December 2018

Calculation of Access Charge for High Speed Rail XpressWest of Nevada

Sameeksha Sapkota
sameekshasapkota@gmail.com

CALCULATION OF ACCESS CHARGE FOR HIGH SPEED RAIL XPRESSWEST OF NEVADA

By

Sameeksha Sapkota

Bachelor of Engineering - Civil Engineering
Tribhuvan University, Nepal
2016

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science in Engineering – Civil and Environmental Engineering

Department of Civil and Environmental Engineering and Construction
Howard R. Hughes College of Engineering
The Graduate College

University of Nevada, Las Vegas
December 2018

Thesis Approval

The Graduate College
The University of Nevada, Las Vegas

November 15, 2018

This thesis prepared by

Sameeksha Sapkota

entitled

Calculation of Access Charge for High Speed Rail XpressWest of Nevada

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Engineering – Civil and Environmental Engineering
Department of Civil and Environmental Engineering and Construction

Jin Ouk Choi, Ph.D.
Examination Committee Chair

Hualiang (Harry) Teng, Ph.D.
Examination Committee Member

Mohamed Kaseko, Ph.D.
Examination Committee Member

Jaewon Lim, Ph.D.
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Interim Dean

ABSTRACT

Calculation of Access Charge for High Speed Rail XpressWest of Nevada

By Sameeksha Sapkota

XpressWest is a High Speed Rail (HSR) system that plans to connect Las Vegas with California at Palmdale. It will utilize the railway network of the California High Speed Rail (CAHSR) to connect Las Vegas with California destinations that include Los Angeles and San Francisco. For sharing the railway network of CAHSR, XpressWest will pay certain charge known as an access charge. The access charge is the fee paid by the train operator to the infrastructure owner for the addition of trains in a track. There are several access charge systems in the world. However, there is no study that calculates access charge for sharing the HSR passenger trains for private railroad system. This study develops a new framework to calculate a reasonable value of access charges for shared HSR systems. The study describes how to calculate access charge in terms of maintenance costs, congestion costs, and costs of installing side tracks mathematically. The study develops a theoretical capacity allocation model to calculate congestion costs. Based on the operation plans of both train systems, delay in operations are determined. The research used 18 different proposed train operating scenarios to calculate the value of the access charges. Based on the scenarios, the access charges range from $3.8 million to $62 million per year, with a fixed one-time cost of $56 million to $84 million in the beginning. Authorities are planning many HSR corridors around the US. The framework used in this research can also be adopted to other shared use track operation systems by changing the variable values.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor Dr. Jin Ouk Choi, for giving me a rewarding graduate school experience by his guidance, comments, criticisms, motivation and demanding high quality work. His door was always open to me whenever I was had any question or trouble in graduate school or writing this thesis.

I am also indebted Dr. Hualiang (Harry) Teng, who provided constant guidance, comments and suggestions throughout the writing process of this thesis. I would like to express gratitude to my other thesis committee members: Dr. Mohamed Kaseko, and Dr. Jaewon Lim for their helpful comments and remarks.

I would also like to acknowledge USDOT and UTC (University Transportation Center) for their financial support, without which I would not have been able to develop my study.

I would also like to acknowledge my friend Sayan Sakhakarmi and my brother Daniel Sapkota for reading my thesis and providing valuable comments and suggestions on it.

Finally, I would like to thank my parents, Bhesh Nath Sapkota and Laxmi Chapagain, for their constant support and love throughout my graduate studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Background

High Speed Rail (HSR) networks are innovative, fast, high capacity systems that efficiently serve the needs of the present century (Campos & de Rus, 2009). HSR services are a comfortable, fast, safe, and reliable method of travel for an increasing number of passengers. They are popular in Japan, Europe, and China, and now interests are increasing in United States (US). At present, in the US there is only one HSR operating line (150mph), which is between Boston and Washington DC (Givoni, 2006). However, authorities are proposing and planning different HSR sections now.

There are different definitions of High-Speed Rail (HSR) in the world. The United States Code defines it as services "reasonably expected to reach sustained speeds of more than 125 mph" (US Code Title, 2011). The European Council Directive (2001) defines HSR as "specially built high-speed lines equipped for speeds equal to or greater than 155mph or upgraded conventional lines equipped for speeds greater than 120 mph."

A HSR is also a highly expensive system (Campos & de Rus, 2009). It involves enormous amounts of capital and operating costs, and can even financially affect the transport policy of a country for the following few decades (Campos & de Rus, 2009). Hence, there is a trend by different train operators to share the same railroad network and utilize the system efficiently. This type of network is called a shared track railroad network. There is a significant increase in the operation and maintenance costs of sharing a railroad network (Sánchez-Borràs, Nash, Abrantes, & López-Pita, 2010). This additional cost is called an access charge.

The access charge is the fees paid by the operating trains to the owner of the infrastructure for their use of its network. This cost is to be paid by the additional operating railroad companies to compensate for the additional costs to the railroad management company (Tsamboulas & Kopsacheili, 2004). The fair value of the access charge will enable train infrastructure owners and operators to carry out shared operations in a fair environment.

There is little existing literature on access charges. There are some methodologies proposed to calculate access charges in the European context. Additionally, there is some existing literature for calculating access charges in North American freight transportation systems. In these cases, access charges are heavily subsidized by the government. However, there is no model that calculates access charge for high speed passenger train sharing tracks with a private passenger railroad system.

XpressWest and California High Speed Rail (CAHSR) are two different HSRs constructed and operated by different agencies in the Western US. The figure shows the connection between the California high speed rail (yellow line) and XpressWest (blue line). The high speed trains of XpressWest operate from Las Vegas of Nevada to Los Angeles and San Francisco by turning South and North at Palmdale respectively. CAHSR is currently built by using federal and state funds in addition to private investments. XpressWest is a private company operating for profit.

Figure 1: Connection between California high speed rail (yellow line) and XpressWest of Nevada (blue line)

XpressWest was formerly known as DesertXpress. DesertXpress was proposed by Marnell Corrao Associates to connect Palmdale, Los Angeles and Victorville of California to Las Vegas. This project was later sold to Florida based railroad company Brightline. Brightline plans to start the construction in 2019.

The purpose of XpressWest is to provide an alternative to Interstate 15 highway between Las Vegas and Los Angeles. This highway carries heavy traffic. XpressWest plans to construct a dedicated double track from Las Vegas to Palmdale. It will run at the speed of 150 mph, using the train technology that will be interoperable with the CAHSR tracks.

The CAHSR is also a high-speed passenger rail system, operating at the speed of 220 mph, connecting popular California destinations like San Francisco and Los Angeles. The project is set to be completed in two phases (CAHSR, 2018a). The first phase will consist of connecting San Francisco to Los Angeles and then to Anaheim (CAHSR, 2018a). The length of this section is about 500 miles (CAHSR, 2018a). The second phase will connect Sacramento to Los Angeles via Merced, and further expand it to San Diego (CAHSR, 2018a). The total length of this entire section is about 800 miles in length (CAHSR, 2018a).

XpressWest and CAHSR have different train characteristics like speed, acceleration, braking, and time-table. These differences could cause some conflicts and constraints between operating trains (Lai et al., 2014). These conflicts and constraints would be in the form of track deterioration and operation delay (Lai et al., 2014). The deterioration and renewal rates of operating infrastructure, like tracks, signals, and stations, would significantly increase by the addition of operating trains (Lai et al., 2014). Hence, XpressWest will have to pay an access charge to CAHSR. This study will calculate the reasonable value of access charge that needs to be paid by XpressWest to CAHSR.

1.2 Research Objective

The primary objective of this research is to calculate a reasonable value of access charge for XpressWest, so that it can operate satisfactorily in the CAHSR network. In doing so, the research also aims to develop a hypothetical train allocation and operation model to see if XpressWest trains can operate satisfactorily, or if they will cause delay to operating CAHSR trains.

1.3 Research Scope and Limitation

The main scope of the research is to calculate the access charge for XpressWest of Nevada to pay CAHSR. To calculate this access charge, it will calculate the maintenance, congestion costs and costs of installing side tracks. The study will calculate maintenance costs based on the historical data of different HSR systems and their speeds around the world. The maintenance cost for XpressWest will be based on the speed and number of CAHSR and XpressWest trains in a mixed flow network.

For the calculation of congestion costs, it is necessary to calculate the delay caused to CAHSR by XpressWest. A theoretical capacity allocation model for train slots has been made to see the train operations and check delays. This model considers the distance between stations and speeds of the trains to make the model. However, the geographical conditions, as well as the presence of curves and train signals in calculating the operating path does not fall within the scope of this research.

The study calculates unit delay costs by adding train operations and train control costs. Train operation costs includes crew costs, energy costs, and supply costs. Train control costs consist of operation control costs, train dispatching costs, and supply costs. The cost of time loss for passengers or crew is not within the scope of this research.

CHAPTER 2: LITERATURE REVIEW

2.1 Access Charge

An access charge is the fee that is charged to an operator of one train service for the use of the network that is owned by another operator. There is a significant increase in the cost of maintenance, renewals, capacity, accidents, and infrastructure deterioration, by the addition of trains in the prevailing railroad network (Nash, 2005; Sánchez-Borràs et al., 2010). The addition of train adds different costs to the system like infrastructure improvements (front-end costs), maintenance costs, and HSR operator overheads, as well as the costs due to lost opportunities, such as delays for freight trains.

An access charge is a widespread practice in US freight railroad networks. Passenger trains use the networks owned by freight railroads and pay to compensate for the additional cost (Lai et al., 2014). In this case, an access charge is levied by tracing the path of and calculating the distance traveled by the trains. Amtrak follows this regime. However, the cost paid is minimal (around 4%) compared to the total operating costs of Amtrak (Lai et al., 2014).

This type of regime also started in Europe after the restructuring of railways to provide access to new entrants (Sánchez-Borràs & Al, 2011). After the restructuring, the state-owned railroads were vertically separated (Tsamboulas & Kopsacheili, 2004). Vertical separation means that the railroad operators and managers are different now. Hence, the managing companies started applying charges to the operating railroad companies based on defined policies (Tsamboulas & Kopsacheili, 2004). These costs are often state-subsidized and only include the marginal costs of operation (Vidaud & Tilière, 2010).

The concept of an access charge is still relatively new, and the existing literature in this area is limited (Levy, Peña-Alcaraz, Prodan, & Sussman, 2015) However, it is agreed there is a significant increase in the cost of maintenance, renewals, capacity, accidents, and infrastructure deterioration, by the addition of trains in a prevailing railroad network (Nash, 2005; Sánchez-Borràs et al., 2010).

2.2 Cost Elements in Access Charge

Different systems use different cost elements in determining an access charge. The different costs involved are:

i) Initial Capital costs – These include a certain share of total cost for the price of purchasing equipment and material, engineering and labor costs, installation costs, and initial training costs. (Tsamboulas & Kopsacheili, 2004).

ii) Train operation costs – These include energy consumption, train control costs, and labor costs during the operation of trains (European Commission, 2001; Tsamboulas & Kopsacheili, 2004). Energy consumption includes the fuel costs. Labor cost includes the crew costs and costs of uniforms, vehicles, and supplies (CAHSR, 2018b). Train control cost includes the costs of traffic signals, dispatching and control costs, vehicles and supplies costs, and repair center costs. (CAHSR, 2018b; Tsamboulas & Kopsacheili, 2004)

iii) Maintenance and renewal or Infrastructure damage costs – These include additional costs to repair and renew infrastructure (Lai et al., 2014). This includes the cost of infrastructure, like maintenance vehicles, maintenance crews, and supply costs (CAHSR, 2018b). These could be periodic, weather-based, and unexpected maintenance costs (Tsamboulas & Kopsacheili, 2004).

iv) Congestion and scarcity costs –The addition of extra trains on the network can prevent the operation of the previously operating trains or cause delay to their operation (Lai et al., 2014). This cost to compensate for extra travel time and a non-availability penalty is known as congestion cost (Tsamboulas & Kopsacheili, 2004).

v) Environmental costs – These costs include compensation costs for causing air, water, and soil pollution (Sánchez-Borràs et al., 2010).

vi) Accident costs – These costs include compensation costs for increase in the risk of accidents by the addition of trains to a network (Sánchez-Borràs et al., 2010).

vii) Cancellation charge – This cost includes the compensation cost if the operation of any train is canceled with or without prior notice (Vidaud & Tilière, 2010).

The computation of access charge and elements included are different for different countries. Johnson & Nash (2008) and Vidaud & Tilière (2010) have listed the cost elements according to different countries. The most commonly included cost elements are maintenance and renewal costs, and congestion costs. Only some countries, such as Sweden, Switzerland and Finland include accident costs, environmental costs, or cancelation charges, since they only account for a small portion of the access charge (Sánchez-Borràs et al., 2010). The researcher has compiled the cost elements in access charges by Lai et al. (2014) and Vidaud & Tilière (2010) for different countries:

Table 1: Cost Elements Included in Access Charge

Country	Maintenance	Congestion	Accident	Environmental	Cancelation Charge
Austria	✔	✔	-	-	?
Denmark	✔	✔	-	-	?
Finland	✔	-	-	✔	?
France	✔	✔	-	-	-
Germany	✔	✔	-	-	✔
Italy	-	✔	-	-	?
Sweden	✔	-	✔	✔	-
Switzerland	✔	✔	-	✔	✔
UK	✔	✔	-	-	✔

Note: ✔ = this element was included
- = this element was not included, ? = this element was not known

2.3 Mathematical Models

During the literature search, the researcher found three mathematical models to calculate access charges in detail. Tsamboulas & Kopsacheili (2004) developed the first model.

a. Mathematical Model developed by Tsamboulas & Kopsacheili (2004)

Tsamboulas & Kopsacheili (2004) have calculated access charges by a life-cycle cost analysis (LCCA) approach. They have carried out seven different steps to estimate the costs:

Step 1: Establish a management profile;

Step 2: Identify all infrastructure components and construct a database;

Step 3: Calculate the cost components;

Step 4: Calculate the present costs;

Step 5: Use inflation rates to calculate future costs;

Step 6: Discount the price to the base year;

Step 7: Calculate the life-cycle costs for the present year.

Tsamboulas & Kopsacheili (2004) divided the infrastructure components into linear and spot fixed categories. They included tracks, tunnels, bridges, noise barriers, and signals, as well as ground and formation substructure as the linear components. They also included switches, turnouts, crossings, and stations, as well as service and light repair facilities, maintenance and heavy repair facilities, and a central maintenance facility as the spot fixed components.

Tsamboulas & Kopsacheili (2004) identified initial capital costs, train planning costs, maintenance and renewal costs, delay and scarcity costs, and disposal costs as the cost data. The life cycle formulation diagram was created as:

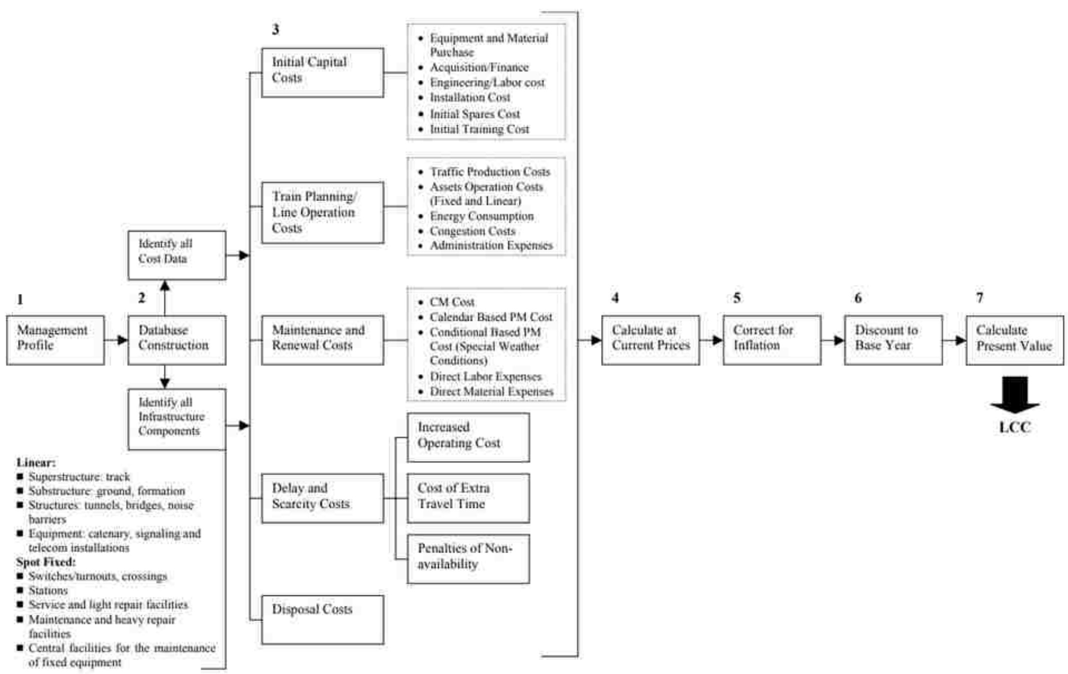

Figure 2: LCCA Formulation by Tsamboulas & Kopsacheili (2004)

Based on the diagram, Tsamboulas & Kopsacheili (2004) used the following relationships for the calculation of access charges:

$TP_{Final} = f(P_{Operation}, P_{Infrastructure\ Damage}, P_{Path\ Allocation}, P_{Additional\ Costs})$……………………...(1)

Where, TP_{Final} = Total Access Charge

$P_{Operation}$= Train Operation Cost

$P_{Infrastructure\ Damage}$= Maintenance Cost

$P_{Path\ Allocation}$= Cost related to priority and quality of service

$P_{Additional\ Costs}$= Energy Consumption and Station Cost

To calculate the access charges, the first equation adopted by Tsamboulas & Kopsacheili (2004) is:

$TP_{Basic} = P_{Operation} * F_{Quality} + P_{Infrastructure\ Damage}$ …..………………………………………...(2)

Where, TP_{Basic} = Total Access Charge

$P_{Operation}$= Train Operation Cost

$P_{Infrastructure\ Damage}$= Maintenance Cost

$F_{Quality}$ = Quality of Service

The first component is train operation cost, which is the cost of planning the train schedule and operation of the train (Tsamboulas & Kopsacheili, 2004). Tsamboulas & Kopsacheili (2004) calculated train operation cost as the component of speed and capacity utilization. Tsamboulas & Kopsacheili (2004) used the following mathematical equation for the calculation of train operation cost:

$P_{Operation}= MC_{Operation} * L_1 * L_2$ ………………………………………………………….(3)

Where, $P_{Operation}$ = Train Operation Cost

$MC_{Operation}$ = Marginal Cost of Train Operation

= Sum of telecommunications, control and command, planning and overhead costs

L_1 = Speed Coefficient = (line speed/ train speed)

L_2 = Capacity Utilization Coefficient = 1.50, peak period

= 1.25, near peak period

= 1.00, off-peak period

The second component is infrastructure damage cost, which is the routine maintenance cost. (Tsamboulas & Kopsacheili, 2004). Tsamboulas & Kopsacheili (2004) calculated infrastructure damage cost by the econometric model of translog formulation. Tsamboulas & Kopsacheili (2004) used the following mathematical equation for the calculation of train operation cost:

$P_{Infrastructure\ Damage} = MC_{Infrastructure\ Damage}$ …………………………………………………..(4)

$= dC/dY$,

where $C = f(\ln Y + \ln B)$, where Y = train-km

B = constant value encompassing all input values in translog function

The third component is the quality of service. This is the priority given to the service of a particular train (Tsamboulas & Kopsacheili, 2004). Tsamboulas & Kopsacheili (2004) used the following values:

1.6 = priority for the demand of specific train

1.35 = priority of specific train for frequent service

1.00 = flexibility in priority

In addition to these three components, Tsamboulas & Kopsacheili (2004) also added the cost for consumption of electricity, charge for the use of stations, and cost for delay at the end. The cost of use of stations is calculated by using the number of stations, number of trains, and direct variable costs of station operations and maintenance (Tsamboulas & Kopsacheili, 2004). The performance regime cost is calculated based on the cost of train personnel, increased energy consumption, delay minutes, number of trains delayed, and lost ridership by delayed trains (Tsamboulas & Kopsacheili, 2004).

b. Mathematical Model developed by Lai et al. (2014)

Lai et al. (2014) developed a mathematical model using congestion cost, opportunity cost, and maintenance cost to calculate the value of access charge. This model was developed to estimate the access charge for freight railroads and passenger railroads in North America (Lai et al., 2014). Lai et al. (2014) proposed different scenarios and calculated the range of access charge values based on these scenarios.

Congestion cost is the cost to recover the delay caused on a track line by allowing auxiliary trains to operate on it (Lai et al., 2014). Lai et al. (2014) used the following mathematical equation for calculating the congestion cost:

$$CC = \frac{C_D(D_M - D_B)}{M_P} \quad \text{......(5)}$$

Where, CC= congestion cost for passenger train ($/train mile)

C_D = unit delay cost ($/h)

D_M = total delay of freight trains in a mixed flow (h)

D_B = total delay of freight trains in a primary flow (h)

M_P = total train miles of passenger trains in a mixed flow

The unit delay cost (C_D) is calculated by summing up the unproductive locomotive cost, idling fuel cost, car and equipment cost and crew cost (Lai et al., 2014). Parametric or simulation models are used to calculate the delays for mixed and primary flows (Lai et al., 2014). Lai et al. (2014) calculated the congestion cost per mile by dividing the total delay cost by miles traveled.

Opportunity cost is the cost to compensate for the loss of sending some primary trains off-network, due to lack of capacity from the addition of other trains (Lai et al., 2014). Lai et al. (2014) used the following mathematical equation to calculate the opportunity cost:

$$OC = \frac{P_B * N_{MP} * E_P * U}{M_P} \quad \text{..........(6)}$$

Where, OC = opportunity cost allocated to passenger trains ($/train mile),

P_B = unit profit of primary train ($/train)

N_{MP} = number of passenger trains in a mixed flow

E_P = base train equivalent (BTE) of passenger trains

U = capacity utilization level in subdivision (%)

Lai et al. (2014) calculated the unit profit of a primary train (P_B) from the revenue and cost data of the train. Parametric or simulation models are used to calculate the number of trains in a flow (Lai et al., 2014). The concept of BTE was proposed by Lai et al. (2014) to convert the different train types into a single standard train type. In the above equation, BTE was used to convert the number of passenger trains into equivalent freight trains.

Congestion and opportunity costs do not co-exist (Lai et al., 2014). Based on the train flow, one of these costs should be calculated. Lai et al. (2014) proposed the following schemes to calculate access charge:

Scheme 1: Maintenance Cost Only;

Scheme 2: Maintenance Cost and Congestion Cost;

Scheme 3: Maintenance Cost and Opportunity Cost.

The value of maintenance cost was adopted from literature (Lai et al., 2014), and the access charge was calculated based on these values.

c. Mathematical Model developed by Kozan & Burdett (2005)

Kozan & Burdett (2005) has calculated access charges with an empirical method using sectional running time (SRT) calculations. SRT is the time taken for a train to travel from the first station to the last station under standard conditions (Kozan & Burdett, 2005). The researchers used four approaches to complete the calculation:

i) Corridor-based charges:

Kozan & Burdett (2005) used the costs of overhead, train investment, and maintenance to calculate the unit cost. They traced the time and train path, and multiplied this by the unit cost to get a corridor-based access charge.

ii) Section-based charges:

Kozan & Burdett (2005) used the time to travel from one station to another. Congestion could be different in different sections (Kozan & Burdett, 2005). Hence, Kozan & Burdett (2005) calculated station to station time and multiplied it by unit cost to get the total access cost.

iii) Weight-based charges:

In this calculation, the train weight per meter is calculated and multiplied by the unit cost of train to get the total access charge (Kozan & Burdett, 2005).

iv) Time-based charges:

Kozan & Burdett (2005) used transit times in this calculation and levied an extra cost if a train needs to travel at a time other than that mentioned in the schedule. Time is split into sub-periods and used per corridor (Kozan & Burdett, 2005). This time is multiplied with unit cost to get access charge (Kozan & Burdett, 2005).

Three different mathematical models proposed by Tsamboulas & Kopsacheili (2004), Lai et al. (2014) and Kozan & Burdett (2005) were studied. The mathematical model created by Tsamboulas & Kopsacheili (2004) requires the values of the constant functions in a log, which the researcher does not have for XpressWest, since XpressWest has not yet come into operation. Also, other proposed constant values, like the quality of service and capacity utilization coefficient are based on European systems. Hence, the researcher concluded that the model does not fit. The third model by Kozan & Burdett (2005) overly simplifies scenarios, and incorporates maintenance, congestion, and opportunity costs into a single value of unit cost. Hence, the researcher does not use this model either. The model by Lai et al. (2014) is based on North American railroads, and it proposes congestion, opportunity, and maintenance costs that are suitable for XpressWest. Hence, the researcher adopts the model proposed by Lai et al. (2014) to calculate access charges for XpressWest.

2.4 Theoretical Capacity Allocation Model for Train Slots

Johnson & Nash (2008) used a theoretical capacity allocation model to show train operation in Great Britain. Railway capacity not only depends on the line and physical characteristics, like the number of tracks, signaling systems, and line speed, but also on train characteristics (Nash, 2005). When the same track was shared by different trains, Nash (2005) used the concept of train slots and illustrated the difference in capacity allocation.

a. Uniform Slots

Johnson & Nash (2008) showed the theoretical capacity allocation between the Huddersfield to Stalybridge section in London, England, when trains of uniform capacity were operating. In this case, it is possible to run the maximum number of trains. Twelve trains are running in a one-hour period in this scenario.

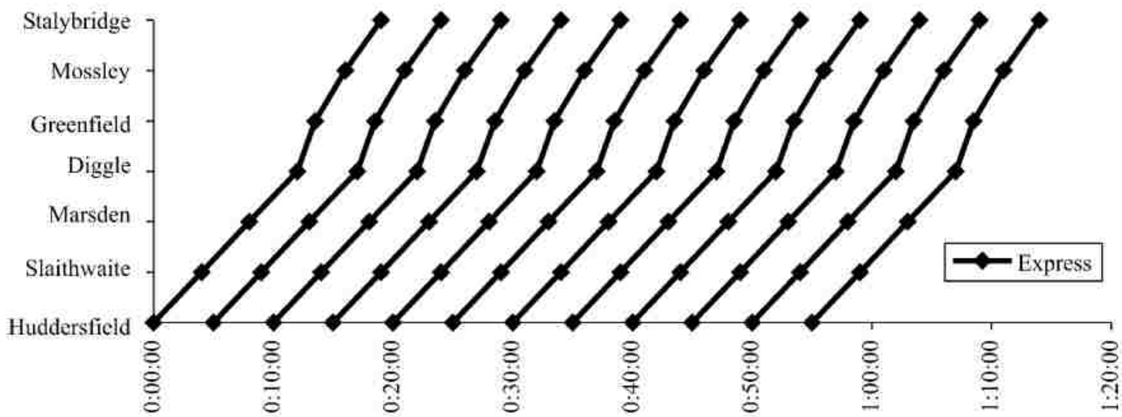

Figure 3: Theoretical capacity allocation of uniform trains between Huddersfield and Stalybridge by Johnson & Nash (2008)

b. Non - Uniform Slots

Johnson & Nash (2008) showed a decrease in theoretical capacity allocation between the same section in London, England, when trains of non- uniform capacity were operating. In this case, it was only possible to run six trains.

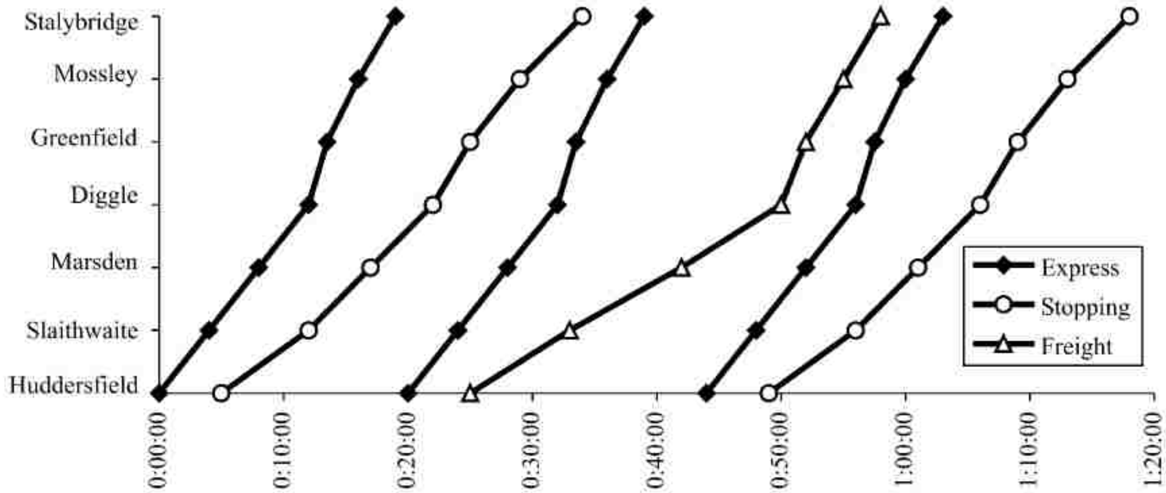

Figure 4: Theoretical capacity allocation of non-uniform trains between Huddersfield and Stalybridge by (Johnson & Nash, 2008)

This model can be adopted to this study to show train operations and calculate the amount of delay in service.

2.5 Calculation of Maintenance Cost

It is hard to predict the exact cost of railway maintenance operations because all of the costs and cost contributions are difficult to quantify (Zarembski, 1993a). Many of these relationships are non-linear (Zarembski, 1993b). For shared track corridors, it is essential to determine the increase in maintenance costs by the addition of trains in a network (Zarembski, AM & Cikota Jr., 2008). Usually, maintenance costs are calculated by two models (Zarembski, 1993):

i) Engineering cost model

This model is deterministic (Zarembski, 1993). In this model, the range of activities required to maintain and replace train infrastructure are noted, and the average costs for those activities are also noted (Zarembski, 1993). These values are then combined, and an annual amount of maintenance cost is produced (Zarembski, 1993). These costs are sensitive to traffic models and parameters (Zarembski, 1993). The costs allocated by this model are correct in the long term, but they do not consider economic turndown or occasional high or low maintenance (Zarembski, 1993).

ii) Allocation model

This model is statistical (Zarembski, 1993). The costs are allocated from historical data (Zarembski, 1993). It uses regression models to determine the relationship of expenses with ton-miles, train hours, and route miles (Zarembski, 1993). Statistics based equations are used by considering the historical data of cost and traffic characteristics (Zarembski, 1993). A prior assumption is made while determining the cost and traffic characteristics in the beginning, so these models are not sensitive to traffic models and parameters (Zarembski, 1993).

There is also a hybrid model, called the engineering allocation model that uses traffic models and parameters to generate regression type output variables (Zarembski, 1993).

In this study, the authors adopt the method of allocation model to determine the access charge for XpressWest of Nevada. The study will collect historical data calculate the value of maintenance costs for XpressWest by using its direct relationship with speed.

2.6 Historical Data and Some Prevailing Practices

Historical Data on HSR

Campos & de Rus (2009) collected and historical data to formulate the costs associated with HSR. Various empirical analyses have been carried out to determine the price of HSR. At the beginning of 2006, an empirical framework analysis was carried out to give the range of the expenses of building, operating, and maintaining HSR using international comparative data from

166 projects from 20 different countries (Campos & de Rus, 2009). Campos & de Rus (2009) collected data from different countries for building tracks, operating and maintaining trains, and maintaining tracks. Infrastructure operating costs are the costs of material, energy and labor, traffic management, safety, terminals, and stations, as well as day-to-day running costs. The maintenance of infrastructure costs includes maintenance of tracks, signaling costs, telecommunications, electrification costs, and other costs. The operating costs include labor costs, administration, and maintenance of equipment. The cost per seat is assumed to be 53,000 euros per year on average (Campos & de Rus, 2009).

Prevailing Practices on Access Charge

Amtrak paid $3.26 to $4.44 per train mile to the freight trains during the period from 2003 to 2009, including usage and incentive payments (USDOT, 2009). This cost is only about 3.3% of the total operating cost of Amtrak (USDOT, 2009). Campos et al. (2009) states that in 2002, the cost of maintaining an HSR line is from €28,000 to €33,000 (2002 euros) per km per year for a single track.

2.7 Summary of Literature Review

The review of the literature showed that US freight railroads and European railways practice access charges. An access charge commonly consists of train operation, maintenance, and congestion costs. Depending on the policies, some countries such as Sweden, Switzerland and Finland include accident and environmental costs as well.

The cost elements are different for different train systems (Lai et al., 2014). In the EU, HSR markets are vertically separated. Vertical separation means the owning railroad companies and operating railroad companies are different. Costs include capacity, maintenance, environmental, and other costs. However, in the Amtrak System and CAHSR systems, the owning and operating railroad companies are same. Amtrak is a freight dominant system, which means it is timetable free. However, EU and CAHSR systems are passenger train systems, so they are based on fixed timetables. A comparative analysis of cost elements among European Union (EU) systems, Amtrak Systems, and CAHSR systems is presented below:

Table 2: Comparison of Cost Elements

System	Market Separation	Dominance	Timetable
EU System	Vertical Separation	Passenger	Fixed
Amtrak System	Non-Vertical Separation	Freight	Timetable Free
CAHSR	Non-Vertical Separation	Passenger	Fixed

The study identified the key-elements of access charge from the literature. The study considered those elements that were used by more than two studies as key elements. The most commonly found factors were maintenance costs, opportunity costs, and congestion costs. Also, capacity analysis, infrastructure deterioration and delay are commonly considered factors. This study will consider these elements for the calculation of access charge. Additionally, the literature recognized train volume and over-head. Two studies reviewed peak and off-peak time charges. In this study, the researcher will include all of the key variables applicable to the CAHSR and XpressWest context. Key elements are shown in the table below:

Table 3: Key Variables Identified from the Literature

Variables	Lai et al. (2014)	Kozan et al. (2004)	Tsamboulas et. Al. (2004)	Levy et. al. (2015)	Macario et al. (2014)	Mallet et al. (2009)	SanJamie et al. (2016)	Borràs et al. (2010)	Campos et al. (2009)	Total
Maintenance Cost	✓	✓	✓		✓			✓	✓	**6**
Opportunity Cost	✓		✓		✓			✓	✓	**5**
Congestion Cost	✓		✓		✓			✓	✓	**5**
Capacity Analysis	✓	✓	✓	✓						**4**
Infrastructure Deterioration	✓		✓					✓		**3**
Delay	✓	✓	✓							**3**
Train Volume							✓	✓	✓	**3**
Overhead			✓		✓					**2**
Peak Time Charges		✓							✓	**2**
Off peak Time Charges		✓							✓	**2**
Total	**9**	**6**	**8**	**3**	**4**	**2**	**4**	**7**	**8**	

This study has placed a summary table with key-information identified from the literature below. The table shows that literature related to the calculation of an access charge, train operator's response to an access charge, competition and economic description of an access charge are included. The collected literature was mostly from US and European countries. The comparative table is:

Table 4: Summary of Key - Literature

SN	Article	Summary	Location	Develop Access Charge	Journal
1	Lai et al. (2014)	Access charge calculation by congestion opportunity cost	US	Yes	TRR
2	Kozan & Burdett (2005)	Determined Capacity of HSR and access charges	None	Yes	Transportation Planning and Technology
3	Tsamboulas & Kopsacheili (2004)	Access charge calculation by operation, maintenance, capacity costs	Europe (Greece)	Yes	TRR
4	Levy et al. (2015)	Train operator's response to access charge	US	No	TRR
5	Macario et. al (2014)	Business logic and frameworks comparison	EU	No	TRR
6	Subcomittee on HSR (1985)	Overview of HSR	US	No	JTE
7	SanJaime et. al (2016)	Competition and economy on HSR	Spain	No	Transport Policy
8	Sánchez-Borràs & Al (2011)	Mark-up comparison on access charge	Europe	No	Transport Reviews
9	Sánchez-Borràs et al., (2010)	HSR description and impact of access charge on market	Europe	No	Transport Policy
10	Campos & de Rus (2009)	Empirical economic characteristics of HSR	International	No	Transport Policy

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research Methodology

This study on the calculation of access charges for HSR XpressWest of Nevada consists of seven primary steps. The first step was conducting a detailed literature review. The second step was developing a theoretical capacity allocation model for train slots of XpressWest and CAHSR and estimating delay hours. Based on the model, the third step was estimating train congestion costs. The next step was determining the maintenance costs. Then, the study calculated the cost of installing the side tracks. Based on these costs, the next step was calculating the access charge. The final step was to prepare a report. The outline of methodology is:

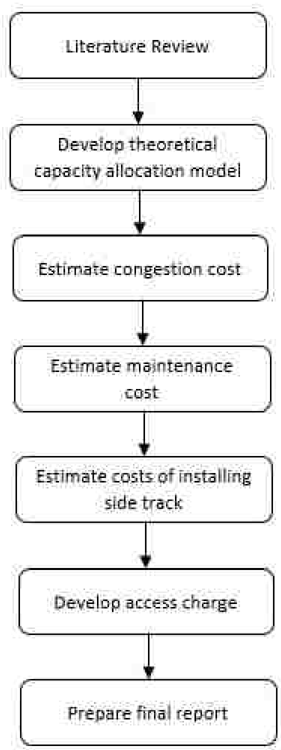

Figure 5: General Outline of Methodology

3.2 Literature Review

The study conducted a literature review to identify a problem and gap in the existing literature. The study searched the literature related to access charges, capacity pricing, and delays for HSR operation from 1990 to 2018 from a list of journals. First, the researcher searched the literature for primary sources, followed by secondary sources. The primary sources were: ASCE's Journal of Transportation Engineering, ASCE's Journal of Infrastructure Systems, the Transportation Research Record: Journal of the Transportation Research Board, the Journal of Traffic and Transportation Engineering, the Journal of Transportation Technologies, the Journal of the Transportation Research Forum, Transportation Planning and Technology, the Journal of Advanced Transportation, and the Journal of Transportation Systems Engineering and Information Technology.

Then the next step was to collect the literature from secondary sources. The secondary sources were: Railway Track & Structure Magazine, the Engineering News-Record, Elsevier's International Journal of Project Management, ASCE's Journal of Construction Engineering and Management, ASCE's Journal of Management in Engineering, and Construction Management and Economics.

The study searched the literature in Google Scholar and engineering databases – Compendex, Transport Research International Documentation (TRID), and Science Direct. The literature thus collected was divided into the following sections: 1) Access Charge, 2) Cost Elements in Access Charge, 3) Mathematical Models, 4) Theoretical Capacity Allocation Model for Train Slots, 5) Calculation of Maintenance Costs, 6) Historical Data and Some Prevailing Practices, and 7) Summary of Literature Review.

3.3 Data Collection

The study obtained the baseline service plan of CAHSR train operations from the Example Service Plan of the 2018 CAHSR Service Planning Methodology. The study received the full capacity service plan from CAHSR 2018 private communication. Also, the study created the service plan of the XpressWest trains based on the travel times estimated in Steer Davies Gleave (2017).

The researcher obtained data from various sources for calculating the maintenance cost. The study collected maintenance costs of France and Spain from Campos & de Rus (2009). The researcher gathered the maintenance costs from US class 4 and class 6 railroads from Zarembski & Patel (2010). The analysis obtained data from Finland and the US from Johansson & Nilsson (2004) and CAHSR (2018c) respectively. Finally, the study obtained data from Korea from KTX (2017).

3.4 Development of Theoretical Capacity Allocation Model for Train Slots and Calculating Delay Hours

The study developed a theoretical track capacity allocation model for train slots to show the train operations of XpressWest and CAHSR. The train allocation model is based on station-to-station travel time. The operation plan of CAHSR trains is based on CAHSR (2018c). The timetable for XpressWest trains has been created based on travel time estimated by Steer Davies Gleave (2017).

While creating the timetable for XpressWest trains, the study did not consider any stops between San Francisco, Palmdale and Los Angeles. The auxiliary trains in a network do not stop at the in-between stations.

For showing the train operations, the researcher entered the stations and train travel times in a Microsoft Excel 2016 sheet. Then the researcher plotted the graph using Python with MATLAB library functions. Station-to-station travel time is input on the X-axis and stations are input on Y-axis. CAHSR and XpressWest trains are distinguished using different colors on the graph. This track capacity allocation graph for train slots will show the delay to CAHSR caused by XpressWest. It will also determine the delay hours.

The researcher plotted the capacity allocation graph for peak hours and non-peak hours. Based on the definition from CAHSR (2018c), the study has considered peak hour as 6 am to 9 am in the morning and 4 pm to 7 pm in the evening. Also, the study has considered off-peak hours, considered as 5 am to 6 am, 9 am to 4 pm, and 7 pm to midnight.

The study will create one representative capacity allocation graph for train slots for one peak hour and one off-peak hour sample each. This research will assume the following operations as baseline capacity and full capacity:

i) **Baseline Capacity:** When 1 CAHSR trains run from San Francisco to Los Angeles every 1 hour, the researcher considered the train operation to be baseline capacity.

ii) **Full Capacity:** When 4 CAHSR trains run from San Francisco to Los Angeles every 1 hour, the researcher considered the train operation is to be full capacity.

In addition to these major trains from San Francisco to Los Angeles every hour, there are also additional trains that operate in shorter routes in between these two stations. This study has also considered those additional trains for development of allocation graph. The data for additional trains are obtained from CAHSR (2018c) and CAHSR private communication.

This graph will be created for baseline capacity and full capacity. The study will calculate the delay hours based on following scenarios:

i) Peak Hour

Scenario 1: One XpressWest Train per Hour

Scenario 2: Two XpressWest Trains per Hour

ii) Off- Peak Hour

Scenario 3: One XpressWest Train per Hour

Scenario 4: Two XpressWest Trains per Hour

3.5 Estimating Congestion Cost

Congestion cost is the cost to compensate for the delay caused on a primary train by the operation of additional train (Lai et al., 2014). Lai et al. (2014) used the following mathematical equation for calculating the congestion cost:

$$CC = \frac{C_D(D_M - D_B)}{M_P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where, CC= congestion cost for passenger train ($/train mile)

C_D = unit delay cost ($/h)

D_M = total delay of freight trains in a mixed flow (h)

D_B = total delay of freight trains in a primary flow (h)

M_P = total train miles of passenger trains in a mixed flow

The model by Lai et al. (2014) used passenger and freight trains in shared track operation. The primary train is considered as a freight train. Freight trains are slower than passenger trains and they are time-table free. So, passenger trains may even be able to force them off-track. However, for this study, both CAHSR and XpressWest are passenger trains. The primary train is CAHSR. The primary train is faster than auxiliary trains, and both trains operate under fixed timetable. The comparison table for these two studies is presented in the table below:

Table 5: Comparison Table of Lai et al.'s (2014) and this study

System	Train Type	Time Table	Speed
This Study	Both Passenger Trains	Both fixed timetable	Primary Train faster
Lai et al. (2014)	Passenger and freight trains	One is timetable free	Primary Train slower

Hence, the researcher has modified the above equation into the following:

$$CC = \frac{C_D * \text{Delay}}{M_P} \qquad (6)$$

Where, CC= congestion cost for XpressWest (auxiliary) train ($/train mile)

C_D = unit delay cost ($/h)

D = total delay of CAHSR (primary) trains by XpressWest (auxiliary) trains (h)

M_P = total train miles of XpressWest (auxiliary) trains in a mixed flow

For the calculation of unit delay cost (C_D), train operations, train dispatching, and control costs are added. The study obtained these values from CAHSR (2018c). Train operations cost consists of wages for train personnel, energy costs, uniforms, vehicles, and supplies cost. Train dispatching and control costs consist of related personnel wages, vehicles, and supply cost.

3.6 Estimating Maintenance Cost

Maintenance Cost includes the routine costs for repairing and replacing the rail infrastructure. For calculating the maintenance cost, the study collected historical data from different countries along with their train speeds. The value of costs is adjusted to 2018 USD values using the inflation rates from World Bank. Then the study plotted a linear graph showing the relationship between speed and maintenance cost. This relationship is used to calculate the total maintenance cost for XpressWest.

The maintenance cost obtained from the graph will be maintenance cost for total of XpressWest. If the number of trains is lower than maximum, the researcher will adjust the maintenance cost by train number factor.

3.7 Cost of Installing Side - Tracks

The analysis has planned the mixed operation of XpressWest and CAHSR in such a way that the trains do not meet each other during operation. However, they can meet at stations. Side-tracks are constructed to bypass two trains in a single station. The study will calculate the number of side-tracks necessary from a capacity allocation model. The researcher will collect the length of side- tracks and the cost of building side-tracks from CAHSR (2018b).

3.7 Calculation of Access Charge

After the calculation of all above costs, finally, access charge is calculated for the following schemes:

Scheme 1: Maintenance Cost Only

Scheme 2: Maintenance Cost and Cost of Installing Side Tracks

Scheme 3: Maintenance Cost and Congestion Cost

Scheme 4: Maintenance, Congestion Costs and Cost of Installing Side Tracks

These costs are calculated for two cases: Baseline Capacity and Full Capacity. The study has proposed four different scenarios for the operation of XpressWest in a single day:

Scenario 1: 1 XpressWest Train Every Two Hours

Scenario 2: 1 XpressWest Train Every Hour During Off- Peak Hours Only

Scenario 3: 1 XpressWest Train Every Hour

Scenario 4: 2 XpressWest Trains Every Hour

The following is a more visual representation for the calculation of access charge:

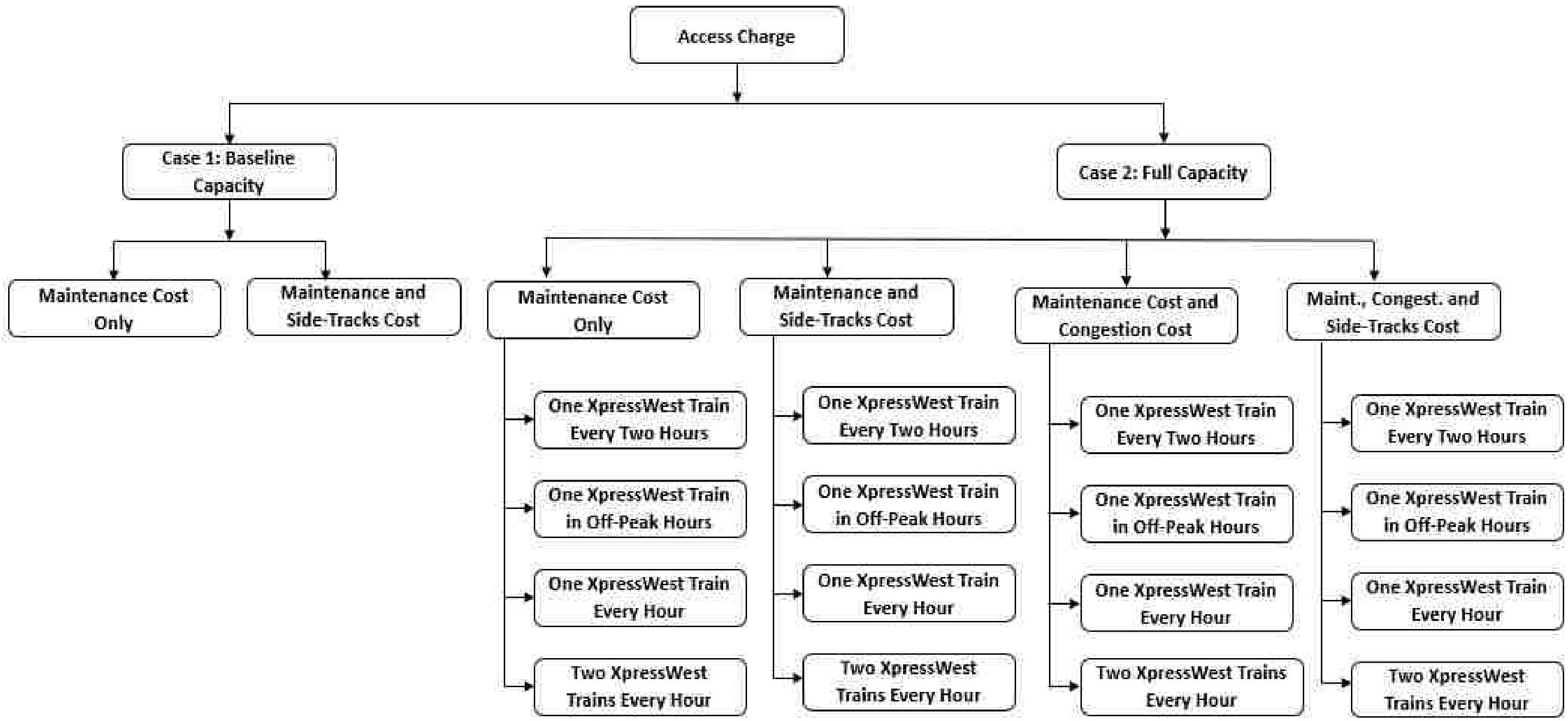

Figure 6: General Outline for Calculation of Access Charge

3.8 Preparation of Final Report

The study compiled the calculation of access charge and all its components - delay hours, congestion costs, maintenance costs and costs of installing side tracks, and presented it as a thesis.

CHAPTER 4: DATA ANALYSIS AND RESULTS

4.1 Development of Theoretical Capacity Allocation Model for Train Slots and Calculating Delay Hours

The study calculated the delay hours for two cases. The first case was for baseline capacity and the second case was for full capacity. The figure below shows the general outline for calculation of delay hours. The cases are explained below:

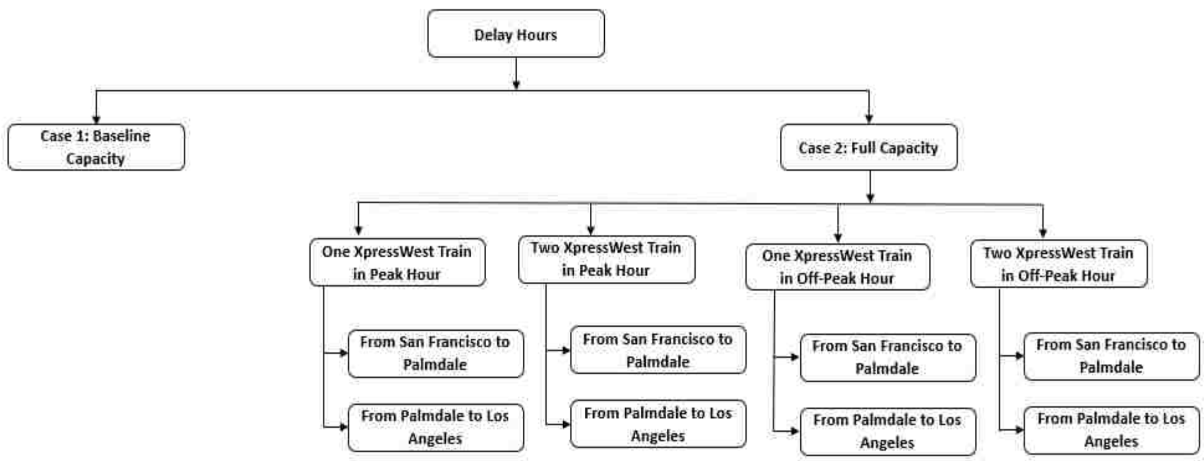

Figure 7: General Outline for Calculation of Delay Hours

4.1.1 Case 1: Calculation Delay Hours for Baseline Capacity

When the CAHSR trains from San Francisco Terminal (SFT) station to Los Angeles Union (LAU) station run every 1 hour, it is assumed to be baseline capacity.

The researcher has tabulated the travel time and stations for CAHSR and XpressWest trains in baseline capacity below:

Table 6: Train Operation Timetable for Baseline Case

Stations	**CAHSR Trains**				**XpressWest Trains**		
Train No.	**401015**	**401035**	**401047**	**401061**	**2001**	**2002**	**2003**
SFT		6:00	7:00	8:00	6:10	7:10	8:10
SFO		6:21	7:21	8:21	6:31	7:31	8:31
SJO		6:43	7:43	8:41	6:56	7:56	8:56
FNO	6:41	7:38	8:38	9:38	8:06	9:06	10:06
BFD	7:19	8:19	9:19	10:19	8:56	9:56	10:56
BUR	8:08	9:16	10:16	11:16	10:04	11:04	12:04
LAU	8:23	9:33	10:33	11:33	10:19	11:19	12:19

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose,
FNO = Fresno, BFD = Bakersfield, BUR = Burbank, LAU = Los Angeles

This time-table has been plotted as follows:

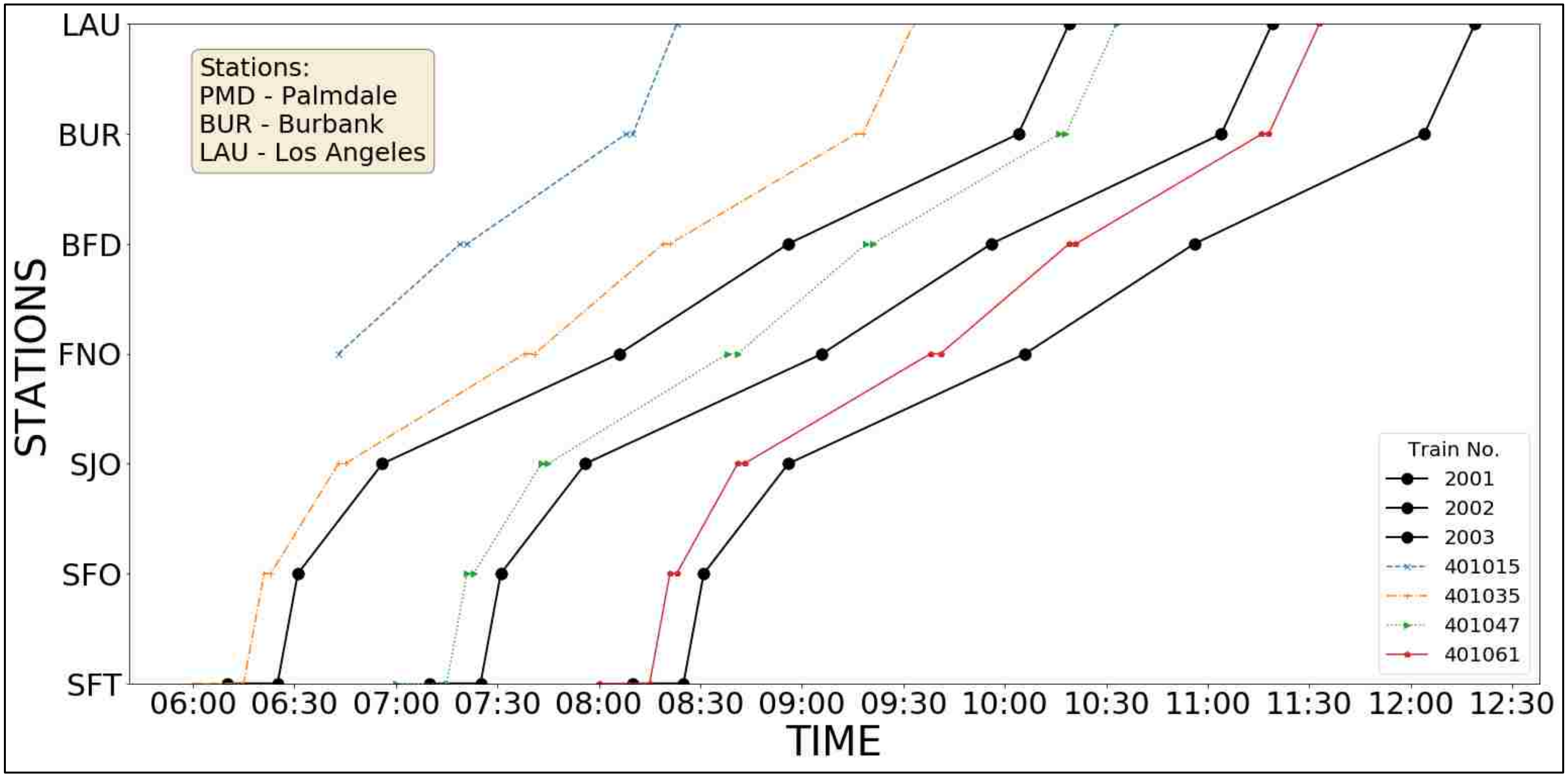

Figure 8: Capacity Allocation Model for Baseline Capacity

The black line shows the operation of XpressWest trains. The remaining lines in blue, orange and green represent CAHSR trains. In this case, the train movements do not cross each other. Hence, the delay hours to CAHSR trains is 0. There is no need to calculate congestion cost.

4.1.2 Case 2: Calculation Delay Hours for Full Capacity

When the 4 CAHSR trains from San Francisco Terminal (SFT) station to Los Angeles Union (LAU) station run every 1 hour, they are assumed to be at full capacity. In addition to four trains from San Francisco to Los Angeles every hour, there are also additional trains that operate in shorter routes in between these two stations. This study has also considered those additional trains for development of allocation graph. The data for additional trains is obtained from CAHSR private communication.

The operation plan of CAHSR trains is based on CAHSR 2018 private communication.

The study has chosen four different scenarios to calculate the delay hours for full capacity. The maximum number of XpressWest trains running in one hour is 2. The analysis has followed the model of Lai et al. (2014), where the auxiliary trains will not exceed 50% of primary trains. Hence, the research has selected scenarios with one and two trains per hour for peak and off-peak hours. The two XpressWest trains have an interval of 30 minutes. This interval has been chosen to minimize delay. The number of CAHSR trains going from San Francisco to Los Angeles is the same during peak and off-peak hours. However, there is a big difference in the number of minor trains during those hours, which also significantly affects the operation of XpressWest. The study has done the following theoretical capacity allocations:

Scenario 1: One XpressWest Train in Peak One Hour

Scenario 2: Two XpressWest Trains in Peak One Hour

Scenario 3: One XpressWest Train in Off-Peak One Hour

Scenario 4: Two XpressWest Trains in Off-Peak One Hour

Also, the researcher has done two different theoretical capacity allocations for each situation: (1) San Francisco to Palmdale and (2) Palmdale to Los Angeles. This has been done because XpressWest trains meet CAHSR at Palmdale and reach either San Francisco or Los Angeles destinations.

Scenario 1: One XpressWest Train in Peak One Hour

A. From San Francisco to Palmdale

The analysis has chosen one peak hour sample of 7 am to 8 am in the morning for thetheoretical capacity allocation model of train slots. The following is the train operation timetable from San Francisco to Palmdale:

Table 7: Train Operation Timetable for Full Capacity for Scenario 1 San Francisco to Palmdale

Station	**CAHSR Trains**										**XW Train**
	291025	**291026**	**291027**	**291028**	**291029**	**291030**	**291031**	**291032**	**291033**	**291034**	**1005**
SFT dp.	7:00		7:15		7:30		7:45			8:00	7:03
SFO ar.	7:11		7:31		7:41		8:01			8:11	7:17
SFO dp.	7:13		7:33		7:43		8:03			8:13	7:17
SJC ar.	7:44		8:04		8:14		8:34			8:44	7:48
SJC dp.	7:47	7:57	8:06		8:17	8:23	8:36	8:41		8:47	7:48
GLY ar.	7:57	8:07	8:22		8:27	8:39	8:47	8:58		8:57	8:03
GLY dp.	7:59	8:09	8:24		8:29	8:41	8:49	9:05		8:59	8:03
MDR ar.	8:28	8:38	8:57	8:51	8:58	9:24	9:21		9:27	9:28	8:47
MDR dp.	8:30	8:40	8:59	8:53	9:00	9:26	9:23		9:29	9:30	8:47
FNO ar.	8:35	8:45	9:05	9:00	9:05	9:34	9:30		9:36	9:35	8:58
FNO dp.	8:37	8:47	9:11	9:02	9:07	9:36	9:32		9:43	9:37	8:58
KTR ar.	8:50	9:00	9:25	9:17	9:20	9:55	9:47		9:56	9:50	9:20
KTR dp.	8:52	9:02	9:31	9:19	9:22	9:57	9:49		10:02	9:52	9:20
BFD ar.	9:10	9:20	9:59	9:40	9:40	10:24	10:10		10:30	10:10	9:52
BFD dp.	9:12	9:22	10:01	9:47	9:42	10:26	10:17		10:32	10:12	9:52
PMD ar.	9:41	9:51	10:41	10:16	10:11	10:36	10:46		11:06	10:41	10:41

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy, MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield, PMD = Palmdale

To properly operate on XpressWest train in the given hour, the operation of CAHSR train 291027 had to be changed by seven minutes. The change in its schedule is shown below:

Table 8: Delay in Train Operation for Full Capacity for Scenario 1 San Francisco to Palmdale

Stations	**Initial CAHSR Time**	**Adjusted CAHSR Time**	**Delay**
Train No.	**291027**	**291027**	
SFT dp.	7:15	7:03	
SFO ar.	7:31	7:17	
SFO dp.	7:33	7:17	
SJC ar.	8:04	7:48	
SJC dp.	8:06	7:48	
GLY ar.	8:22	8:03	
GLY dp.	8:24	8:03	
MDR ar.	8:57	8:47	
MDR dp.	8:59	8:47	
FNO ar.	9:05	8:58	
FNO dp.	9:11	8:58	
KTR ar.	9:25	9:20	
KTR dp.	9:31	9:20	
BFD ar.	9:59	9:52	
BFD dp.	10:01	9:52	
PMD ar.	**10:34**	**10:41**	**7 mins**

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy, MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield, PMD = Palmdale

The total delay cause to CAHSR trains from this adjustment is **7 minutes**. The black line represents XpressWest trains. The study has created the following capacity allocation model for the above data:

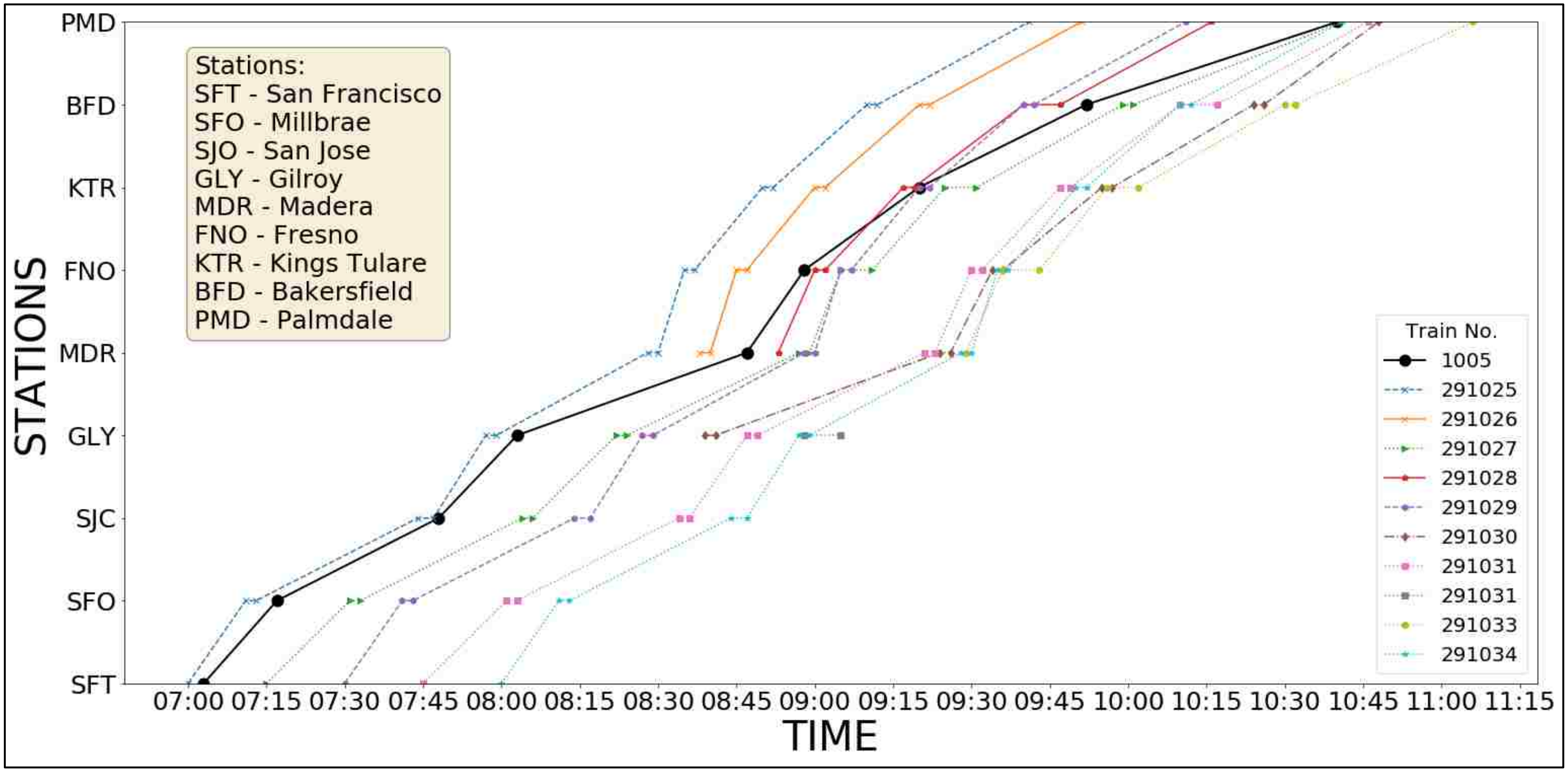

Figure 9: Capacity Allocation Model for Full Capacity from 7:00 AM to 8:00 AM with 1 XpressWest Train from San Francisco to Palmdale

B. From Palmdale to Los Angeles

The study has done the theoretical capacity allocation for the same sample peak hour time, 7am to 8am in the morning, for train operation from Palmdale (PMD) to Los Angeles (LAU). The following is the train operation timetable:

Table 9: Train Operation Timetable for Full Capacity for Scenario 1 Palmdale to Los Angeles

Station	CAHSR Trains										XW Trains
Train No.	291025	291026	291027	291028	291029	291030	291031	291032	291033	291034	1005
PMD dp.	9:43	9:53	10:43	10:18	10:13	10:38	10:48		11:08	10:45	10:00
BUR ar.	9:58	10:08	10:55	10:33	10:28	10:42	11:03		11:24	10:58	10:19
BUR dp.	10:00	10:10	10:57	10:35	10:30	10:44	11:05		11:26	11:00	10:19
LAU ar.	10:15	10:25	11:09	10:50	10:45	10:59	11:20		11:41	11:15	10:38
LAU dp.	10:15	10:25	11:09	10:50	10:45	10:59	11:20		11:47	11:15	10:38

Note: PMD = Palmdale, BUR = Burbank, LAU = Los Angeles

There is no delay to CAHSR trains in this operation. XpressWest is represented by the black line. The following capacity allocation model has been plotted for the above data:

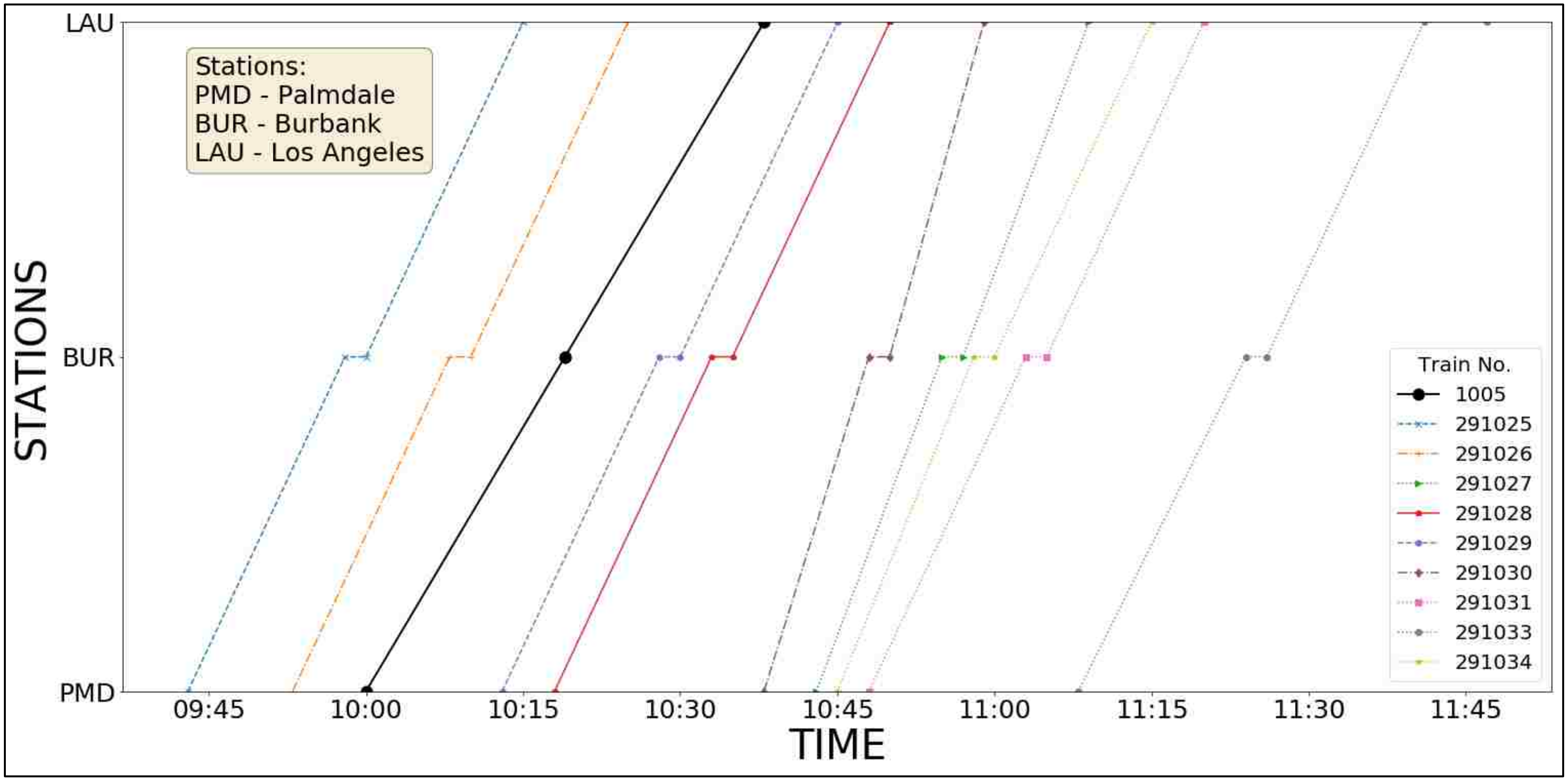

Figure 10: Capacity Allocation Model for Full Capacity 7:00AM to 8:00AM with 1 XpressWest Train from Palmdale to Los Angeles

Scenario 2: Two XpressWest Train in Peak One Hour

A. From San Francisco to Palmdale

The analysis has carried out the theoretical capacity allocation for the same time - 7am to 8am in the morning. The following is the train operation timetable from San Francisco to Palmdale:

Table 10: Train Operation Timetable for Full Capacity for Scenario 2 San Francisco to Palmdale

Station	CAHSR Trains										XW Train	
	291025	291026	291027	291028	291029	291030	291031	291032	291033	291034	1005	1006
SFT dp.	7:00		7:15		7:30		7:45			8:00	7:03	7:33
SFO ar.	7:11		7:31		7:41		8:01			8:11	7:17	7:47
SFO dp.	7:13		7:33		7:43		8:03			8:13	7:17	7:47
SJC ar.	7:44		8:04		8:14		8:34			8:44	7:48	8:18
SJC dp.	7:47	7:57	8:06		8:17	8:23	8:36	8:41		8:47	7:48	8:18
GLY ar.	7:57	8:07	8:22		8:27	8:39	8:47	8:58		8:57	8:03	8:33
GLY dp.	7:59	8:09	8:24		8:29	8:41	8:49	9:05		8:59	8:03	8:33
MDR ar.	8:28	8:38	8:57	8:51	8:58	9:24	9:21		9:27	9:28	8:47	9:17
MDR dp.	8:30	8:40	8:59	8:53	9:00	9:26	9:23		9:29	9:30	8:47	9:17
FNO ar.	8:35	8:45	9:05	9:00	9:05	9:34	9:30		9:36	9:35	8:58	9:30
FNO dp.	8:37	8:47	9:11	9:02	9:07	9:36	9:32		9:43	9:37	8:58	9:30
KTR ar.	8:50	9:00	9:25	9:17	9:20	9:55	9:47		9:56	9:50	9:20	9:53
KTR dp.	8:52	9:02	9:31	9:19	9:22	9:57	9:49		10:02	9:52	9:20	9:53
BFD ar.	9:10	9:20	9:59	9:40	9:40	10:24	10:10		10:30	10:10	9:52	10:25
BFD dp.	9:12	9:22	10:01	9:47	9:42	10:26	10:17		10:32	10:12	9:52	10:25
PMD ar.	9:41	9:51	10:41	10:16	10:11	10:36	10:46		11:06	10:41	10:41	11:13

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy, MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield, PMD = Palmdale

CAHSR train 291027 had to be delayed by seven minutes, CAHSR train 291033 had to be delayed by eight minutes and CAHSR train 291034 had to be delayed by three minutes to adjust for this operation. The changes are illustrated in the table below:

Table 11: Delay in Train Operation for Full Capacity for Scenario 2 San Francisco to Palmdale

Stations	Initial CAHSR Time	Adjusted CAHSR Time	Delay	Initial CAHSR Time	Adjusted CAHSR Time	Delay	Initial CAHSR Time	Adjusted CAHSR Time	Delay
Train No.	291027	291027		291033	291033		291034	291034	
SFT dp.	7:15	7:15					8:00	8:00	
SFO ar.	7:31	7:31					8:11	8:11	
SFO dp.	7:33	7:33					8:13	8:13	
SJC ar.	8:04	8:04					8:44	8:44	
SJC dp.	8:06	8:06					8:47	8:47	
GLY ar.	8:22	8:22					8:57	8:57	
GLY dp.	8:24	8:24					8:59	8:59	
MDR ar.	8:57	8:57		9:27	9:27		9:28	9:28	
MDR dp.	8:59	8:59		9:29	9:29		9:30	9:30	
FNO ar.	9:05	9:05		9:36	9:36		9:35	9:35	
FNO dp.	9:11	9:11		9:43	9:43		9:37	9:37	
KTR ar.	9:25	9:25		9:56	9:56		**9:50**	**9:53**	**3 mins**
KTR dp.	9:31	9:31		10:02	10:02		9:54	9:56	
BFD ar.	9:59	9:59		10:30	10:30		10:10	10:13	
BFD dp.	10:01	10:01		10:32	10:32		10:12	10:15	

Stations	Initial CAHSR Time	Adjusted CAHSR Time	Delay	Initial CAHSR Time	Adjusted CAHSR Time	Delay	Initial CAHSR Time	Adjusted CAHSR Time	Delay
PMD ar.	**10:34**	**10:41**	**7 mins**	**11:06**	**11:14**	**8 mins**	10:40	10:43	

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy, MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield, PMD = Palmdale

The total delay caused to CAHSR trains by this adjustment is **7+8+3 = 18 minutes**.

The black line represents XpressWest trains. The study has created the following capacity allocation model for the above data:

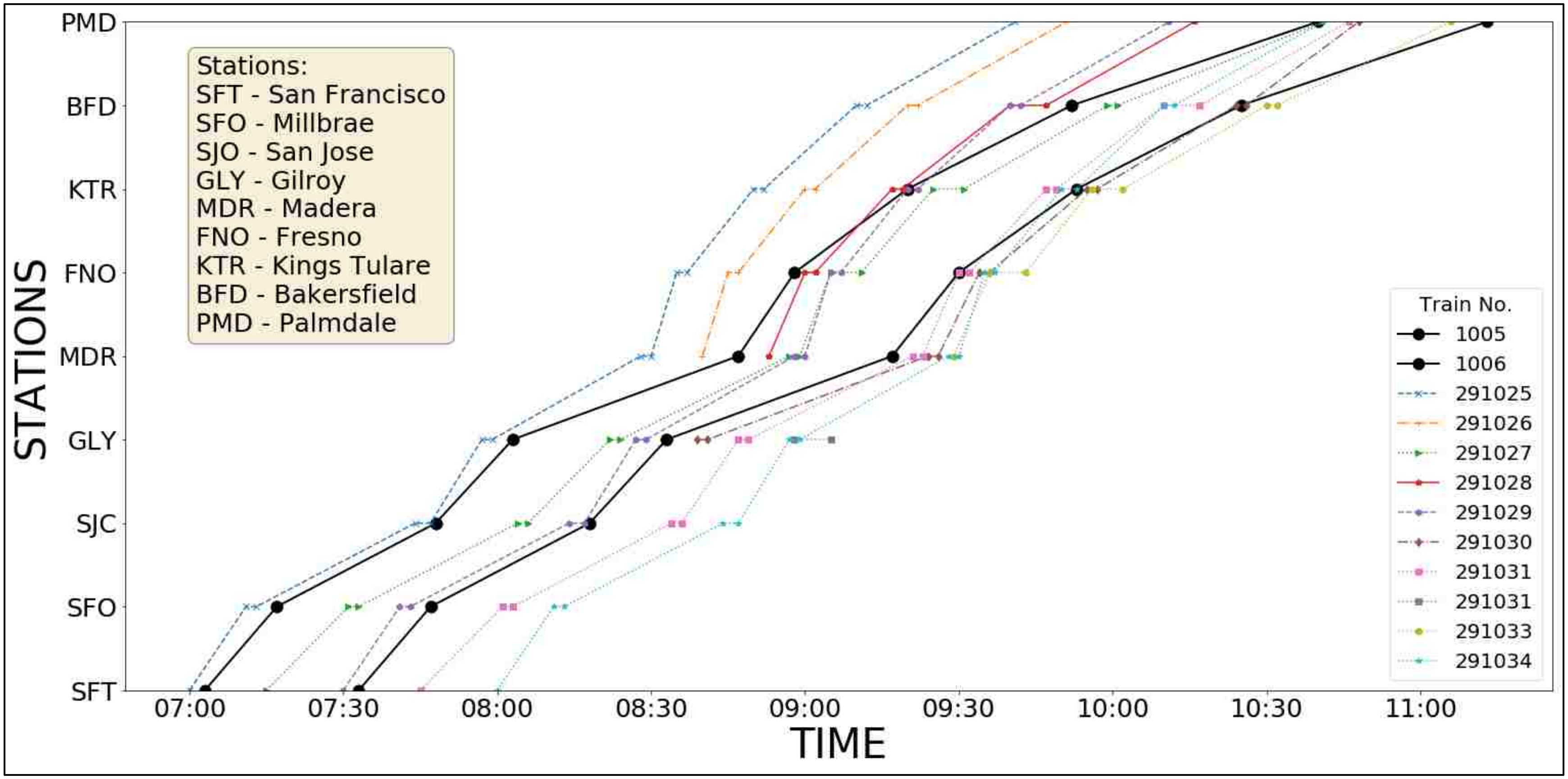

Figure 11: Capacity Allocation Model for Full Capacity 7:00AM to 8:00AM with 2 XpressWest Train from San Fransisco to Palmdale

B. From Palmdale to Los Angeles

The researcher has carried out the theoretical capacity allocation from 7am to 8am in the morning. The following is the train operation timetable from Palmdale (PMD) to Los Angeles (LAU):

Table 12: Train Operation Timetable for Full Capacity for Scenario 2 Palmdale to Los Angeles

Station	CAHSR Trains										XW Trains	
Train No.	291025	291026	291027	291028	291029	291030	291031	291032	291033	291034	1005	1006
PMD dp.	9:43	9:53	10:43	10:18	10:13	10:38	10:48		11:08	10:45	10:00	10:55
BUR ar.	9:58	10:08	10:55	10:33	10:28	10:42	11:03		11:24	10:58	10:19	11:14
BUR dp.	10:00	10:10	10:57	10:35	10:30	10:44	11:05		11:26	11:00	10:19	11:14
LAU ar.	10:15	10:25	11:09	10:50	10:45	10:59	11:20		11:41	11:15	10:38	11:33
LAU dp.	10:15	10:25	11:09	10:50	10:45	10:59	11:20		11:47	11:15	10:38	11:33

Note: PMD = Palmdale, BUR = Burbank, LAU = Los Angeles

There is no delay to CAHSR trains in this operation. XpressWest trains are represented by the black lines. The researcher has plotted the following capacity allocation model for the above data:

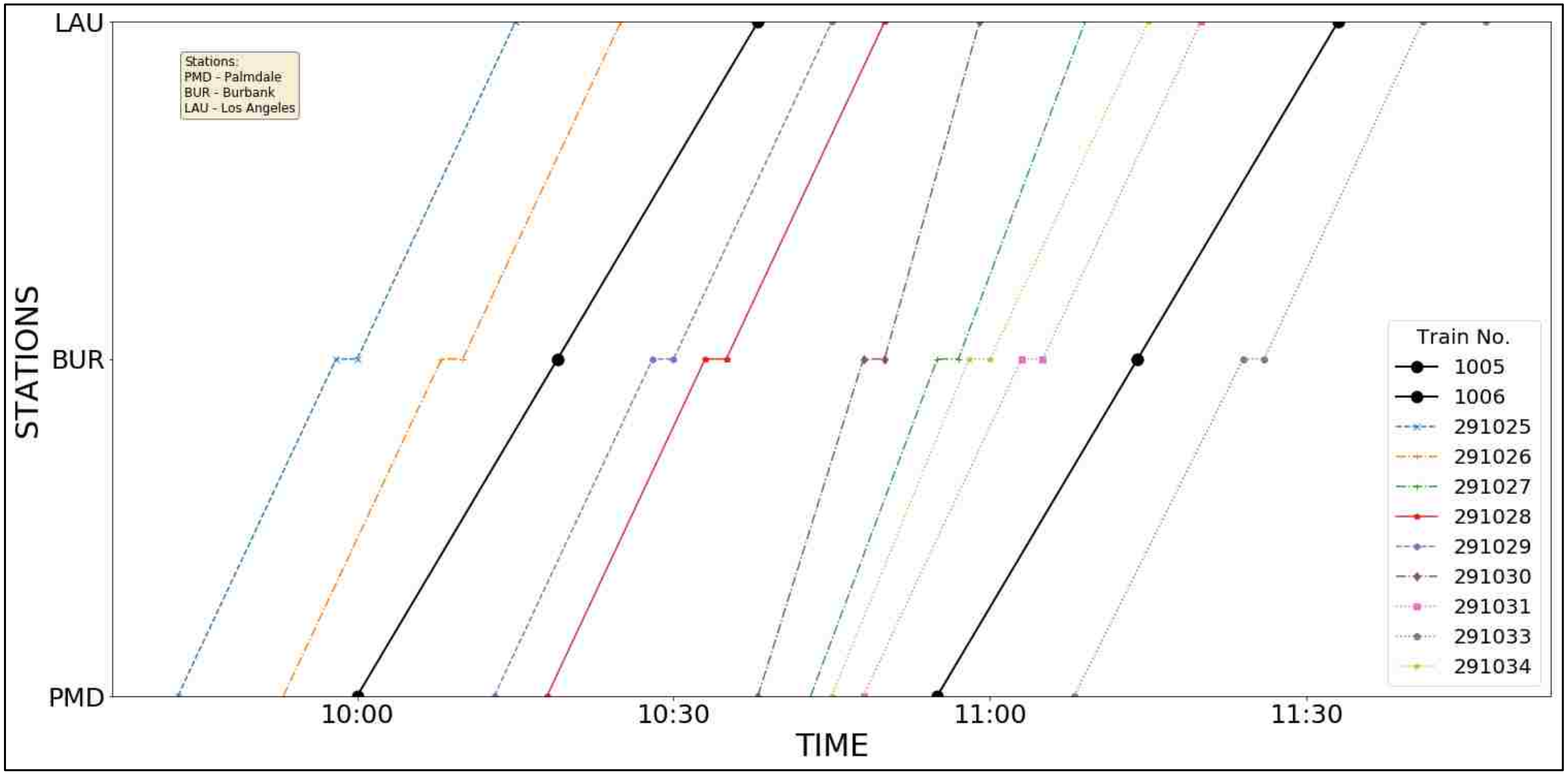

Figure 12: Capacity Allocation Model for Full Capacity 7:00 AM to 8:00 AM with 2 XpressWest Train from Palmdale to Los Angeles

Scenario 3: One XpressWest Train in Off - Peak One Hour

A. From San Francisco to Palmdale

The analysis has been done for the theoretical capacity allocation for an off-peak sample hour – 10 am to 11 am in the morning. The following is the train operation methodology from San Francisco to Palmdale:

Table 13: Train Operation Timetable for Full Capacity for Scenario 3 San Francisco to Palmdale

Stations	**CAHSR Trains**							**XW Train**
	291050	291051	291052	291053	291048	291054	291049	1001
SFT dp.	10:00	10:15	10:30	10:45				10:03
SFO ar.	10:11	10:31	10:41	11:01				10:17
SFO dp.	10:13	10:33	10:43	11:03				10:17
SJC ar.	10:44	11:04	11:14	11:34				10:49
SJC dp.	10:47	11:07	11:17	11:36	10:41	11:41		10:49
GLY ar.	10:57	11:23	11:27	11:47	10:58	11:58		11:04
GLY dp.	10:59	11:25	11:29	11:49	11:05	12:05		11:04
MDR ar.	11:28	11:58	11:58	12:21			11:27	11:47
MDR dp.	11:30	12:00	12:00	12:23			11:29	11:47
FNO ar.	11:35	12:07	12:05	12:30			11:36	11:58
FNO dp.	11:37	12:13	12:07	12:32			11:43	11:58
KTR ar.	11:50	12:27	12:20	12:47			11:56	12:20
KTR dp.	11:52	12:33	12:22	12:49			12:03	12:20
BFD ar.	12:10	13:01	12:40	13:10			12:31	12:53
BFD dp.	12:12	13:03	12:42	13:17			12:33	12:53
PMD ar.	12:41	13:42	13:11	13:46			13:07	13:41
SFT dp.	12:43	13:44	13:13	13:48			13:09	13:41

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy, MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield, PMD = Palmdale

CAHSR train 291051 had to be adjusted by 6 minutes to accommodate one XpressWest train at the given time. The adjustment is shown in the table below:

Table 14: Delay in Train Operation for Full Capacity for Scenario 3 San Francisco to Palmdale

Stations	Initial CAHSR Time	Adjusted CAHSR Time	Delay
Train No.	291051	291051	
SFT dp.	10:15	10:15	
SFO ar.	10:31	10:31	
SFO dp.	10:33	10:33	
SJC ar.	11:04	11:04	
SJC dp.	11:07	11:07	
GLY ar.	11:23	11:23	
GLY dp.	11:25	11:25	
MDR ar.	11:58	11:58	
MDR dp.	12:00	12:00	
FNO ar.	12:07	12:07	
FNO dp.	12:13	12:13	
KTR ar.	12:27	12:27	
KTR dp.	12:33	12:33	
BFD ar.	13:01	13:01	
BFD dp.	13:03	13:03	
PMD ar.	**13:36**	**13:42**	**6 mins**

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy,
MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield,
PMD = Palmdale

The total delay occurred to CAHSR trains by this adjustment is **6 minutes**. The black line represents XpressWest trains. The researcher has plotted the following capacity allocation model for the above data:

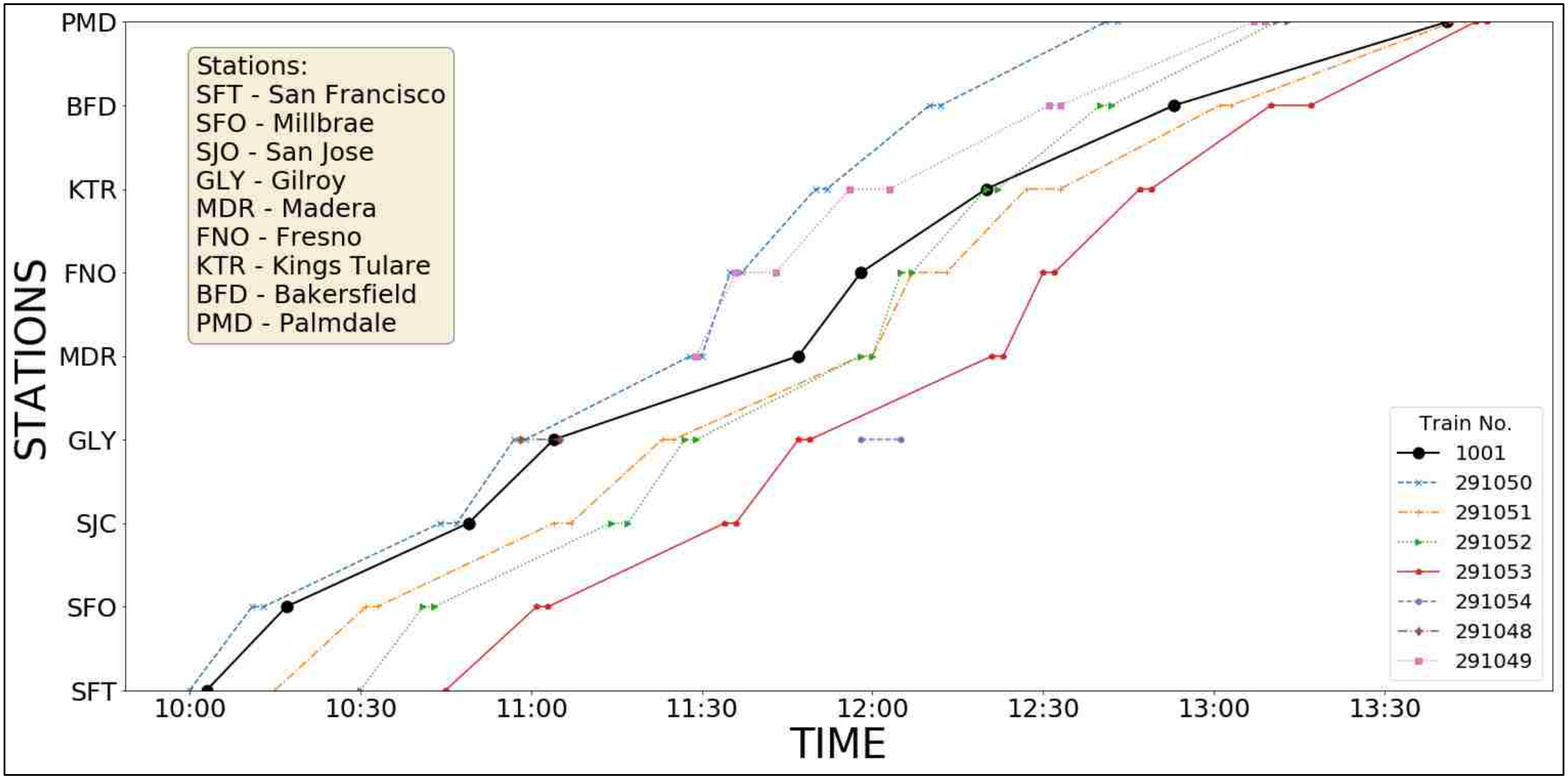

Figure 13: Capacity Allocation Model for Full Capacity 10:00AM to 11:00AM with 1 XpressWest Train from San Francisco to Palmdale

B. From Palmdale to Los Angeles

The researcher has done the theoretical capacity allocation for train slots from 10 am to 11 am in the morning. The following is the train operation methodology from Palmdale (PMD) to Los Angeles (LAU):

Table 15: Train Operation Timetable for Full Capacity for Scenario 3 Palmdale to Los Angeles

Stations	**CAHSR Trains**							**XW Train**
Train No	**291050**	**291051**	**291052**	**291053**	**291048**	**291054**	**291049**	**1001**
PMD dp.	12:43	13:44	13:13	13:48			13:09	12:55
BUR ar.	12:58	14:01	13:28	14:03			13:25	13:14
BUR dp.	13:00	14:03	13:30	14:05			13:27	13:14
LAU ar.	13:15	14:18	13:45	14:20			13:42	13:33
LAU dp.	13:15	14:24	13:45	14:20			13:48	13:33

Note: PMD = Palmdale, BUR = Burbank, LAU = Los Angeles

There is no delay to CAHSR trains in this operation. XpressWest trains are represented by the black lines. The researcher has created the following capacity allocation model for the above data:

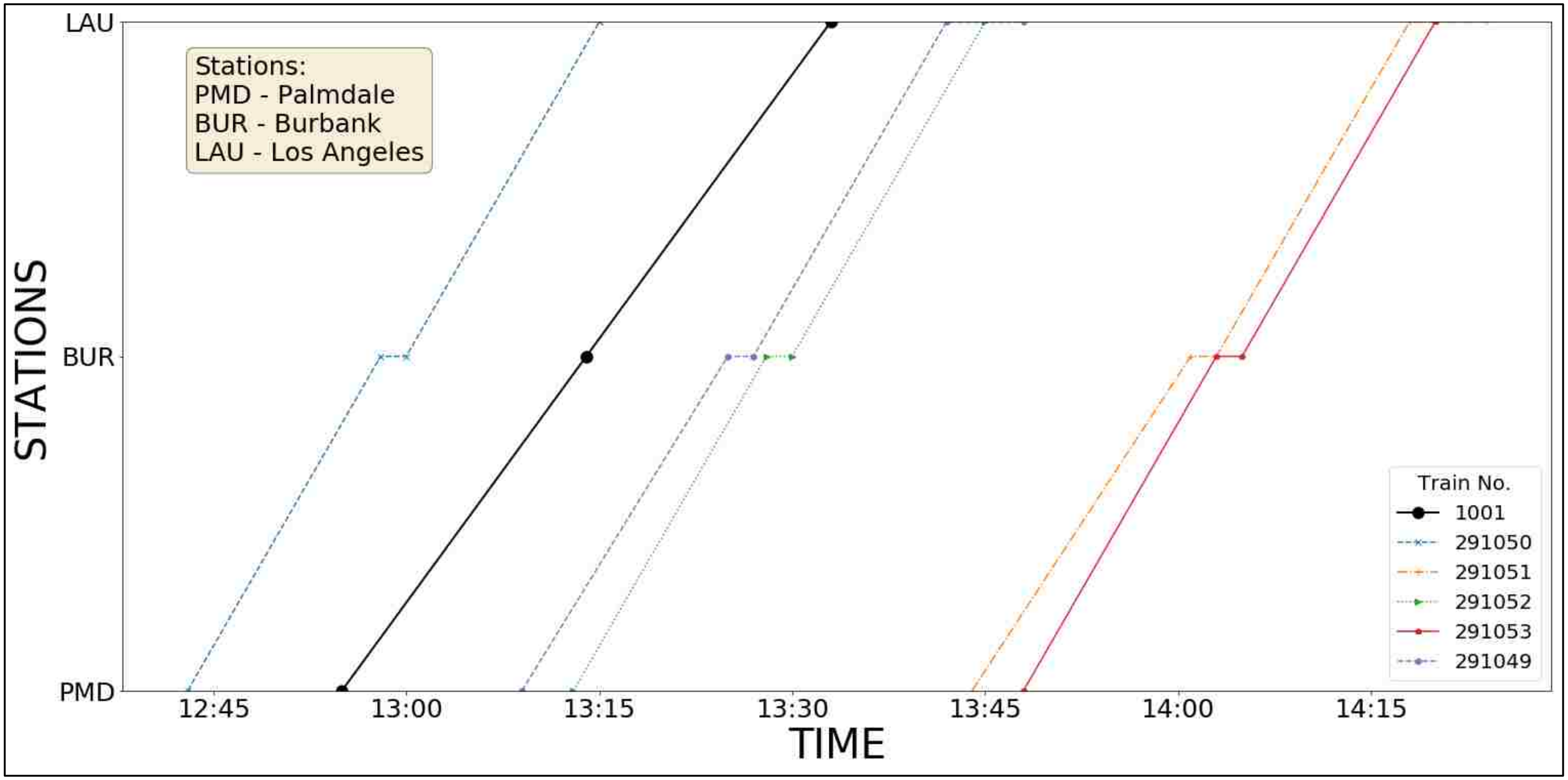

Figure 14: Capacity Allocation Model for Full Capacity 10:00 AM to 11:00 AM with 1 XpressWest Train from Palmdale to Los Angeles

Scenario 4: Two XpressWest Trains in Off - Peak One Hour

A. From San Francisco to Palmdale

The study has done the theoretical capacity allocation for the same sample time of 10 am to 11 am in the morning. The following is the train operation methodology from San Francisco to Palmdale:

Table 16: Train Operation Timetable for Full Capacity for Scenario 4 San Francisco to Palmdale

Stations	**CAHSR Trains**							**XW Train**	
	291050	291051	291052	291053	291048	291054	291049	1001	1003
SFT dp.	10:00	10:15	10:30	10:45				10:03	10:33
SFO ar.	10:11	10:31	10:41	11:01				10:17	10:47
SFO dp.	10:13	10:33	10:43	11:03				10:17	10:47
SJC ar.	10:44	11:04	11:14	11:34				10:49	11:19
SJC dp.	10:47	11:07	11:17	11:36	10:41	11:41		10:49	11:19
GLY ar.	10:57	11:23	11:27	11:47	10:58	11:58		11:04	11:34
GLY dp.	10:59	11:25	11:29	11:49	11:05	12:05		11:04	11:34
MDR ar.	11:28	11:58	11:58	12:21			11:27	11:47	12:17
MDR dp.	11:30	12:00	12:00	12:23			11:29	11:47	12:17
FNO ar.	11:35	12:07	12:05	12:30			11:36	11:58	12:29
FNO dp.	11:37	12:13	12:07	12:32			11:43	11:58	12:29
KTR ar.	11:50	12:27	12:20	12:47			11:56	12:20	12:52
KTR dp.	11:52	12:33	12:22	12:49			12:03	12:20	12:52
BFD ar.	12:10	13:01	12:40	13:10			12:31	12:53	13:25
BFD dp.	12:12	13:03	12:42	13:17			12:33	12:53	13:25
PMD ar.	12:41	13:42	13:11	13:46			13:07	13:41	14:13
PMD dp.	12:43	13:44	13:13	13:48			13:09	13:41	14:13

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy, MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield, PMD = Palmdale

The same CAHSR train 291051 had to be adjusted by 6 minutes in this operation of two XpressWest trains. This is because of the difference in the number of stations and speeds of different CAHSR trains going from San Francisco to Palmdale.

Table 17: Delay in Train Operation for Full Capacity for Scenario 4 San Francisco to Palmdale

Stations	**Initial CAHSR Time**	**Adjusted CAHSR Time**	**Delay**
Train No.	**291051**	**291051**	
SFT dp.	10:15	10:15	
SFO ar.	10:31	10:31	
SFO dp.	10:33	10:33	
SJC ar.	11:04	11:04	
SJC dp.	11:07	11:07	
GLY ar.	11:23	11:23	
GLY dp.	11:25	11:25	
MDR ar.	11:58	11:58	
MDR dp.	12:00	12:00	
FNO ar.	12:07	12:07	
FNO dp.	12:13	12:13	
KTR ar.	12:27	12:27	
KTR dp.	12:33	12:33	
BFD ar.	13:01	13:01	
BFD dp.	13:03	13:03	
PMD ar.	**13:36**	**13:42**	**6 mins**

Note: SFT = San Francisco Terminal, SFO = Millbrae, SJC = San Jose, GLY = Gilroy,
MDR = Madera, FNO = Fresno, KTR = Kings/ Tulare, BFD = Bakersfield,
PMD = Palmdale

The total delay caused to CAHSR trains by this adjustment is still **6 minutes**. The black line represents XpressWest trains. The study has done the following capacity allocation model for the above data:

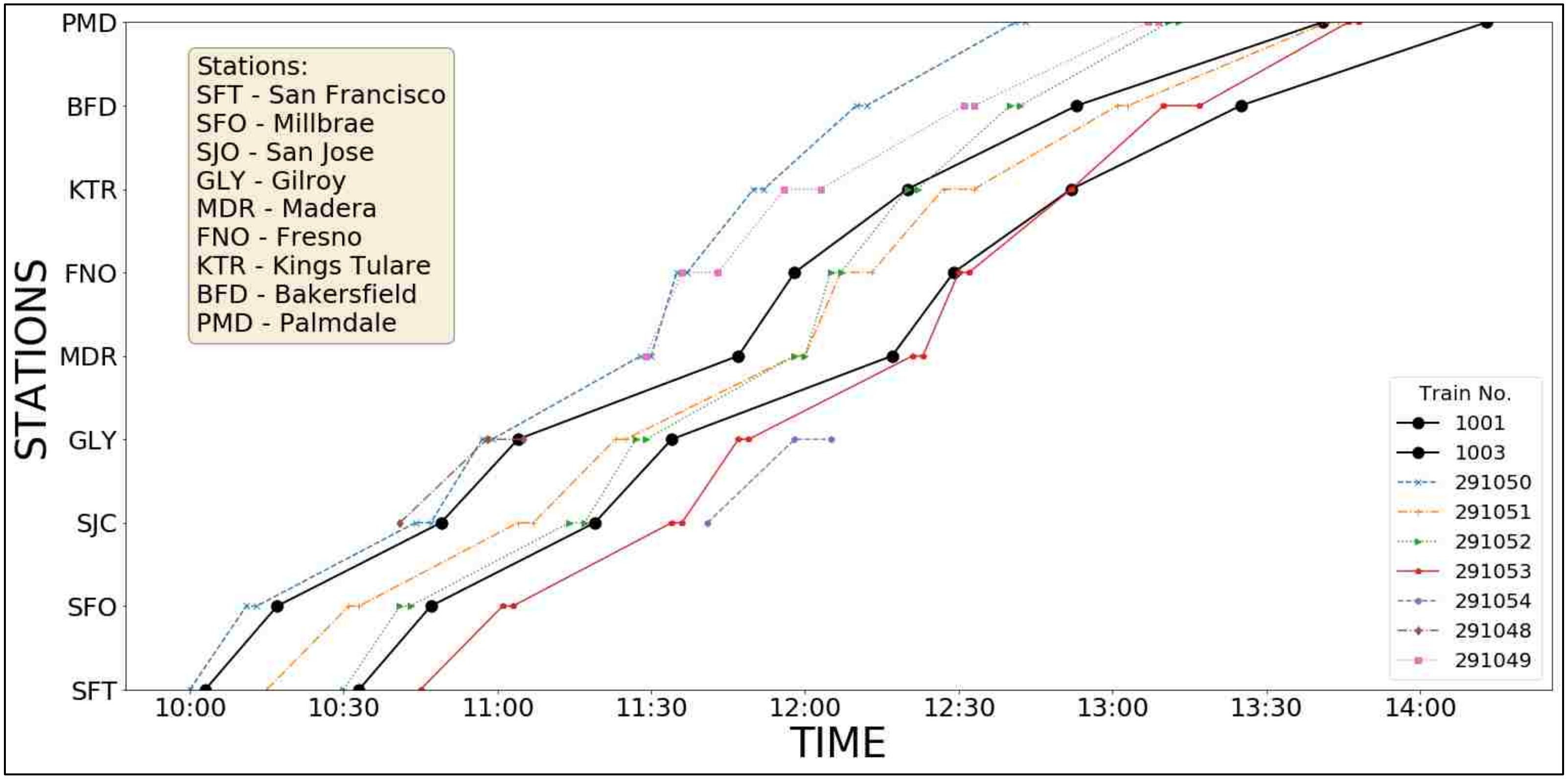

Figure 15: Capacity Allocation Model for Full Capacity 10:00 AM to 11:00 AM with 2 XpressWest Trains from San Francisco to Palmdale

B. From Palmdale to Los Angeles

The researcher has done the theoretical capacity allocation for train slots from 10 am to 11 am in the morning. The following is the train operation methodology from Palmdale (PMD) to Los Angeles (LAU):

Table 18: Train Operation Timetable for Full Capacity for Scenario 4 Palmdale to Los Angeles

Stations	CAHSR Trains							XW Train	
Train No	291050	291051	291052	291053	291048	291054	291049	1001	1003
PMD dp.	12:43	13:44	13:13	13:48			13:09	12:55	13:30
BUR ar.	12:58	14:01	13:28	14:03			13:25	13:14	13:49
BUR dp.	13:00	14:03	13:30	14:05			13:27	13:14	13:49
LAU ar.	13:15	14:18	13:45	14:20			13:42	13:33	14:08
LAU dp.	13:15	14:24	13:45	14:20			13:48	13:33	14:08

Note: PMD = Palmdale, BUR = Burbank, LAU = Los Angeles

There is no delay to CAHSR trains in this operation. XpressWest trains are represented by the black lines. The study has done the following capacity allocation model for train slots for the above data:

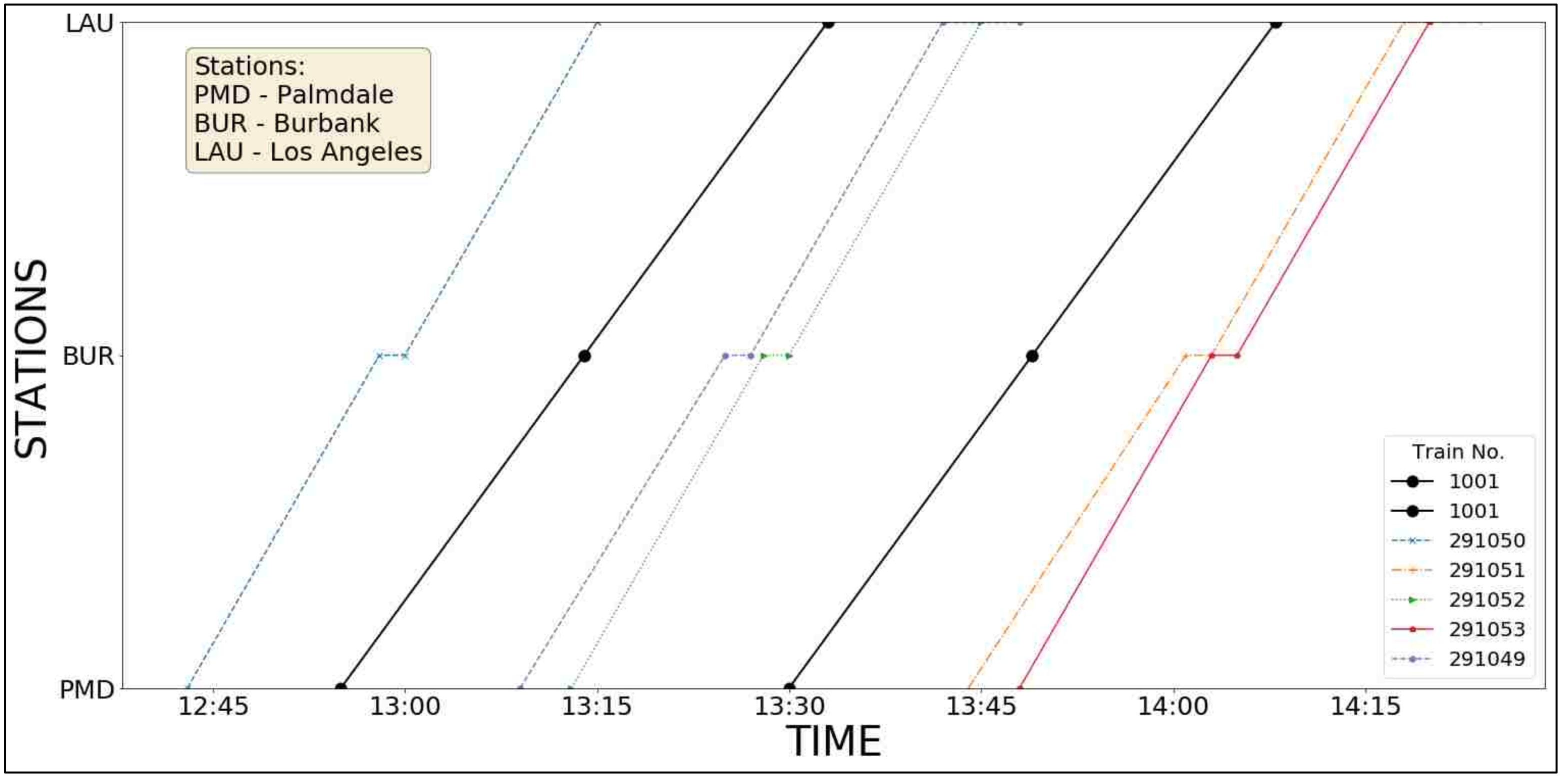

Figure 16: Capacity Allocation Model for Full Capacity 10:00AM to 11:00AM with 2 XpressWest Trains from Palmdale to Los Angeles

4.1.2 Summary of Delay Hours

Case 1: Baseline Capacity

The research has summarized the delay hours calculated for baseline capacity in the table below. There is no delay to CAHSR trains by the operation of XpressWest trains in baseline capacity.

Table 19: Summary of Delay Hours for Baseline Capacity

Scenario	Case	Peak / Off peak Hours	Delay Time per Hour (in Minutes)
1	One XpressWest Train Every Hour	Both	**0**

Case 2: Full Capacity

The study has compiled the delay hours calculated for full capacity in the table below. There is a delay of 6 minutes to 18 minutes to CAHSR trains by the operation of XpressWest trains depending upon the scenario.

Table 20: Summary of Delay Hours for Full Capacity

Scenario	Case	Peak / Off peak Hours	Delay Time per Hour (in Minutes)
1	One XpressWest Train Every Hour	Peak	**7 mins**
2	Two XpressWest Trains Every Hour	Peak	**18 mins**
3	One XpressWest Train Every Hour	Off-Peak	**6 mins**
4	Two XpressWest Trains Every Hour	Off-Peak	**6 mins**

4.2 Estimating Congestion Cost

The study has calculated congestion cost from the formula suggested from the methodology section of the study.

From methodology,

$$\text{Congestion Cost (CC)} = \frac{C_D * \text{Delay}}{M_P}$$

Where, CC= congestion cost for XpressWest (auxiliary) train ($/train mile)

C_D = unit delay cost ($/h)

D = total delay of CAHSR (primary) trains by XpressWest (auxiliary) trains (h)

M_P = total train miles of XpressWest (auxiliary) trains in a mixed flow

From methodology,

Unit Delay Cost (C_D) = Train Operations Cost + Train Control and Dispatching Cost

Train Operations Cost

Train Operations Cost consists of a) crew cost, b) energy cost and c) uniform, vehicle and supplies cost. The analysis has been obtained from the following data about train operations cost from CAHSR (2018c):

Table 21: Estimation of Train Operations Cost

S.N.	Component	Total Cost ($/Year)
1	Crew Cost	$21,345, 393
2	Energy Cost	$365,905
3	Uniform, Vehicle and Supplies Cost	$593,481
	Total	**$22,208,780.00**

Train Control and Dispatching Cost

Train Operations Cost consists of a) operations control center cost, b) yard cost and c) vehicle and supplies cost. The following data has been obtained about train operations cost from CAHSR (2018c):

Table 22: Estimation of Train Control Cost

S.N.	Component	Total Cost ($/Year)
1	Operations Control Center	$1,109,778
2	Yard Cost	$170,052
3	Uniform, Vehicle and Supplies Cost	$79,439
	Total	**$1,359,269**

Hence,

Unit Delay Cost (C_D) = $22,208,780.00 + $1,359,269

= $23,668,045 / year

Since distance from San Fransisco to Los Angeles = 476.3 miles,

= $23,668,045 / year / 476.3 miles

= $49,691.47 /year/miles

Congestion cost is calculated for four different scenarios. Based on the delay hours calculated above, the delay hours for the different scenarios are shown below:

Table 23: Calculation of Delay Hours for Different Scenarios

S.N.	XpressWest Trains	Number of Trains		Total TPD	Miles Traveled by XpressWest TPD	Incremental Delay (h/day)
		XpressWest (TPD)	CAHSR (TPD)			
1.	1 Train Every 2 Hours	6	59	65	2857.8	7*6/2 +6*10/2 = **51 mins**
2.	1 Train Every Off-Peak Hour	10	59	69	4763	6* 10 = **60 mins**
3.	1 Train Every Hour	18	59	77	8573.4	7*6+6*10= **102 mins**
4.	2 Trains Every Hour	24	59	83	11431.2	18*6+ 6*10= **168 mins**

Congestion only occurs when trains run at full capacity. The study calculated the congestion costs for different scenarios per year in the table below:

Table 24: Estimation of Congestion Cost for Different Scenarios

S.N.	Frequency of Xpress West Trains	Delay (hrs/ day)	Delay (hrs/year)	Congestion Cost (/year/mile)	Total Congestion Cost Per year
1	1 Train Every 2 Hours	0.85	310.25	$32,367.79	**$15,416,770**
2	1 Train Every Off-Peak Hour	1	365	$38,079.75	**$18,137,380**
3	1 Train Every Hour	1.7	620.5	$64,735.58	**$30,833,560**
4	2 Trains Every Hour	2.8	1022	$106,623.31	**$50,784,680**

4.3 Estimating Maintenance Cost

For calculating the maintenance cost, the researchers collected data from France, Spain, South Korea, Finland and the United States. The study collected data from class 4 and class 6 railroads, and from CAHSR for United States. The study collected the data from normal speed and high-speed trains.

Johansson & Nilsson (2004) have mentioned that the maintenance cost in Finland was 2.95 million FMK for an 81.22 km track length, and speed was 41.55 kmph in the year 1999.

Unit cost of train maintenance in 1999 = $\frac{2.95\ million}{81.22\ km}$ = FMK 36,321 X 0.21= $7,627.43

Zarembski & Patel (2010) calculated the cost of a FRA class 6 rail maintenance cost of 153.7 track miles from Buffington Harbor to Ft Wayne. The given train section has five freight trains and sixteen passenger trains per day (Zarembski & Patel, 2010). They have noted that the FRA class 6 freight transportation speed is 60mph and passenger transportation is 110 mph. Similarly, Zarembski & Patel (2010) have noted that the speed of FRA class 4 freight operation is 60 mph and passenger train operation is 79mph. Also, Zarembski & Patel (2010) calculated a maintenance cost of $45,354/mile for a FRA class 6 railroad and a total cost of $4,193,474 per 153.7 miles for a FRA class 4 railroad.

Based on these values, mathematical formulations were carried out to calculate the average speed for class 6 and class 4 tracks as follows:

For a FRA class 6 railroad,

Average speed = $\frac{16\ \text{X}\ 110\text{mph} + 5\ \text{X}\ 60\text{mph}}{16+5}$ = 98.1 mph = **157.8 kmph**

Total maintenance costs per track mile in 2003 = $45,354/ mile = **$28,078.55 / km**

For a FRA class 4 railroad,

Average speed of FRA class 4 railroad = $\frac{16 \text{ X } 79\text{mph}+5 \text{ X } 60\text{mph}}{16+5}$ = 74.47mph = **120 kmph**

Total Maintenance cost per track mile in 2003 = $4,193,474 / 153.7 miles = $27,283.5 / mile = **$16,946.27/km**

Campos & de Rus (2009) have reported the maintenance cost of France and Spain to be $28,420 and $33,457 per km in 2002 euros, respectively. Also, the speed on trains in France has been reported as 310 km/hr, and the speed on trains in Spain as 300km/hr.

The researchers calculated the maintenance of infrastructure cost for CAHSR from CAHSR (2018c).

Based on these collected data, the researcher created the following table:

Table 25: List of Collected Maintenance Cost Data

S.N.	Country	Train	Speed (kmph)	Cost/km	Year	Source
1	France	TGV Reseau	310	34,851	2002	Campos & de Rus (2009)
2	Spain	AVE	300	41,028	2002	Campos & de Rus (2009))
3	US	Class 6	165.52	28,170	2003	Zarembski & Patel (2010)
4	US	CAHSR	321	44,5614	2017	CAHSR (2018c)
5	Korea	KTX	300	65,706	2013	KTX (2017)
6	Finland	FMK	41.55	7627	1999	Johansson & Nilsson (2004)
7	US	Class 4	121.07	16,946	for 2003	Zarembski & Patel (2010)

The researcher collected these cost data from different sources for different years. Hence, to bring uniformity to the data, they were all converted to 2017 dollar values by using the inflation rates from the World Bank. The following table shows the inflation rates for the French train TGV Reseau. The study found that the cost of $34,851.49 in the year 2002 was equivalent to $42,980 in the year 2017. This cost is for the maintenance of a single track per year.

Table 26: Inflation Table for France (TGV Reseau)

Country	**Year**	**Inflation Rates (annual %)**	**Cost ($)**
France	2002	1.917	34851.49
	2003	2.109	35519.59
	2004	2.135	36268.70
	2005	1.736	37043.03
	2006	1.684	37686.10
	2007	1.488	38320.73
	2008	2.814	38890.95
	2009	0.088	39985.34
	2010	1.53	40020.53
	2011	2.117	40632.84
	2012	1.956	41493.04
	2013	0.864	42304.64
	2014	0.508	42670.15
	2015	0.038	42886.92
	2016	0.183	42903.21
	2017	1.032	**42980**

The study shows the inflation table for the Spanish train (AVE) below. The cost of $41,028.38 in the year 2003 was found to be $53,800 in the year 2017. This cost is for the maintenance of a single track per year.

Table 27: Inflation Table for Spain (AVE)

Country	Year	Inflation Rates (annual %)	Cost ($)
Spain	2003	3.04	41028.38
	2004	3.037	42275.64
	2005	3.37	43559.55
	2006	3.515	45027.51
	2007	2.787	46610.22
	2008	4.076	47909.25
	2009	-0.288	49862.03
	2010	1.8	49718.43
	2011	3.196	50613.36
	2012	2.446	52230.96
	2013	1.409	53508.53
	2014	-0.151	54262.47
	2015	-0.5	54180.53
	2016	-0.203	53909.63
	2017	1.956	**53800**

The following table shows the inflation rates for the South Korean train KTX. The cost of $65,706 in the year 2013 was found to be $68,540 in the year 2017. This cost is for double-track maintenance per year.

Table 28: Inflation Table for South Korea (KTX)

Country	Year	Inflation Rates (annual %)	Cost ($)
South Korea	2013	1.301	65706
	2014	1.275	66560.83
	2015	0.707	67409.48
	2016	0.97	67886.07
	2017	1.944	**68540**

The following table shows the inflation rates for Finnish train FMK. The cost of $7627.43 in the year 1995 was calculated to be $10,570 in the year 2017. This cost is for maintenance of a double track per year.

Table 29: Inflation Table for Finland (FMK)

Country	Year	Inflation Rates (annual %)	Cost ($)
Finland	1995	0.985	7627.43
	1996	0.617	7702.56
	1997	1.195	7750.08
	1998	1.399	7842.70
	1999	1.159	7952.41
	2000	3.368	8044.58
	2001	2.566	8315.52
	2002	1.562	8528.90
	2003	0.877	8662.12
	2004	0.187	8738.09
	2005	0.861	8754.43
	2006	1.567	8829.81
	2007	2.511	8968.17
	2008	4.066	9193.36
	2009	0.001	9567.16

Country	Year	Inflation Rates (annual %)	Cost ($)
	2010	1.21	9567.26
	2011	3.417	9683.02
	2012	2.808	10013.89
	2013	1.478	10295.08
	2014	1.041	10447.24
	2015	-0.207	10556
	2016	0.357	10534.15
	2017	0.754	**10570**

The analysis shows the inflation rates for US Class 6 trains below. The analysis found that the cost of $28,170 in the year 2003 was equivalent to $37,590 in the year 2017. This cost is a double track maintenance cost.

Table 30: Inflation Table for US (Class 6)

Country	Year	Inflation Rates (annual %)	Cost ($)
US	2003	2.27	28170
(class 6)	2004	2.677	28809.45
	2005	3.393	29580.68
	2006	3.226	30584.36
	2007	2.853	31571.01
	2008	3.839	32471.73
	2009	-0.356	33718.32
	2010	1.64	33598.28
	2011	3.157	34149.29
	2012	2.069	35227.39
	2013	1.465	35956.24
	2014	1.622	36483
	2015	0.119	37074.75

Country	Year	Inflation Rates (annual %)	Cost ($)
	2016	1.262	37118.87
	2017	2.13	**37590**

Finally, the study shows the inflation rates for US Class 4 trains. The study found that the cost of $16,946.27 in the year 2003 was equivalent of $22,610 in the year 2017. This cost is for double track maintenance per year.

Table 31: Inflation Table for US (Class 4)

Country	Year	Inflation Rates (annual %)	Cost
US	2003	2.27	16,946.27
(class 4)	2004	2.677	17330.95
	2005	3.393	17794.89
	2006	3.226	18398.68
	2007	2.853	18992.22
	2008	3.839	19534
	2009	-0.356	20283.98
	2010	1.64	20211.77
	2011	3.157	20543.24
	2012	2.069	21191.79
	2013	1.465	21630.25
	2014	1.622	21947.13
	2015	0.119	22303.11
	2016	1.262	22329.66
	2017	2.13	**22610**

The following table shows the number of trains per day for different train systems. There are 18 to 21 trains operating every day for these different types of trains.

Table 32: Number of Trains Per Day for Different Trains

Country	Number of Trains Per Day	Source
South Korea	54	Korail (2013)
US (Class 6)	21	Zarembski & Patel (2010)
Finland	18	VR Group (2017)
CAHSR	59	CAHSR (2018c)
US (Class 4)	21	Zarembski & Patel (2010)

After calculating all the inflated maintenance cost values, the researcher summarized them in the table below:

Table 33: Maintenance Cost Data for 2017 and Speed

Country	Speed (kmph)	Cost per km (USD 2017)
South Korea	300	$68540
US (Class 6)	157.8	$37590
Finland	41.5	$10570
CAHSR	320	$73460
US (Class 4)	121.1	$22610

The study made the graph for maintenance cost and speed below. The maintenance cost of Spain and France are for single track. Hence, they are not plotted in the graph. The graph shows that speed and maintenance costs have a linear and directly proportional relationship. The following equation has been derived to show their relationship:

Unit Maintenance Cost (USD/ year / km) = 232.7 * Speed – 1571

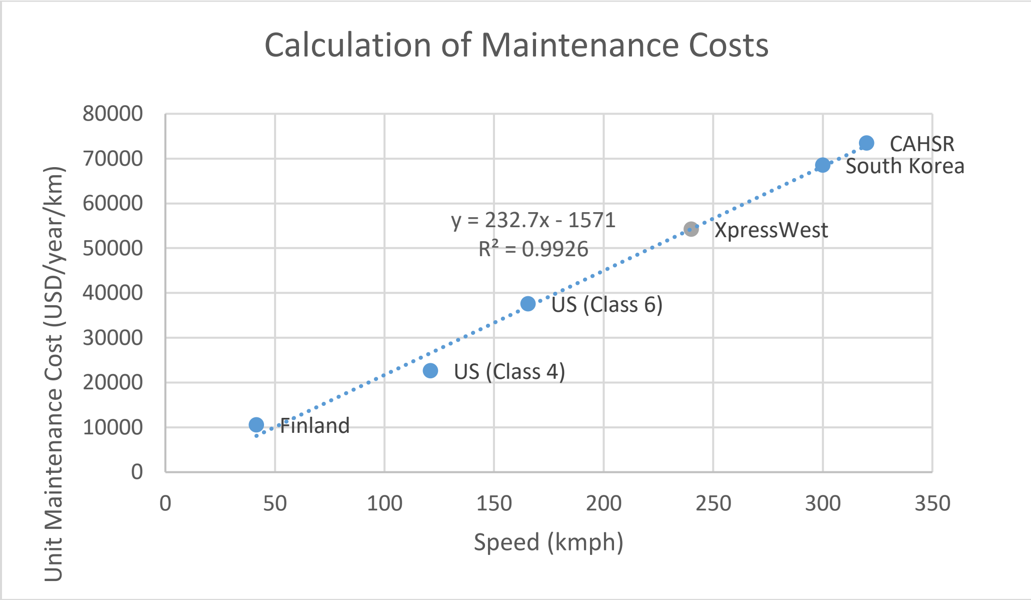

Figure 17: Calculation of Maintenance Cost by Unit Maintenance Cost VS Speed

This is the maintenance cost for full occupancy of trains. There is not enough literature about the effect of addition of auxiliary trains in maintenance cost. However, after the trains start operating, the actual value of maintenance cost can be known. The following relationship is proposed for the calculation of maintenance cost after the operation of trains:

Maintenance Cost for auxiliary trains

$$= \text{Actual Maintenance Cost} * \frac{\text{No. of Auxiliary Trains}}{\text{No. ofAuxiliaryTrains+No. of Primary Trains}} * \frac{(232.7 * \text{Speed of Auxuliary Trains} - 1571)}{(232.7 * \text{Speed of Primary Trains} - 1571)}$$

Due to unavailability of value of maintenance cost right now, the following relationship is used in this research:

Unit Maintenance Cost for auxiliary trains (/km/year)

$$= \mathbf{(232.7 * Speed – 1571) *} \frac{\text{No.of Auxiliary Trains}}{\text{No.of Auxiliary Trains+No.of Primary Trains}}$$

For XpressWest,

Unit Maintenance Cost = (232.7 * 240 – 1571) * $\frac{\text{No.of XpressWest Trains}}{\text{No.of XpressWest Trains+No.of CAHSR Trains}}$

= $ 54, 277/year/km * $\frac{\text{No.of XpressWest Trains}}{\text{No.of XpressWest Trains+No.of CAHSR Trains}}$

= $ 87, 331.7 /year/miles* $\frac{\text{No.of XpressWest Trains}}{\text{No.of XpressWest Trains+No.of CAHSR Trains}}$

Based on this equation, the study has calculated maintenance costs for Baseline capacity and full capacity for XpressWest.

i) Baseline Capacity

The maintenance cost for XpressWest is found to be $20,798,000/year for baseline capacity.

For baseline capacity,

No. of XpressWest trains/day = 19

No. of CAHSR trains/day = 19

Length of Tracks from San Francisco (SFT) to Las Angeles (LAU) = 476.3 miles

Maintenance Cost = $ 87, 331.7 /year/miles* $\frac{19}{19+19}$ * 476.3

= **$20,798,000 / year**

ii) Full Capacity

The study has considered four scenarios for calculation of maintenance cost for XpressWest. These scenarios are the same ones chosen for calculating congestion cost.

Maintenance cost was found to be from $3.8 million to $12 million for different scenarios for full capacity.

Table 34: Calculation of Maintenance Cost for Different Scenarios

S.N.	XpressWest Trains	No. of XW Trains	No. of CAHSR Trains	Maintenance Cost (/ year)
1	1 Train Every 2 Hours	6	59	$3,839,640
2	1 Train Every Off-Peak Hour	10	59	$6,028,420
3	1 Train Every Hour	18	59	$9,723,760
4	2 Trains Every Hour	24	59	$12,027,780

4.4 Estimating Cost of Installing Side-Tracks

The study has calculated the total number and the total cost of installing side tracks for baseline capacity and full capacity. Then, the researchers plotted a graph between stations and travel time, like the one for the capacity allocation model. The station where the operation plan of XpressWest and CAHSR meet is the station where side-track needs to be installed.

i) Baseline Capacity

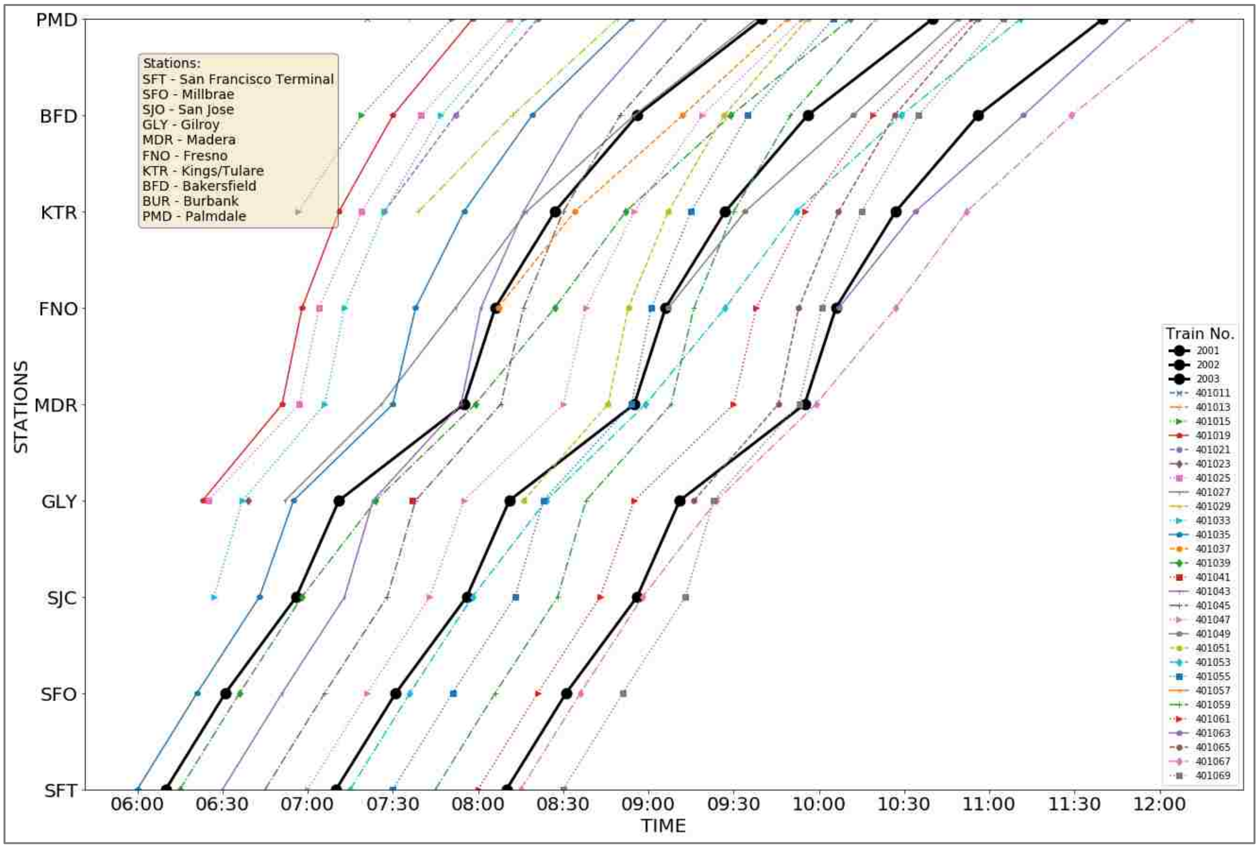

Figure 18: Calculation of Number of Side Tracks Using Baseline Capacity

Based on the graph,

Number of side tracks = 6

Stations that need side tracks are SJC, MDR, FNO, KTR, BFD and PMD.

ii) Full capacity

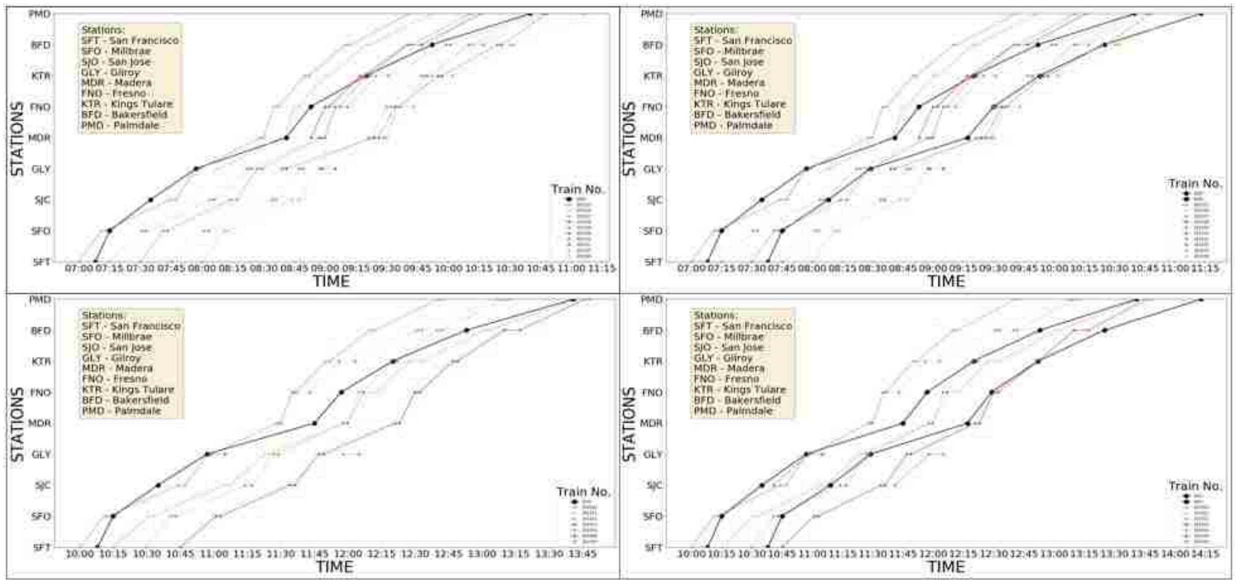

Figure 19: Calculation of Number of Side Tracks Using Full Capacity

Based on the capacity allocation graph, the number of side tracks needed for different scenarios are:

Table 35: Calculation of Number of Side Tracks for Full Capacity

S.N.	**XpressWest Trains**	**Hour**	**No. of Side Tracks**	**Stations needing Side Tracks**
1	1 Train Every 2 Hours	Peak	5	SFO, GLY, MDR, KTR, PMD
2	1 Train Every Off-Peak Hour	Peak	8	SFO, SJC, GLY, MDR, FNO, KTR, BFD, PMD
3	1 Train Every Hour	Off-Peak	4	SFO, GLY, KTR, PMD
4	2 Trains Every Hour	Off-Peak	5	SFO, GLY, FNO, KTR, PMD

After calculating the number of side-tracks, the researchers estimated the cost of installing the side tracks. The study assumed the length of side tracks to be equal to the length of the stations. The cost of installing side tracks was found to be $294,694 million for the entire section (CAHSR, 2018b).

From CAHSR (2018b), for Phase 1,

Cost of Installing Tracks and Structures = $29,694 millions

Total Miles = 507.4 miles

Cost/mile = $58,521,876.2 / mile

From CAHSR (2012),

Length of side track = 1,300 feet = 0.24 miles

Cost of each side track = **$14,045,250**

Based on the unit cost of side tracks, the cost of installing side tracks was determined for the same four scenarios. The cost of installing side tracks ranges from $56 million to $112 million.

Table 36: Cost of Installing Side Tracks for Different Scenarios for Full Capacity

S.N.	**XpressWest Trains**	**No. of Side Tracks**	**Total Cost of Side Tracks**
1	1 Train Every 2 Hours	5	**$70,226,250**
2	1 Train Every Off-Peak Hour	8	**$56,181,000**
3	1 Train Every Hour	4	**$70,226,250**
4	**2 Trains Every Hour**	**5**	**$112,362,000**

4.5 Calculation of Access Charge

After the calculation of congestion, maintenance cost and cost of installing side tracks, the study estimated the value of access charge. Following the different cases, schemes and scenarios are used for calculation of access charge.

Case 1: Baseline Capacity

Scheme 1: Maintenance Cost Only

Scheme 2: Maintenance Cost and Cost of Installing Side Tracks

Case 2: Full Capacity

Scheme 1: Maintenance Cost Only

Scheme 2: Maintenance Cost and Cost of Installing Side Tracks

Scheme 3: Maintenance and Congestion Cost

Scheme 4: Maintenance, Congestion Cost and Cost of Installing Side Tracks

Scenario 1: 1 XpressWest Train Every Two Hours

Scenario 2: 1 XpressWest Train During Off-Peak Hours

Scenario 3: 1 XpressWest Train Every Hour

Scenario 4: 2 XpressWest Trains Every Hour

Case 1: Baseline Capacity

Scheme 1: Maintenance Cost Only

The study has calculated the access charge calculated for baseline capacity considering maintenance cost only. The access charge for this scenario is $20 million per year.

Maintenance Cost for Baseline Capacity= $20,798,000/ year

Hence, Access Charge = $ **20,798,000/ year**

Case 1: Baseline Capacity

Scheme 2: Maintenance Cost and Cost of Installing Side Tracks

The researcher has calculated access charge for baseline capacity considering maintenance cost and cost of installing side tracks. The number of side tracks required for baseline capacity is 6. The access charge for this scenario is $20 million per year, with a fixed cost of $84 million for installing sidetracks at the beginning of the operation.

Maintenance Cost = $20,798,000/ year

Cost of Each Side Track = $14,045,250

No. of Side Tracks = 6

Total Cost of Side Tracks = $84,271,500

Hence, Access Charge = **$20,798,000/ year and $84,271,500 fixed cost at the beginning**

Case 2: Full Capacity

Scheme 1: Maintenance Cost Only

The study has estimated access charge for full capacity considering maintenance cost only. The study has considered four different scenarios. The value of access charge is between $3.8 million to $12 million per year.

Table 37: Calculation of Access Charge for Full Capacity, Maintenance Cost Only

S.N.	XpressWest Trains	Access Charge
1	1 Train Every 2 Hours	$3,839,640 / year
2	1 Train Every Off-Peak Hour	$6,028,420 / year
3	1 Train Every Hour	$9,723,760 / year
4	2 Trains Every Hour	$12,027,780 / year

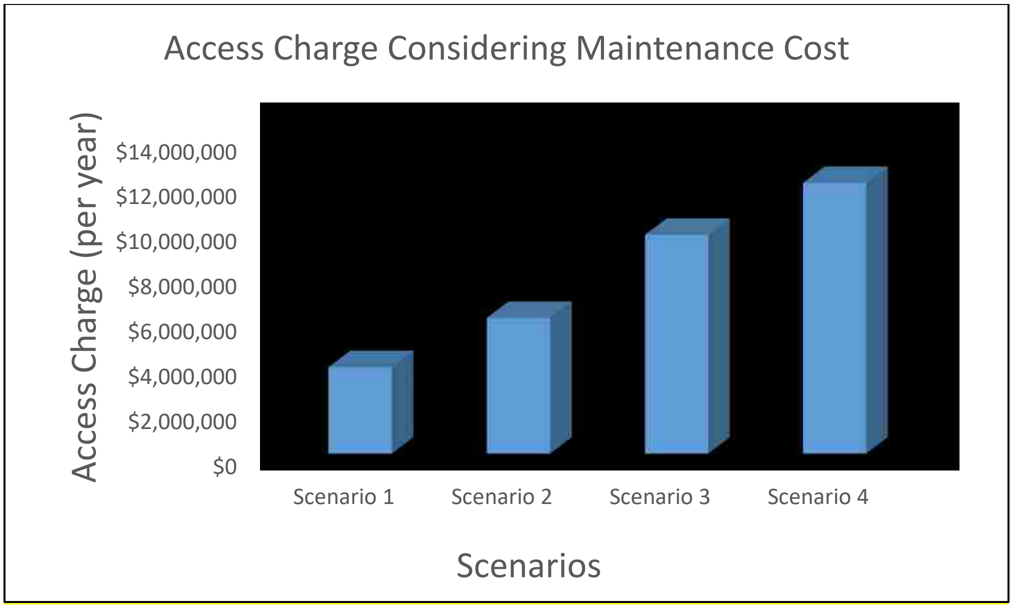

Figure 20: Calculation of Access Charge for Full Capacity Considering Maintenance Cost Only

Case 2: Full Capacity

Scheme 2: Maintenance Cost and Cost of Installing Side Only

The study has calculated access charge for full capacity considering maintenance cost and cost of installing side tracks. The access charge for this scenario is between $3.8 million to $12 million per year, with a fixed price of $56 million to $112 million for installing side tracks at the beginning of the operation.

Table 38: Calculation of Access Charge for Full Capacity, Maintenance Cost and Installing Side Tracks Only

S.N.	XpressWest Trains	Access Charge (Maintenance Cost)	Total Cost of Side Tracks (Fixed Cost at Beginning)
1	1 Train Every 2 Hours	$3,839,640 / year	$70,226,250
2	1 Train Every Off-Peak Hour	$6,028,420 / year	$56,181,000
3	1 Train Every Hour	$9,723,760 / year	$70,226,250

S.N.	XpressWest Trains	Access Charge (Maintenance Cost)	Total Cost of Side Tracks (Fixed Cost at Beginning)
4	2 Trains Every Hour	$12,027,780 / year	$112,362,000

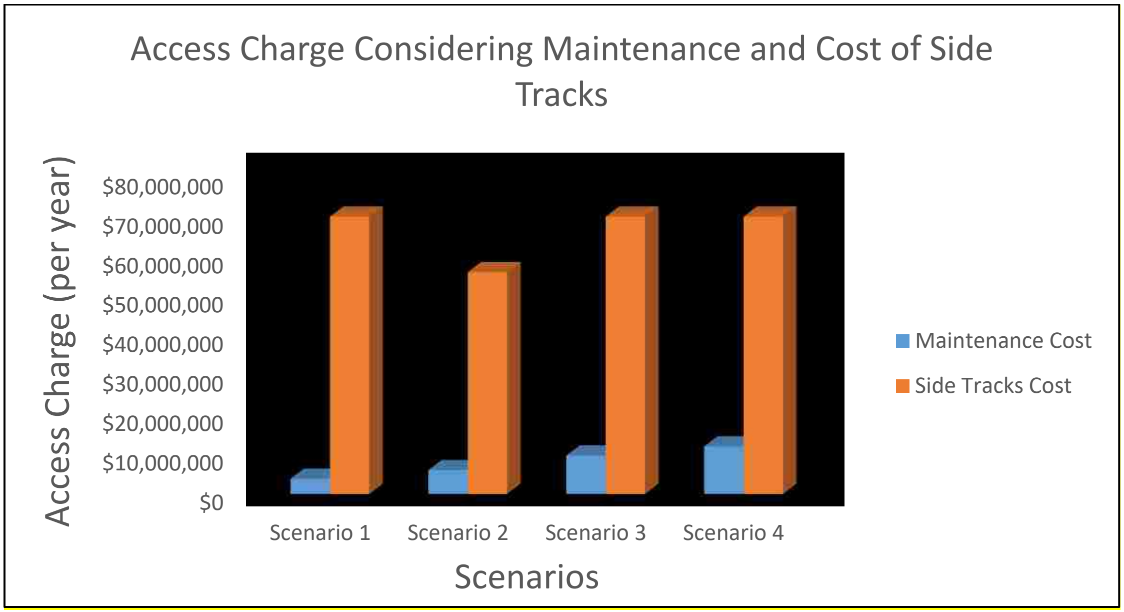

Figure 21: Calculation of Access Charge for Full Capacity Considering Maintenance Cost and Cost of Installing Side Tracks

Case 2: Full Capacity

Scheme 3: Maintenance Cost and Congestion Cost

The researcher has calculated access charge for full capacity considering maintenance cost and congestion cost. The access charge is found to be between $19.2 million to $62.8 million per year for this scenario.

Table 39: Calculation of Access Charge for Full Capacity, Maintenance and Congestion Cost

S.N.	XpressWest Trains	Maintenance Cost (/ year)	Congestion Cost (/year)	Access Charge (/year)
1	1 Train Every 2 Hours	$3,839,640	$15,416,770	$19,256,520 / year
2	1 Train Every Off-Peak Hour	$6,028,420	$18,137,380	$24,165,800 / year
3	1 Train Every Hour	$9,723,760	$30,833,560	$40,557,320 / year
4	2 Trains Every Hour	$12,027,780	$50,784,680	$62,812,460 / year

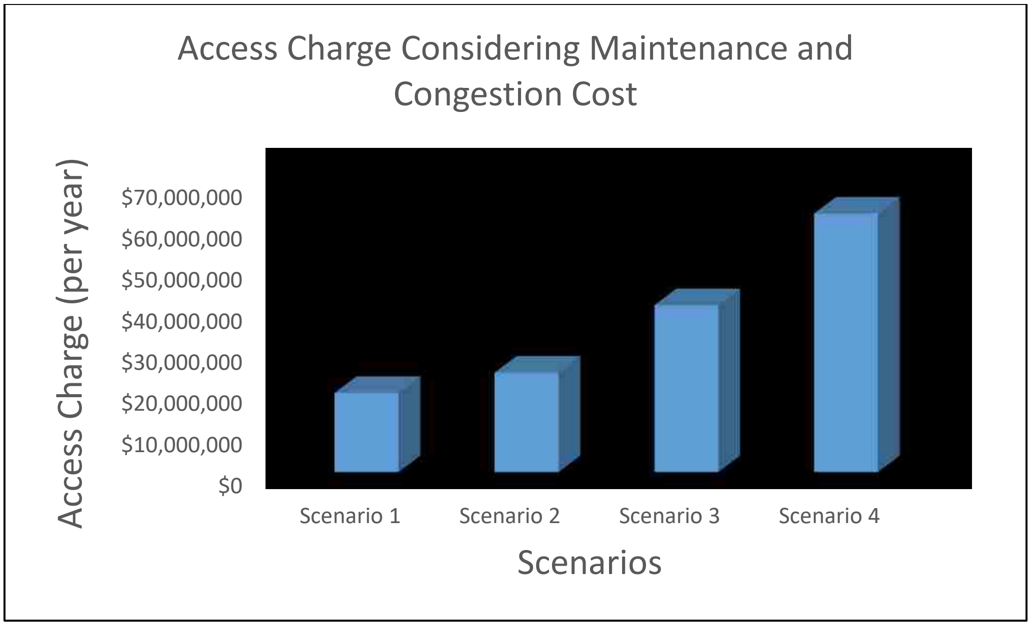

Figure 22: Calculation of Access Charge for Full Capacity Considering Maintenance and Congestion Costs

Case 2: Full Capacity

Scheme 4: Maintenance, Congestion Cost and Cost of Installing Side Tracks

In this scheme, the study has calculated access charge considering the cost of maintenance, cost of congestion, and cost of installing side tracks. The access charge for this scenario is between $19.2 million to $62.8 million per year, with a fixed price of $56 million to $112 million for installing side tracks at the beginning of the operation.

Table 40: Calculation of Access Charge for Full Capacity, Maintenance, Congestion Cost and Cost of Installing Side Tracks

S.N.	XpressWest Trains	Access Charge (Maintenance + Congestion Cost) (/year)	Side Tracks Cost (Beginning, Fixed Cost)
1	1 Train Every 2 Hours	$19,256,520 / year	$70,226,250
2	1 Train Every Off-Peak Hour	$24,165,800 / year	$56,181,000
3	1 Train Every Hour	$40,557,320 / year	$70,226,250
4	2 Trains Every Hour	$62,812,460 / year	$112,362,000

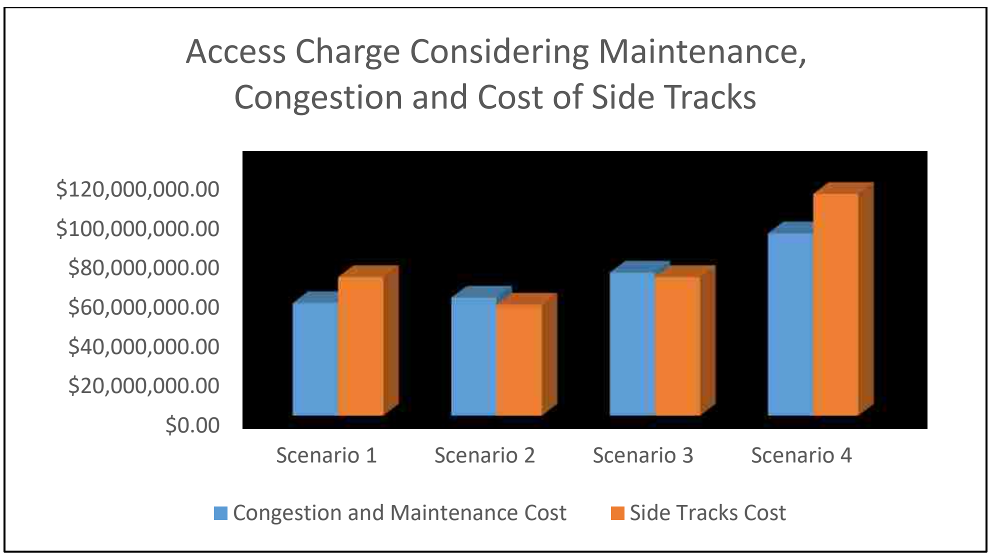

Figure 23: Calculation of Access Charge for Full Capacity Considering Maintenance, Congestion Costs and Cost of Installing Side-Tracks

Hence, depending upon the scenario, the value of access charge ranges from $20 million per year to $62 million per year.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study on the calculation of access charge for HSR XpressWest of Nevada demonstrates that there is a significant increase in the amount of congestion and maintenance costs by the addition of XpressWest trains on a given running track of CAHSR. Hence, train infrastructure owners and operators need a fair and reasonable calculation of access charge before carrying out the mixed train operation. Before the operation, access charge should be discussed and negotiated by XpressWest and CAHSR. Depending upon the operation plan, they should select a suitable scenario on mutual agreement.

The study calculated the values of congestion cost, maintenance cost and cost of installing side tracks for two different cases. The first case is baseline capacity: the situation when a CAHSR train operates every hour from San Francisco to Los Angeles. The second case is full capacity: when 4 CAHSR trains run every hour from San Francisco to Los Angeles. For both cases, the study proposed different scenarios, and developed an operation plan for each scenario.

For determining delay, the theoretical capacity allocation graph for train slots was plotted. For cases with delay, the operation plan was changed to minimize the delay. The researchers calculated the minimum delay from the allocation model in minute per day. The value of delay ranged from 51 minutes to 168 minutes per day depending upon the scenario. The study obtained the total number of CAHSR and XpressWest trains from the allocation model. Based on the delay hours and number of trains, the study obtained the value of congestion cost for each scenario. The value of congestion cost ranges from $15.4 million to $50.7 million per year for full capacity train operation. There was no delay for baseline capacity. Hence, there was no need to calculate congestion cost.

For the calculation of maintenance cost, the study obtained historical data from different countries based on speed. Inflation rates from the World Bank were used to adjust the cost data. The study obtained a linear relationship between speed and maintenance cost. This cost was then adjusted with the number of trains in a shared operation. For baseline capacity, maintenance cost was $20.7 million per year. For full capacity, maintenance cost ranged from $3.8 million to $12 million per year.

Side tracks were proposed at relevant stations to allow two trains to by-pass each other. For baseline capacity, the analysis found that 6 different side tracks are required. The study estimated the cost of these side tracks to be $84.27 million. This estimated cost is a fixed cost to be paid only at the beginning of the operation. For full capacity, 4 to 5 side tracks are necessary depending upon the scenario. The cost of these sidetracks ranges from $56 million to $70 million.

In total, this study proposed 18 different scenarios. The study assessed and compared possible values of access charges. The amount of access charge ranges from $3.8 million to $62.8 million per year depending upon the scenario. Also, the fixed cost of installing side tracks varies from $56 million to $84 million.

During the operation process, the number of trains will increase with time. During the preliminary phase of operation, baseline capacity will be more suitable for XpressWest and CAHSR. Hence, the value of the access charge will be $20.7 million per year. Later, the number of trains will increase, and the cost of access charges for full capacity will increase. These access charge amounts can be assumed as upper range value for the full capacity and lower range value for the baseline capacity. The lower and upper range values can show the whole picture to CAHSR and XpressWest train operators.

5.2 Contributions

This section will describe the contributions of this research to the calculation of access charge. The following are considered as the key-contributions of this research:

- **Development of framework:** This study has developed a systematic framework for the calculation of access charge for mixed track HSR systems. This framework can be adopted by other train systems willing to share their tracks between different train operators. This will help the infrastructure owner and operators to come up with a fair and reasonable value of access charge that will satisfy both parties.
- **Development of train allocation model:** This study has developed the train allocation model to check if auxiliary trains can operate satisfactorily in a network. In absence of simulation or parametric models, this model can serve as an easy way of calculating delay hours and conducting train operation modeling.
- **Extensive collection of factors affecting access charge:** The literature review section of this study has been carried out extensively. The prevailing access charge methodologies around the world have been collected and key factors affecting access charge has been identified. These key factors will provide a path for conducting sensitivity analysis in the future.

5.3 Recommendation for Future Research

This research calculated the access charge by calculating maintenance cost, congestion cost and cost of installing side tracks. The researcher recommends the following studies to be done in future to better understand and implement access charge:

- **Use of simulation or parametric models:** This research calculated the number of trains and delay hours by using the theoretical capacity allocation model. The model could not consider track geometry, elevation differences, signals and weather conditions. The researcher believes that these factors can change the train time-table in real world operations. Hence, the researcher recommends using simulation or parametric models to accommodate all these factors. Simulation models like Rail Traffic Controller (RTC) can achieve better operation time-table. It can calculate closer value of delay hours and the number of trains for real time operation
- **Use of other mathematical models:** The researcher has adopted one model from literature review for the calculation of access charge. The researcher recommends access charge to be calculated by other mathematical models in the literature review. The researcher recommends the relevant values for those calculations to be determined. Then, the researcher recommends the value of charge obtained from different models to be compared. This comparison will help generating a fairer value of access charge.
- **Analysis of effect of auxiliary trains in maintenance cost:** The effect of addition of lower speed trains in the total maintenance cost has not been well identified in literature yet. This study also developed a formula based on actual maintenance cost after train operation. For the purpose of this calculation, the researcher has taken a value of maintenance cost from historical data based on speed. Hence, the researcher recommends

further studies to be done about the relationship between increase maintenance costs, number of trains and speeds of trains in a network.

- **Sensitivity analysis for factors affecting access charge:** This study has calculated a range of values of access charge for a given train system. However, the researcher recommends conducting a sensitivity analysis can be done for the factors affecting access charge. The key variables identified from literature review can be used for conducting the sensitivity analysis. Access charge can be simulated by those key variables to obtain the cost relationship of access charge with each of the key variables. This will better help other train systems to adopt this model. This will also provide a policy recommendation for the train system for access pricing.
- **Calculation of a long term LCC and IRR analysis:** After the calculation of access charge, the researcher recommends generating a long-term Life Cycle Cost Analysis (LCCA) or Internal Rate of Return (IRR) analysis for a period of 20 years to 30 years. This analysis will be an extension of this study, and will include the revenue, cost and profit generated during each year. This type of calculation can provide a bigger picture to XpressWest. This will significantly help XpressWest in setting their policies or their goals.

5.4 Discussion

This research calculated the amount of access charge concerning congestion, maintenance and cost of installing side-tracks for XpressWest of Nevada. XpressWest plans to reach San Francisco and Los Angeles by operating in the tracks of CAHSR. The value of access charges ranged between $20.7 million to $62.8 million depending upon the operation plan.

This research assumed a “perfect world” for the development of train operation model. In real-world operation, the delay will be higher than the delay hours calculated in this study. There are lots of factors affecting train operation in real world. Weather conditions and human error are not considered in this study. Hence, access charge will be higher than the value calculated in this study.

This research calculated the maintenance cost by using the linear equation developed by historical data. Then, this cost was adjusted by train number. This was done due to lack of actual maintenance cost data after sharing the CAHSR tracks with XpressWest. Hence, in this study the maintenance cost obtained was higher for baseline case than for full case. However, once the trains start operating this will not be the case. After train operation, the actual maintenance cost needs to be adjusted using the formula developed in methodology section.

Sharing of tracks to other operators allows the train infrastructure owners to gain more profit. This would make HSR more sustainable and enable it to serve the society in the long run. Similarly, the auxiliary train operators also get a chance to increase their destinations and gain more profit. Hence, shared track operations are assumed to be mutually beneficial operations.

This research contributes to the knowledge by provide a framework for the calculation of access charge in mixed flow passenger train operations. The need and of HSR is rising in US. Authorities are planning many HSR corridors around the country. This framework can be adopted by other train operators planning to include additional trains in trains and willing to share tracks as well.

REFERENCES

Álvarez-SanJaime, Ó., Cantos-Sanchez, P., Moner-Colonques, R., & Sempere-Monerris, J. J. (2016). Rail access charges and internal competition in high speed trains. *Transport Policy*, *49*, 184–195. https://doi.org/10.1016/j.tranpol.2016.04.006

CAHSR. (2012). California High-Speed Train Project Design Criteria.

CAHSR. (2018a). 2018 Business Plan.

CAHSR. (2018b). Capital Cost Estimate Report.

CAHSR. (2018c). Operations and Maintenance Cost Forecasting.

CAHSR. (2018d). Service Planning Methodology Report.

Campos, J., & de Rus, G. (2009). Some stylized facts about high-speed rail: A review of HSR experiences around the world. *Transport Policy*, *16*(1), 19–28. https://doi.org/10.1016/j.tranpol.2009.02.008

Givoni, M. (2006). Development and impact of the modern high-speed train: A review. *Transport Reviews*, *26*(5), 593–611. https://doi.org/10.1080/01441640600589319

Johansson, P., & Nilsson, J. E. (2004). An economic analysis of track maintenance costs. *Transport Policy*, *11*(3), 277–286. https://doi.org/10.1016/j.tranpol.2003.12.002

Johnson, D., & Nash, C. (2008). Charging for Scarce Rail Capacity in Britain: A Case Study. *Review of Network Economics*, *7*(1), 53–76. https://doi.org/10.2202/1446-9022.1138

Kozan, E., & Burdett, R. (2005). A railway capacity determination model and rail access charging methodologies. *Transportation Planning and Technology*, *28*(1), 27–45. https://doi.org/10.1080/0308106052000340378

Korail (2013). Korail Info. Retrived from:
http://www.letskorail.com/ebizbf/EbizbfForeign_pr16100.do;jsessionid=WaaZ1EmJwYgCAa1uPSUW4ggzZ0nyWQL4hGjvKe9V4KaZ8n1E0Mf9sysryp1JcyN6?gubun=1

Korea Train eXpress (KTX): Case Study. (2017).

Lai, Y.-C. (Rex), Lin, Y.-J., & Cheng, Y.-F. (2014). Assessment of Capacity Charges for Shared-Use Rail Lines. *Transportation Research Record: Journal of the Transportation Research Board*, *2448*, 62–70. https://doi.org/10.3141/2448-08

Levy, S., Peña-Alcaraz, M., Prodan, A., & Sussman, J. M. (2015). Analyzing financial relationship between railway industry players in shared railway systems. *Transportation Research Record: Journal of the Transportation Research Board*, *2475*, 27–36. https://doi.org/10.3141/2475-04

Nash, C. (2005). Rail infrastructure charges in Europe. *Journal of Transport Economics and Policy*, *39*(3), 259–278. https://doi.org/10.2307/20053968

Sánchez-Borràs, M., & Al, L.-P. et. (2011). Rail infrastructure charging systems for high-speed lines in Europe. *Transport Reviews*, *31*(1), 49–68. https://doi.org/10.1080/01441647.2010.489340

Sánchez-Borràs, M., Nash, C., Abrantes, P., & López-Pita, A. (2010). Rail access charges and the competitiveness of high speed trains. *Transport Policy*, *17*(2), 102–109. https://doi.org/10.1016/j.tranpol.2009.12.001

Steer Davies Gleave. (2017). *High Desert Corridor: Investment Grade Ridership and Revenue Forecasts*. Retrieved from http://www.xpresswest.com/pdf/HDC RR Forecasting - Executive Summary 2016.pdf

Tsamboulas, D., & Kopsacheili, A. (2004). Rail Access Pricing for Suburban Services in Europe.

Transportation Research Record: Journal of the Transportation Research Board, *1872*(1), 28–36. https://doi.org/10.3141/1872-04

Urban, S. on H.-S. R. S. of the C. on P. T. of the. (1985). High-Speed Rail Systems in the United States. *Journal of Transportation Engineering*, *111*(2), 79–94.

US Code Title. (2011). https://doi.org/10.1007/s00253-005-1916-3

Vidaud, M., & Tilière, G. De. (2010). Railway access charge systems in Europe. In *10th Swiss Transport Research Conference-STRC*.

VR Group (2018). Passenger Service. Retrieved from: https://www.vrgroup.fi/en/vrgroup/vr-group/

Zarembski, A. M. (1993a). Determining the Cost of Track Maintenance. *Railway Track and Structures*, (April).

Zarembski, A. M. (1993b). Track Maintenance Costing : Alternative Approaches.

Zarembski, A. M., & Cikota Jr., J. F. (2008). Estimating maintenance costs for mixed high-speed passenger and freight rail corridors: A new tool for rail planners. *TR News*, (255).

Zarembski, A. M., & Patel, P. (2010). Estimating Maintenance Costs for Mixed Higher Speed Passenger and Freight Rail Corridors. In *2010 Joint Rail Conference. American Society of Mechanical Engineers* (pp. 383–393).

December 2018

CURRICULUM VITAE

Sameeksha Sapkota

4505 S. Maryland Parkway

Las Vegas, Nevada 89154

Email: sameekshasapkota@gmail.com

Education:

Bachelor of Engineering in Civil Engineering, February 2016

Institute of Engineering, Tribhuvan University, Nepal

Thesis Title:

Calculation of Access Charge for High Speed Rail XpressWest of Nevada

Thesis Examination Committee:

Dr. Jin Ouk Choi (Advisory Committee Chair)

Dr. Hualiang (Harry) Teng (Advisory Committee Member)

Dr. Mohamed Kaseko (Advisory Committee Member)

Dr. Jaewon Lim (Graduate College Representative)