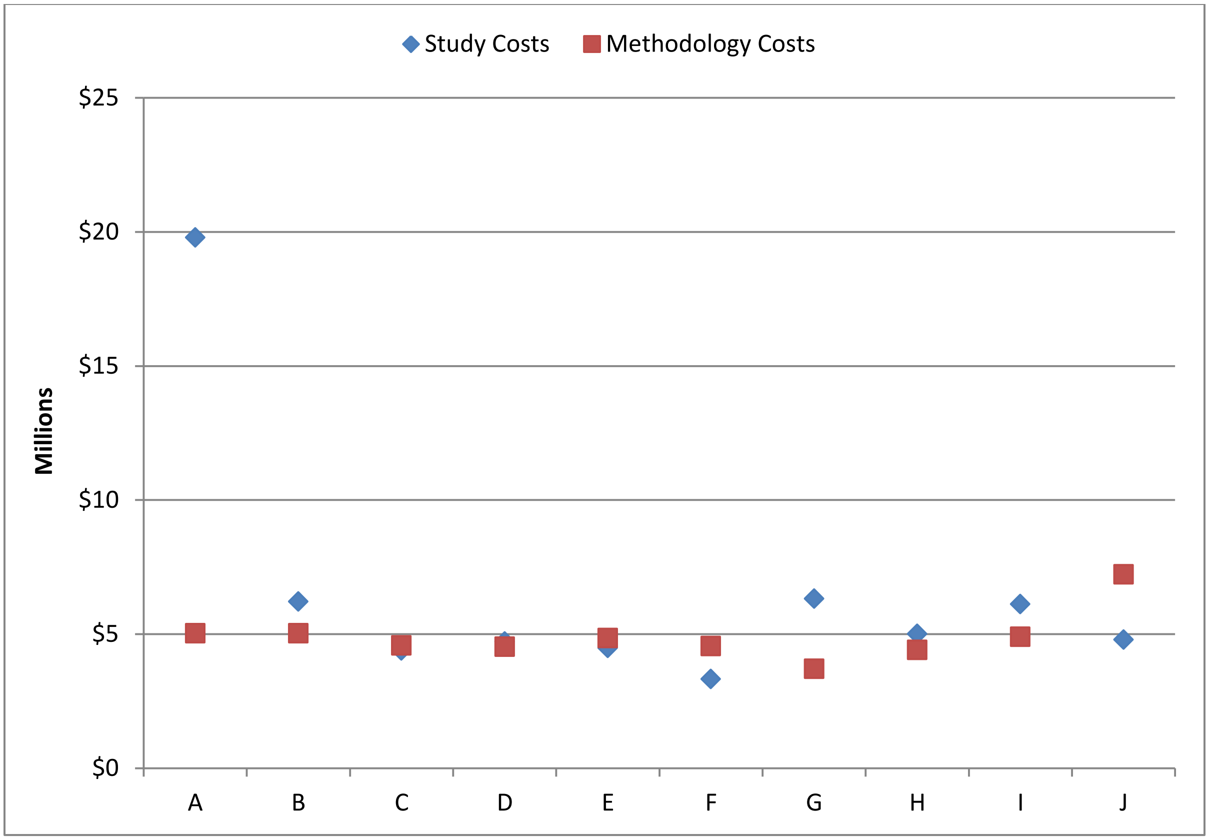

Figure D-2: Individual Cost Comparison 125 - mph Non-Electric - Graph

Table D-3: Individual Cost Comparison Statistics: 125 - mph Non-Electric

Individual Cost Comparison Statistics: 125 - mph Non-Electric		
Individual Comparison	Count	%
Within 10%	3	30%
Within 30%	6	60%
Within 50%	8	80%
Within 80%	10	100%
Over 100%	0	0%

Table D-4: Individual Cost Comparison: 125 - mph Non-Electric - Data

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
California North & South	A	Upgrade Single Non-Electric Suburban Plains	$19,789,565	$5,024,756	-$14,764,809	-74.6%
California South	B	Upgrade Single Non-Electric Suburban Plains	$6,206,708	$5,024,756	-$1,181,951	-19.0%
Chicago Hub	C	Upgrade Single Non-Electric Suburban Plains	$4,380,619	$4,570,541	$189,922	4.3%
Chicago to Detroit	D	Upgrade Single Non-Electric Suburban Plains	$4,713,486	$4,527,958	-$185,527	-3.9%
Chicago to St. Louis	E	Upgrade Single Non-Electric Suburban Plains	$4,476,983	$4,854,426	$377,443	8.4%
Pacific Northwest	F	Upgrade Single Non-Electric Suburban Plains	$3,316,608	$4,556,347	$1,239,739	37.4%
Texas Triangle	G	Upgrade Single Non-Electric Suburban Plains	$6,316,832	$3,704,693	-$2,612,139	-41.4%
Ontario to Quebec	H	Upgrade Single Non-Electric Suburban Plains	$5,005,903	$4,407,307	-$598,596	-12.0%
Florida	I	Upgrade Single Non-Electric Urban Plains	$6,122,007	$4,897,510	-$1,224,497	-20.0%
Charlotte to Macon	J	Build Single Non-Electric Suburban Plains	$4,795,920	$7,230,806	$2,434,886	50.8%

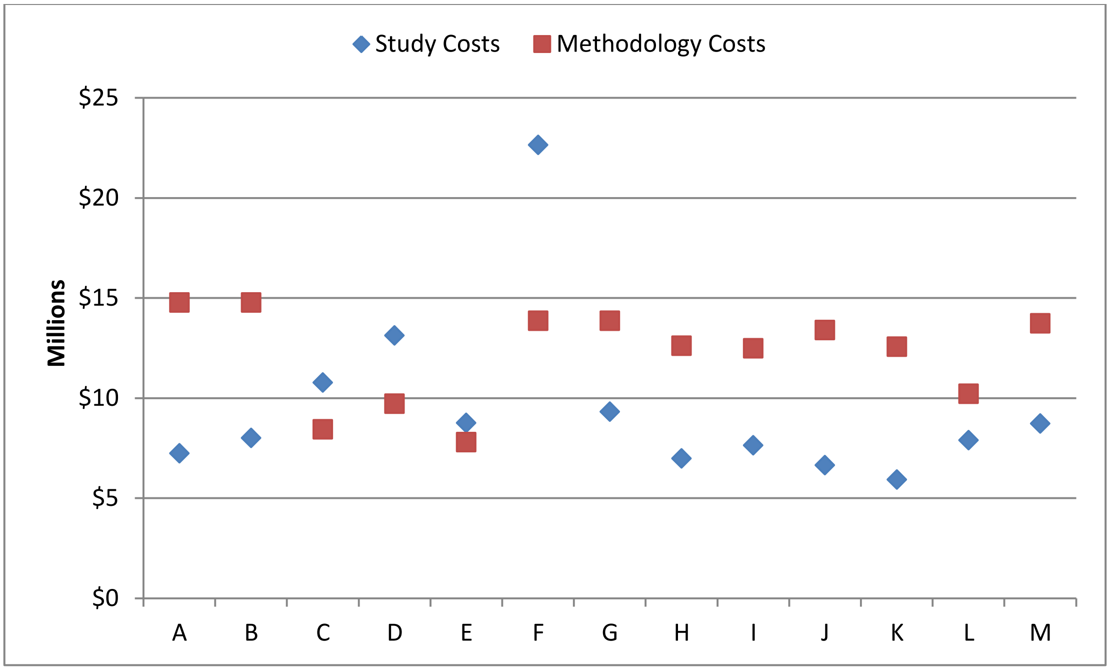

Figure D-3: Individual Cost Comparison 125 - mph Electric – Graph

Table D-5: Individual Cost Comparison Statistics: 125 - mph Electric

Individual Cost Comparison Statistics: 125 - mph Electric		
Individual Comparison	Count	%
Within 10%	0	0%
Within 30%	4	31%
Within 50%	6	46%
Within 80%	8	62%
Over 100%	3	23%

Table D-6: Individual Cost Comparison: 125 - mph Electric - Data

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
Texas	A	Build Double Electric Suburban Plains	$7,235,145	$14,778,148	$7,543,003	104.3%
Texas	B	Build Double Electric Suburban Plains	$8,007,451	$14,778,148	$6,770,696	84.6%
PBD&Q Suburban	C	Upgrade Double Electric Suburban Plains	$10,775,756	$8,435,790	-$2,339,966	-21.7%
PBD&Q Urban	D	Upgrade Double Electric Urban Plains	$13,117,102	$9,713,788	-$3,403,314	-25.9%
PBD&Q Rural	E	Upgrade Double Electric Rural Plains	$8,756,425	$7,793,158	-$963,267	-11.0%
California North & South	F	Build Single Electric Suburban Plains	$22,640,247	$13,862,166	-$8,778,081	-38.8%
California South	G	Build Single Electric Suburban Plains	$9,314,573	$13,862,166	$4,547,593	48.8%
Chicago Hub	H	Build Single Electric Suburban Plains	$6,988,238	$12,609,089	$5,620,851	80.4%
Chicago to Detroit	I	Build Single Electric Suburban Plains	$7,640,361	$12,491,613	$4,851,252	63.5%
Chicago to St. Louis	J	Build Single Electric Suburban Plains	$6,636,731	$13,392,262	$6,755,531	101.8%
Pacific Northwest	K	Build Single Electric Suburban Plains	$5,924,977	$12,569,930	$6,644,953	112.2%
Texas Triangle	L	Build Single Electric Suburban Plains	$7,885,553	$10,220,411	$2,334,858	29.6%

Table D-6: Individual Cost Comparison: 125 - mph Electric – Data (Continued)

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
Florida	M	Build Single Electric Urban Plains	$8,720,606	$13,729,798	$5,009,192	57.4%

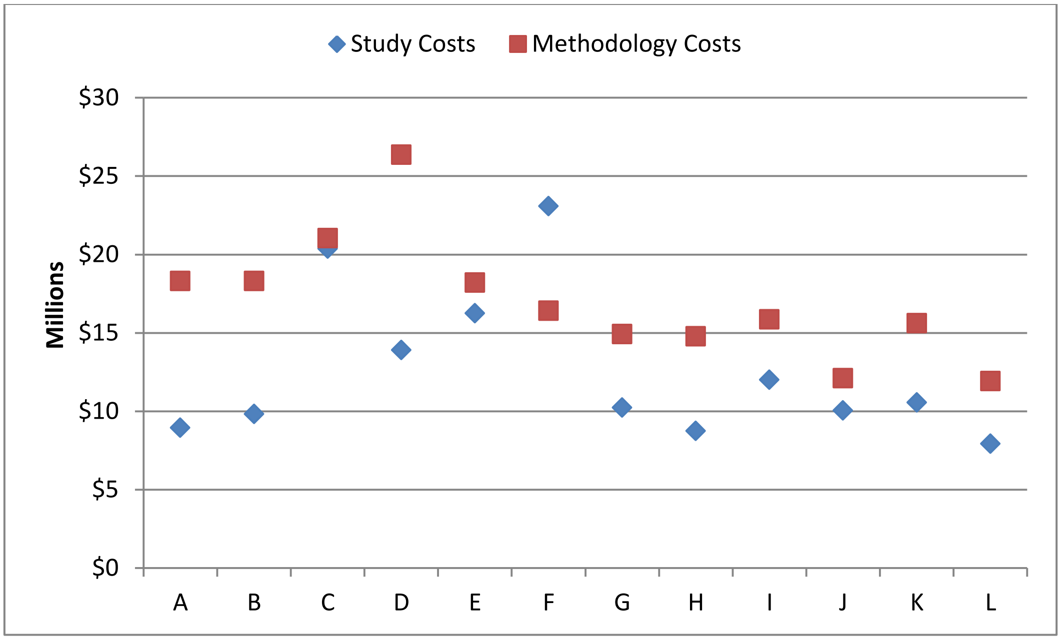

Figure D-4: Individual Cost Comparison 150 - mph Electric – Graph

Table D-7: Individual Cost Comparison Statistics: 150 - mph Electric

Individual Cost Comparison Statistics: 150 - mph Electric		
Individual Comparison	Count	%
Within 10%	1	8%
Within 30%	4	33%
Within 50%	5	42%
Within 80%	8	67%
Over 100%	2	17%

Table D-8: Individual Cost Comparison: 150 - mph Electric - Data

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
Texas	A	Build Double Electric Suburban Plains	$8,946,569	$18,307,879	$9,361,311	104.6%
Texas	B	Build Double Electric Suburban Plains	$9,817,171	$18,307,879	$8,490,708	86.5%
PBD&Q Suburban.	C	Build Double Electric Suburban Plains	$20,358,762	$21,043,539	$684,777	3.4%
PBD&Q Urban	D	Build Double Electric Urban Plains	$13,910,456	$26,355,855	$12,445,399	89.5%
PBD&Q Rural	E	Build Double Electric Rural Plains	$16,241,354	$18,211,670	$1,970,316	12.1%
California North & South	F	Build Single Electric Suburban Plains	$23,085,266	$16,411,568	-$6,673,698	-28.9%
Chicago Hub	G	Build Single Electric Suburban Plains	$10,231,867	$14,928,036	$4,696,169	45.9%
Chicago to Detroit	H	Build Single Electric Suburban Plains	$8,750,222	$14,788,955	$6,038,733	69.0%
Chicago to St. Louis	I	Build Single Electric Suburban Plains	$12,013,032	$15,855,243	$3,842,211	32.0%
Texas Triangle	J	Build Single Electric Suburban Plains	$10,047,430	$12,100,054	$2,052,624	20.4%
Chicago to Twin Cities	K	Build Single Electric Suburban Plains	$10,550,137	$15,623,441	$5,073,305	48.1%
Charlotte to Macon	L	Build Single Electric Suburban Plains	$7,919,904	$11,914,613	$3,994,709	50.4%

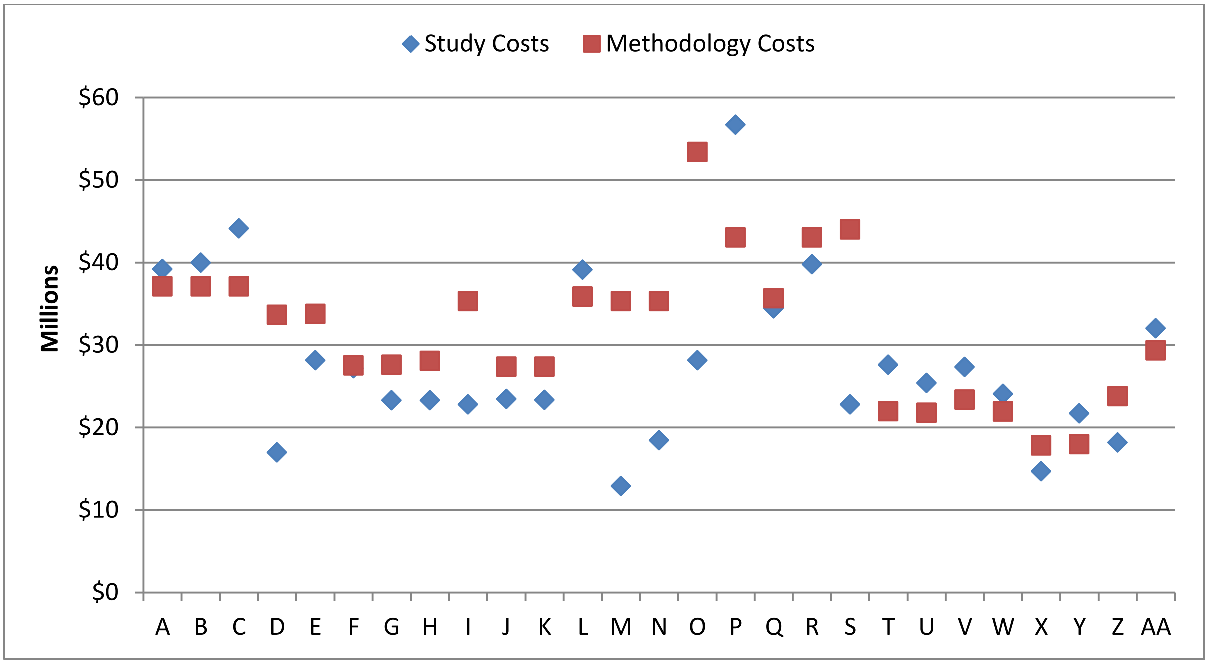

Figure D-5: Individual Cost Comparison 220 - mph Electric – Graph

Table D-9: Individual Cost Comparison Statistics: 220 - mph Electric

Individual Cost Comparison Statistics: 220 - mph Electric		
Individual Comparison	Count	%
Within 10%	9	33%
Within 30%	19	70%
Within 50%	20	74%
Within 80%	21	78%
Over 100%	5	19%

Table D-10: Individual Cost Comparison: 220 - mph Electric – Data

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
California North & South	A	Build Double Electric Suburban Plains	$39,190,694	$37,095,427	-$2,095,268	-5.3%
California South	B	Build Double Electric Suburban Plains	$39,981,039	$37,095,427	-$2,885,613	-7.2%
California	C	Build Double Electric Suburban Plains	$44,133,968	$37,095,427	-$7,038,541	-15.9%
Pacific Northwest	D	Build Double Electric Suburban Plains	$16,974,603	$33,637,378	$16,662,775	98.2%
Chicago Hub	E	Build Double Electric Suburban Plains	$28,129,342	$33,742,168	$5,612,826	20.0%
South Central	F	Build Double Electric Suburban Plains	$27,159,365	$27,507,202	$347,837	1.3%
South East	G	Build Double Electric Suburban Plains	$23,279,456	$27,585,794	$4,306,338	18.5%
Gulf	H	Build Double Electric Suburban Plains	$23,279,456	$28,057,346	$4,777,890	20.5%
New England	I	Build Double Electric Suburban Plains	$22,794,467	$35,314,008	$12,519,541	54.9%
Texas	J	Build Double Electric Suburban Plains	$23,419,120	$27,350,018	$3,930,898	16.8%
Texas	K	Build Double Electric Suburban Plains	$23,304,481	$27,350,018	$4,045,537	17.4%
Chicago to St. Louis	L	Build Double Electric Suburban Plains	$39,115,868	$35,837,955	-$3,277,913	-8.4%

Table D-10: Individual Cost Comparison: 220 - mph Electric – Data (Continued)

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
Chicago to Twin Cities	M	Build Double Electric Suburban Plains	$12,888,199	$35,314,008	$22,425,809	174.0%
Chicago to Twin Cities	N	Build Double Electric Suburban Plains	$18,447,205	$35,314,008	$16,866,803	91.4%
Keystone Corridor	O	Build Double Electric Urban Hills	$28,129,342	$53,405,001	$25,275,659	89.9%
Northeast Corridor	P	Build Double Electric Urban Plains	$56,677,920	$43,017,009	-$13,660,912	-24.1%
Florida	Q	Build Double Electric Urban Plains	$34,434,195	$35,665,701	$1,231,506	3.6%
Northeast Corridor	R	Build Double Electric Urban Plains	$39,769,070	$43,017,009	$3,247,939	8.2%
Empire Corridor	S	Build Double Electric Urban Plains	$22,794,467	$44,012,992	$21,218,525	93.1%
Chicago Hub	T	Build Single Electric Suburban Plains	$27,604,848	$21,977,913	-$5,626,935	-20.4%
Chicago to Detroit	U	Build Single Electric Suburban Plains	$25,385,207	$21,773,150	-$3,612,058	-14.2%
Chicago to St. Louis	V	Build Single Electric Suburban Plains	$27,331,015	$23,343,001	-$3,988,014	-14.6%
Pacific Northwest	W	Build Single Electric Suburban Plains	$24,046,957	$21,909,659	-$2,137,299	-8.9%
Texas Triangle	X	Build Single Electric Suburban Plains	$14,670,938	$17,814,395	$3,143,458	21.4%
Southeast	Y	Build Single Electric Suburban Plains	$21,701,542	$17,967,968	-$3,733,575	-17.2%

Table D-10: Individual Cost Comparison: 220 - mph Electric – Data (Continued)

State	Code	Category	Study Costs	Methodology Costs	Difference $	Difference %
Florida	Z	Build Single Electric Urban Plains	$18,159,755	$23,770,502	$5,610,747	30.9%
Empire Corridor	AA	Build Single Electric Urban Plains	$32,029,067	$29,333,811	-$2,695,256	-8.4%

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