1. Report No. RailTEAM UNLV-2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle High Speed Rail Access Charge for the Xpresswest of Nevada		5. Report Date September 30, 2024 6. Performing Organization Code:
7. Author(s) Sameeksha Sapkota, Komal Sree Teja Boyapati, JinOuk Choi https://orcid.org/0000-0003-3212-2304 and Mohamed Kaseko https://orcid.org/0000-0003-4608-7757		8. Performing Organization Report No. UNLV-2
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Nevada, Las Vegas 4505 S. Maryland Pkwy. Las Vegas, NV 89154		10. Work Unit No. 11. Contract or Grant No. 69A3551747132
12. Sponsoring Agency Name and Address Office of Research, Development and Technology (RD&T) US Department of Transportation 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The study was done in two parts. Part 1 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

Part 2 developed a framework for the analysis of train operations including the impact of incidents on the operations and determining access charges for a shared HSR system using VISSIM traffic simulation software. The California High-Speed Rail (CHSR), which is currently under construction, is used as a case study to analyze a potentially shared corridor from Palmdale to Los Angeles. XpressWest, a HSR system that plans to connect Las Vegas with Los Angeles through Palmdale, plans to utilize the CHSR network from Palmdale to Los Angeles for the California part of its operations. This study develops a VISSIM simulation model for analysis of train operations and evaluation of the impact of XpressWest operations on CHSR operations. The study also calculates what should be the access charges that may be levied to XpressWest for the right to operate on that part of the network. levied. Thus, a framework to calculate access charges for the shared CHSR corridor was developed in the study. The analysis of train operations showed that the XpressWest can operate together with the planned operations of the CHSR on the shared corridor without causing any additional congestion for normal operations. Access charge pricing for the operation and maintenance of the Palmdale - Burbank corridor was calculated to be $16.47 per train-mile. A separate estimate is made for fees to be charged for each incident caused by XpressWest.

17. Key Words Shared high speed rail, train operation scenarios, access charge, railroad operation simulation	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161. http://www.ntis.gov		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 168	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

USDOT Tier 1
University Transportation Center
on Improving Rail Transportation
Infrastructure Sustainability and Durability

Final Report UNLV-2

HIGH SPEED RAIL ACCESS CHARGE FOR THE XPRESSWEST OF NEVADA

By

Sameeksha Sapkota, Graduate Student

Komal Sree Teja Boyapati, Graduate Student

JinOuk Choi, Ph.D. Associate Professor

and

Mohamed Kaseko, Ph.D. Associate Professor

Department of Civil & Environmental Engineering and Construction,
University of Nevada Las Vegas

September 30, 2024

Grant Number: 69A3551747132

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation's University Transportation Centers Program. However, the U.S. Government assumes no liability for the contents or use thereof.

Executive Summary

Shared High-Speed Rail (HSR) networks are networks where two or more railway operators use the same railway network infrastructure for train operations. The train operations in the shared HSR network can be composed of different types of trains operating at different speeds with varying stops at stations in a network. The interactions between different types of trains in the shared HSR network depends on the characteristics of the network's infrastructure and train operations and affect the capacity of the network. When a rail operator who owns the infrastructure allows other operators to access its infrastructure, the additional traffic will lead to an increase in the cost of operations and maintenance of the infrastructure. In such cases, it is common for the other operators to be required to pay a fee, generally referred to as "access charge". An access charge is a fee paid by a train operator to the owner of the infrastructure to compensate for the increased expenditure and other impacts of additional traffic such as additional delays due to congestion and incidents.

The study was done in two parts. Part 1 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

Part 2 developed a framework for the analysis of train operations including the impact of incidents on the operations and determining access charges for a shared HSR system using VISSIM traffic simulation software. The California High-Speed Rail (CHSR), which is currently under construction, is used as a case study to analyze a potentially shared corridor from Palmdale to Los Angeles. XpressWest, a HSR system that plans to connect Las Vegas with Los Angeles through Palmdale, plans to utilize the CHSR network from Palmdale to Los Angeles for the California part of its operations. This study develops a VISSIM simulation model for analysis of train operations and evaluation of the impact of XpressWest operations on CHSR operations. The study also calculates what should be the access charges that may be levied to XpressWest for the right to operate on that part of the network. levied. Thus, a framework to calculate access charges for the shared CHSR corridor was developed in the study. The analysis of train operations showed that the XpressWest can operate together with the planned operations of the CHSR on the shared corridor without causing any additional congestion for normal operations. Access charge pricing for the operation and maintenance of the Palmdale - Burbank corridor was calculated to be $16.47 per train-mile. A separate estimate is made for fees to be charged for each incident caused by XpressWest.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

PART 1

CALCULATION OF ACCESS CHARGE FOR HIGH SPEED RAIL XPRESSWEST OF NEVADA

By

Sameeksha Sapkota
JinOuk Choi

PART 1: ABSTRACT

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.

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.

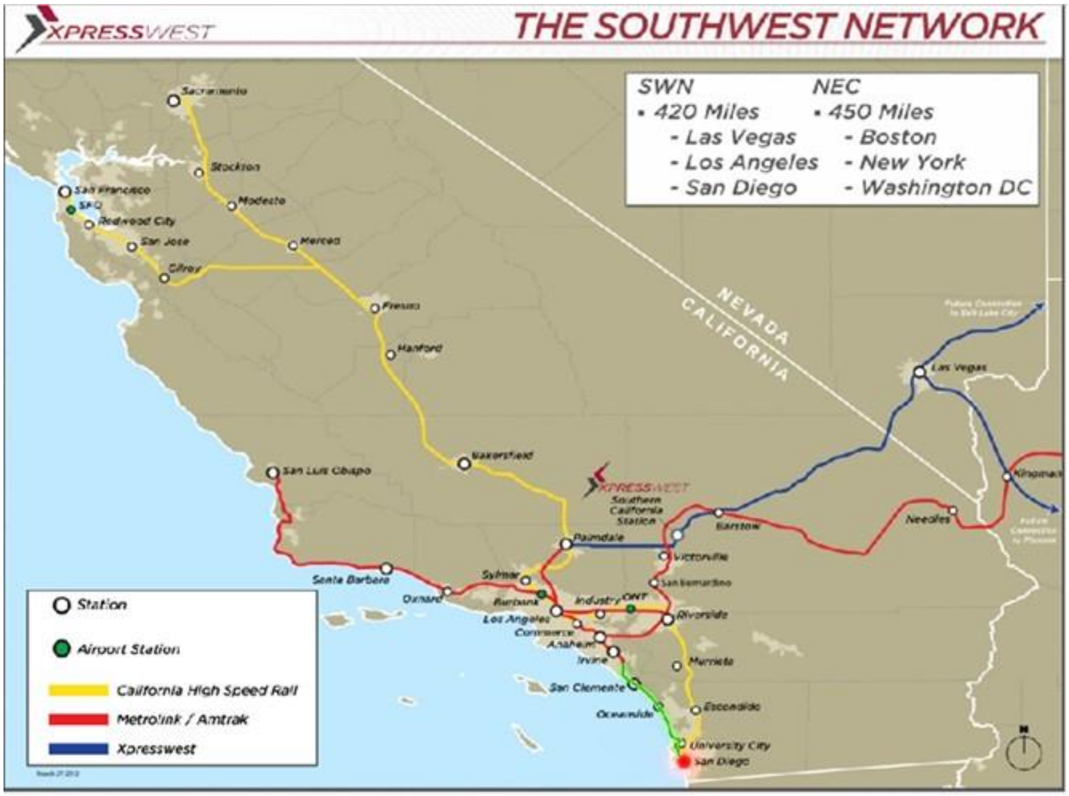


Figure 1: Connection between California high speed rail (yellow line) and XpressWest of Nevada (blue line)

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 include 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)

b. 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:

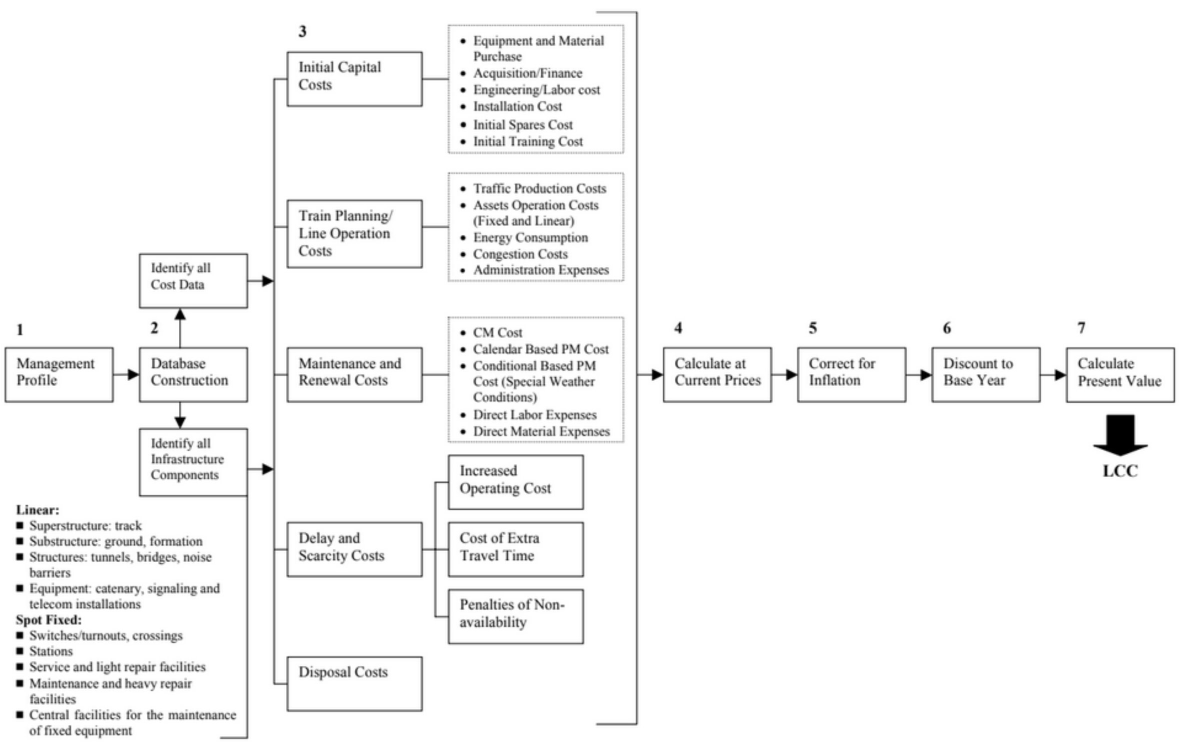


Figure 2: LCCA Formulation by Tsamboulas & Kopsacheili (2004)

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

TPFinal = f(POperation, PInfrastructure Damage, PPath Allocation, PAdditional osts) (1)

where, TPFinal = Total Access Charge
POperation = Train Operation Cost
PInfrastructure Damage = Maintenance Cost
PPath Allocation = Cost related to priority and quality of service
PAdditional Costs = Energy Consumption and Station Cost

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

TPBasic = POperation * FQuality + PInfrastructureDamage (2)

where, TPBasic = Total Access Charge
POperation = Train Operation Cost
PInfrastructure Damage = Maintenance Cost
FQuality = 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:

POperation = MCOperation * L1 * L2 .(3)

where,
POperation = Train Operation Cost
MCOperation = Marginal Cost of Train Operation
= Sum of telecommunications, control and command, planning and overhead costs
L1 = Speed Coefficient = (line speed/ train speed)
L2 = 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:

PInfrastructure Damage = MCInfrastructure Damage = dC/Dy (4)

Where C = f (lnY + 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).

c. 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:

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

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:

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

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.

d. 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.

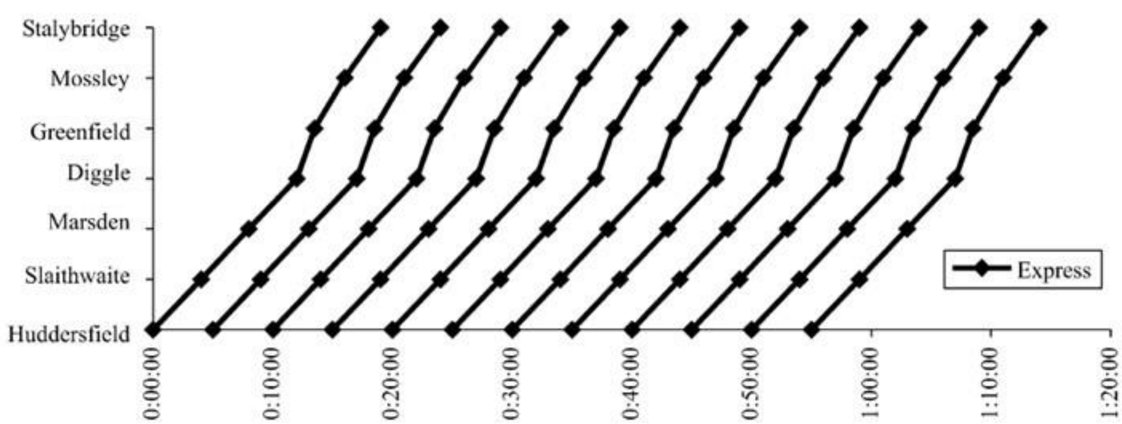


Figure 3: Theoretical capacity allocation of uniform trains between Huddersfield and Stalybridge by Johnson & Nash (2008)

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.

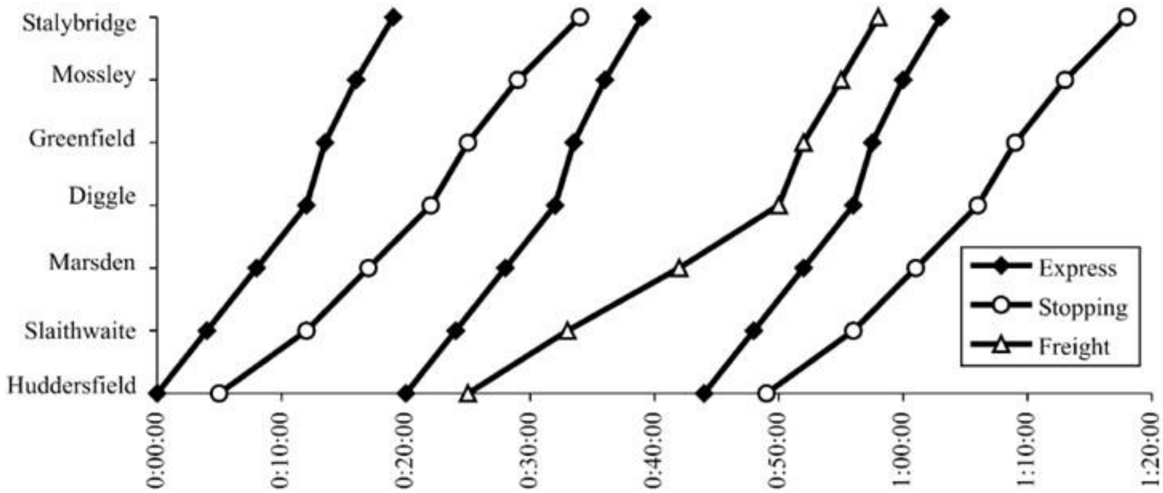


Figure 4: Theoretical capacity allocation of non-uniform trains between Huddersfield and Stalybridge by (Johnson & Nash, 2008)

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 adopted the method of allocation model to determine the access charge for XpressWest of Nevada. The study will collect historical data and 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 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:

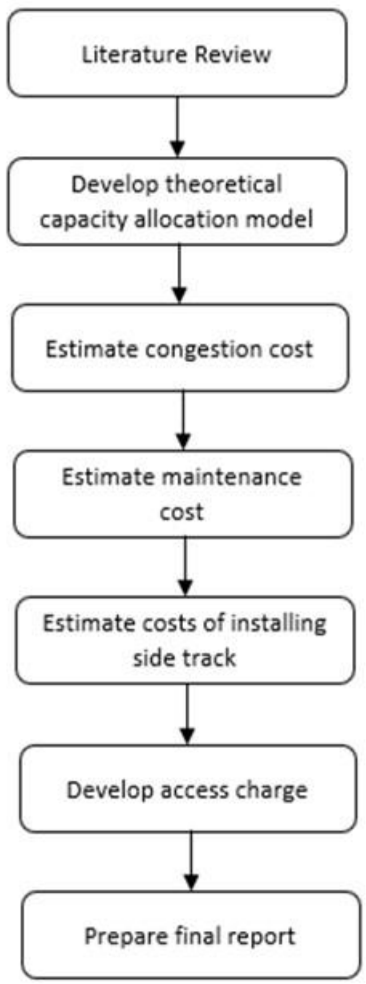


Figure 5: General Outline of Methodology

3.2: Literature Review

The study conducted a literature review to identify a problem and gap in existing literature. The study researched 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 the 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:

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

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:

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

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 the 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).

3.8: 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:

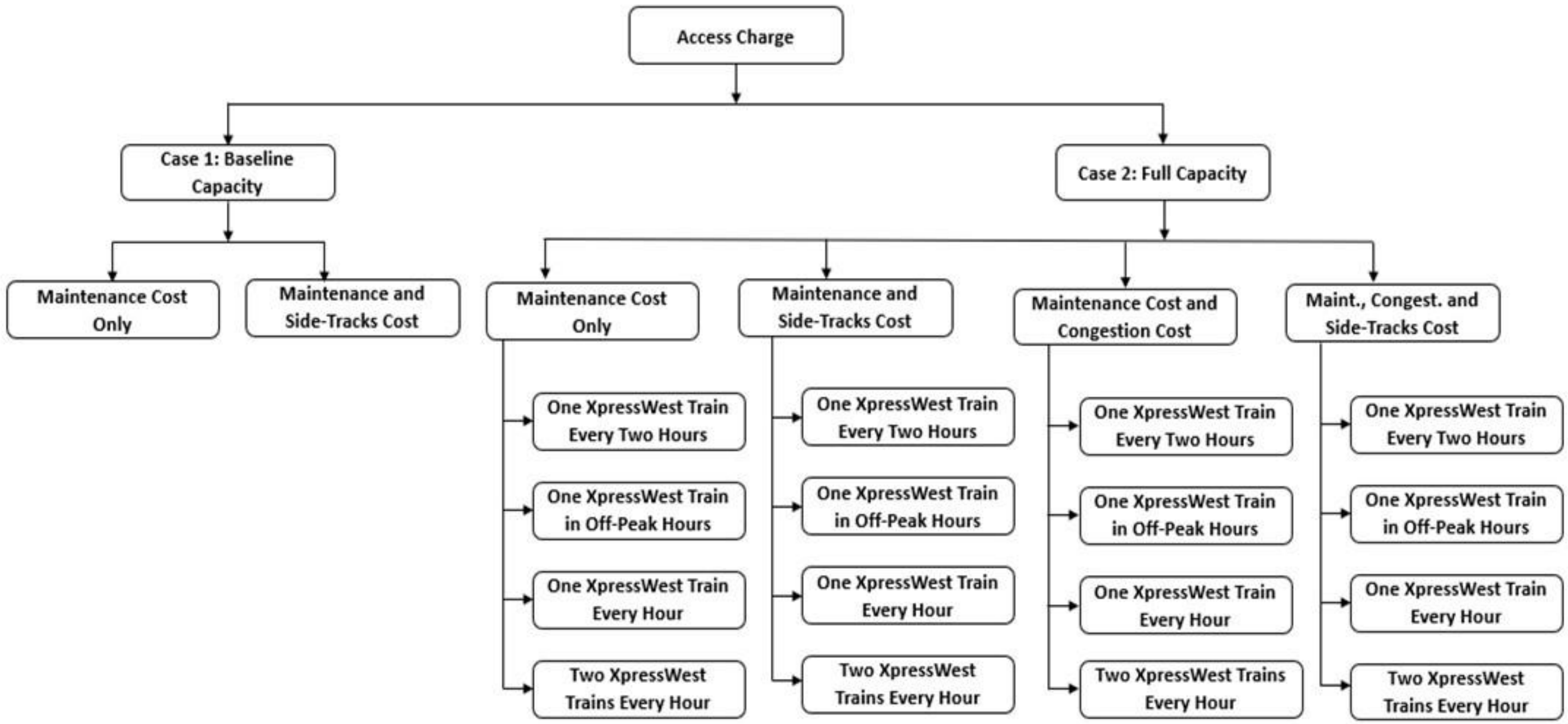


Figure 6: General Outline for Calculation of Access Charge

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:

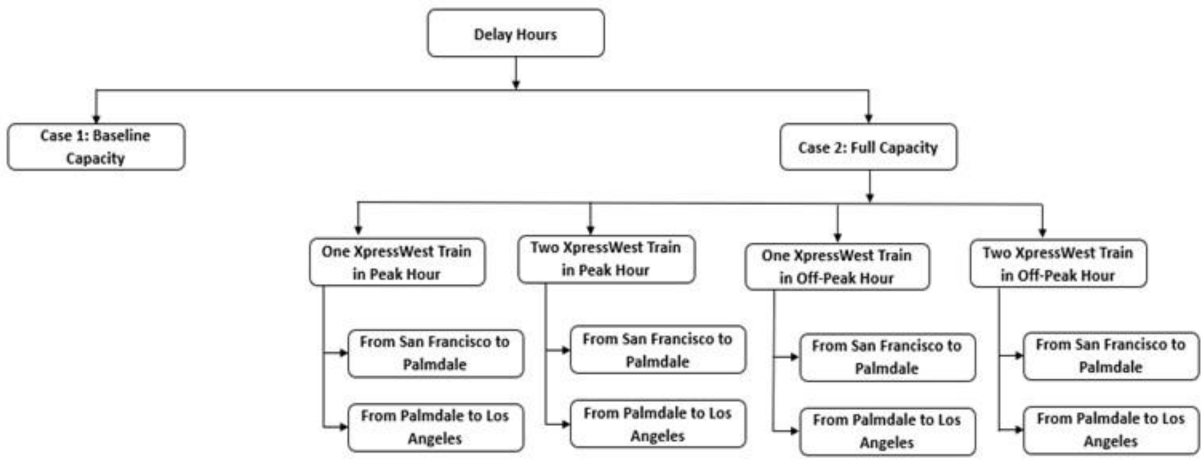


Figure 6: General Outline for Calculation of Delay Hours

4.2: 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 the figure below. 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.

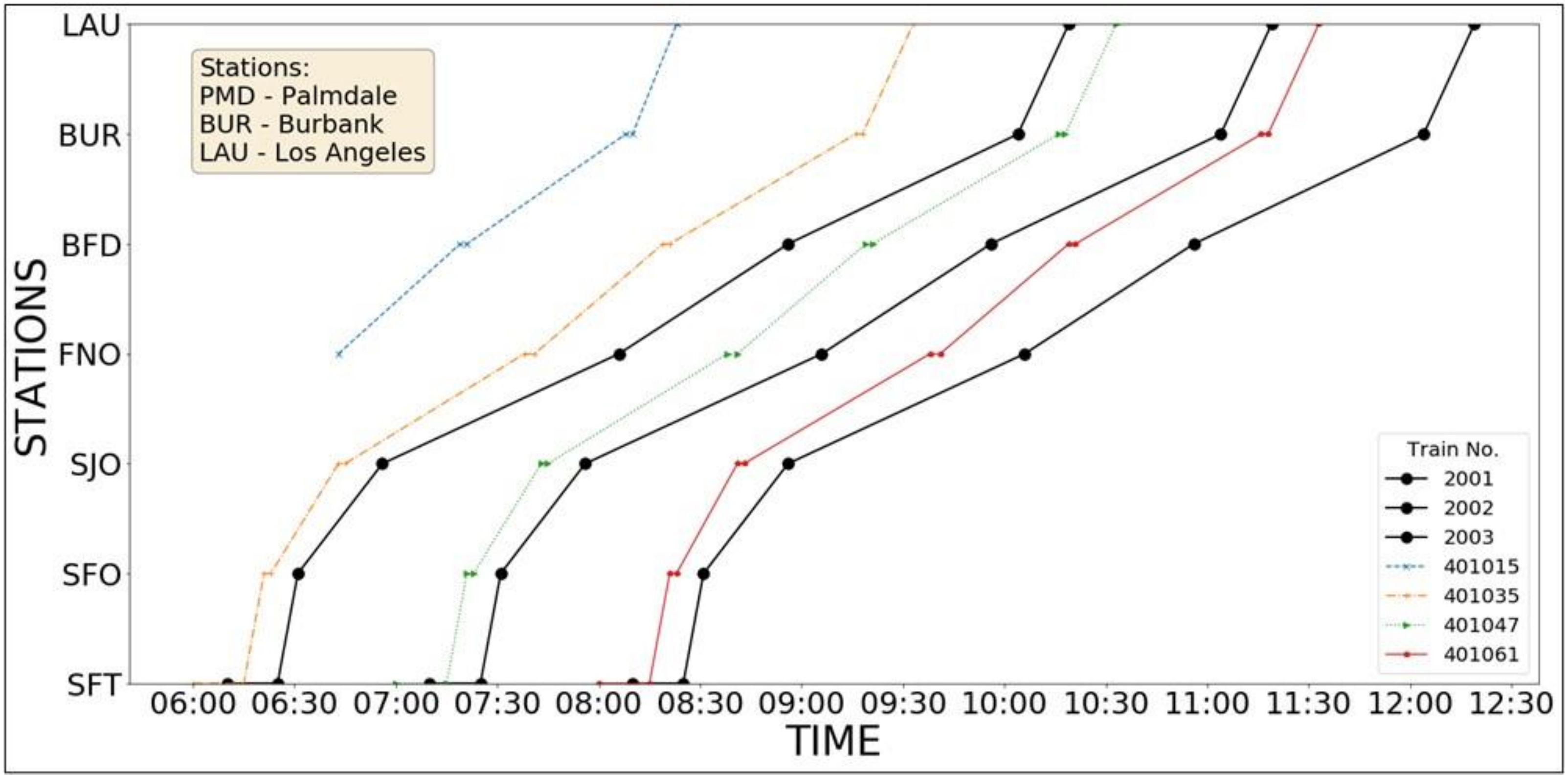


Figure 7: Capacity Allocation Model for Baseline Capacity

4.3: 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 the theoretical 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:

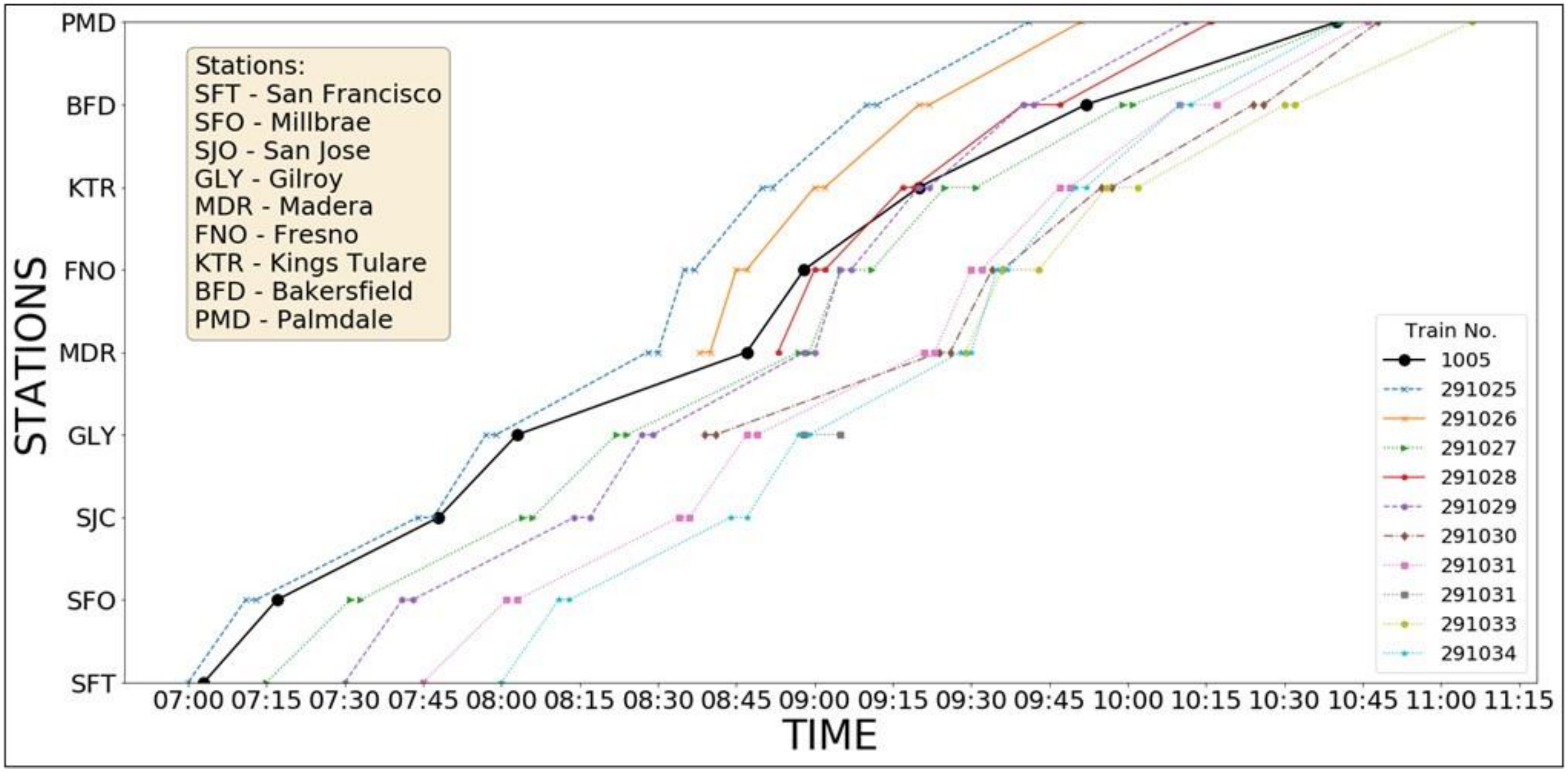


Figure 8: Capacity Allocation Model for Full Capacity from 7:00 AM to 8:00 AM with 1 XpressWest Train from San Francisco to PalmdaleFrom Palmdale to Los Angeles

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:

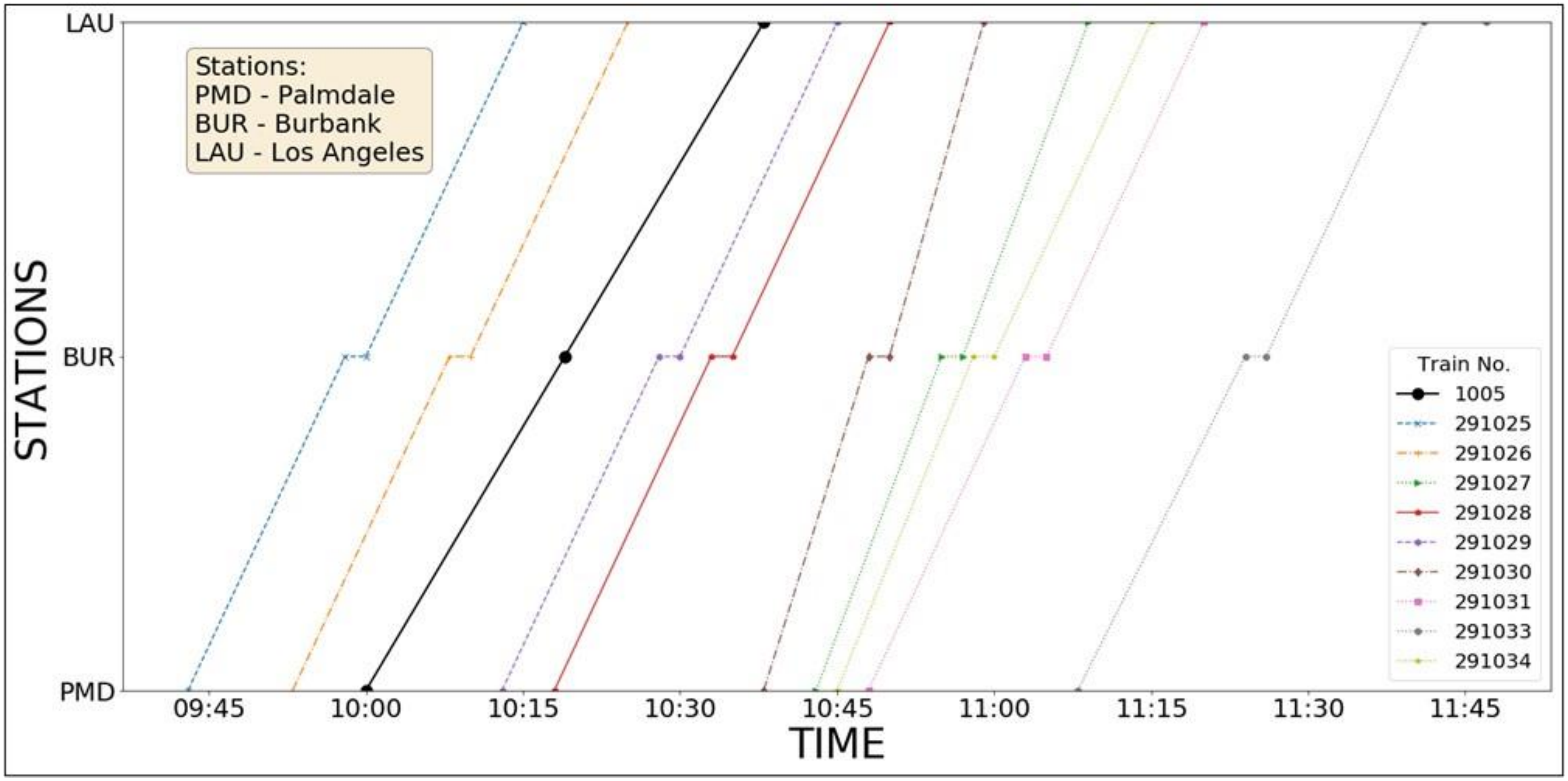


Figure 9: Capacity Allocation Model for Full Capacity 7:00AM to 8:00AM with 1 XpressWest Train from Palmdale to Los Angeles
Scenario 2: Two XpressWest Train in Peak One Hour

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	
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:

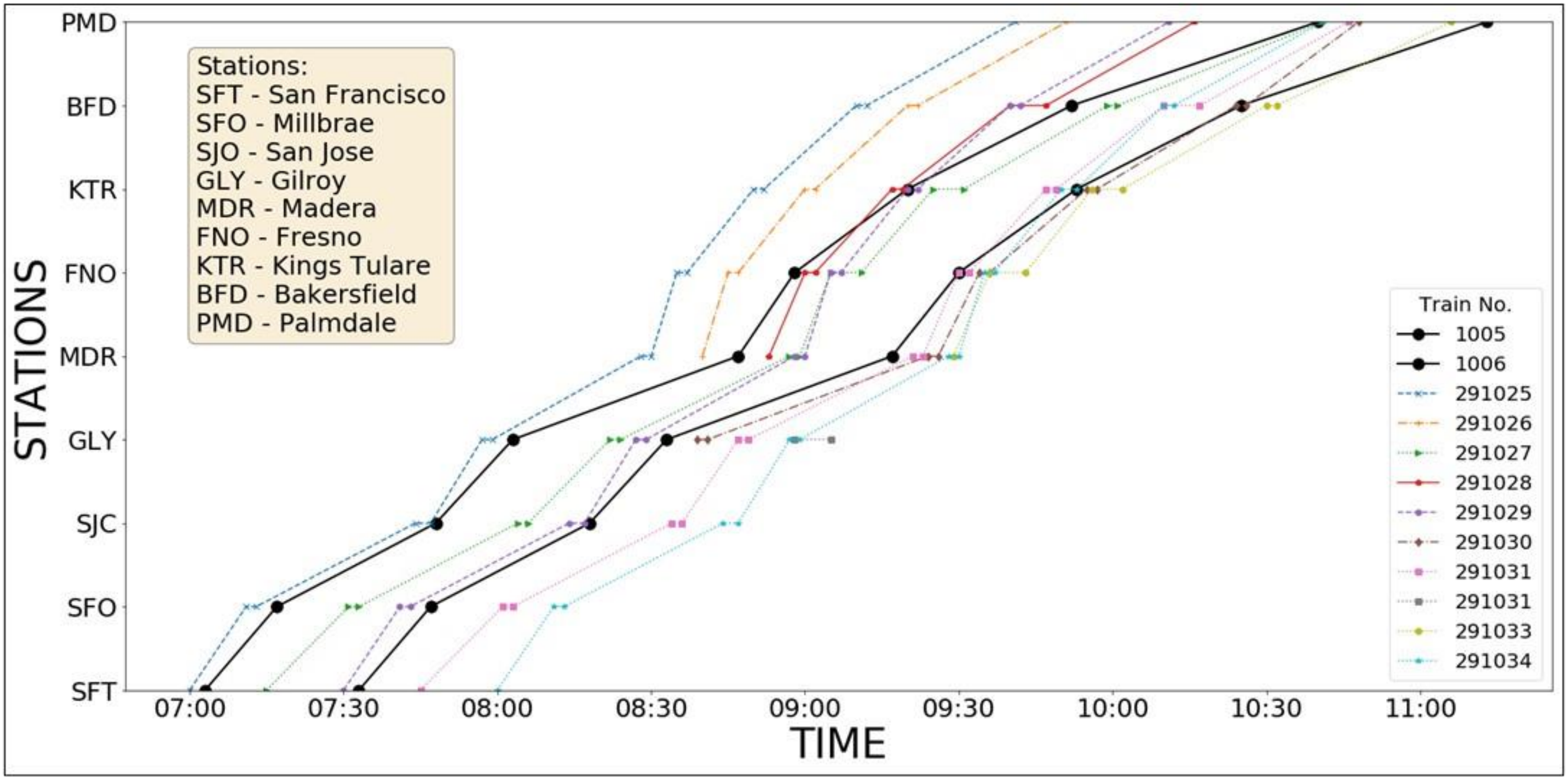


Figure 10: Capacity Allocation Model for Full Capacity 7:00AM to 8:00AM with 2 XpressWest Train from San Fransisco to PalmdaleFrom Palmdale to Los Angeles

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:

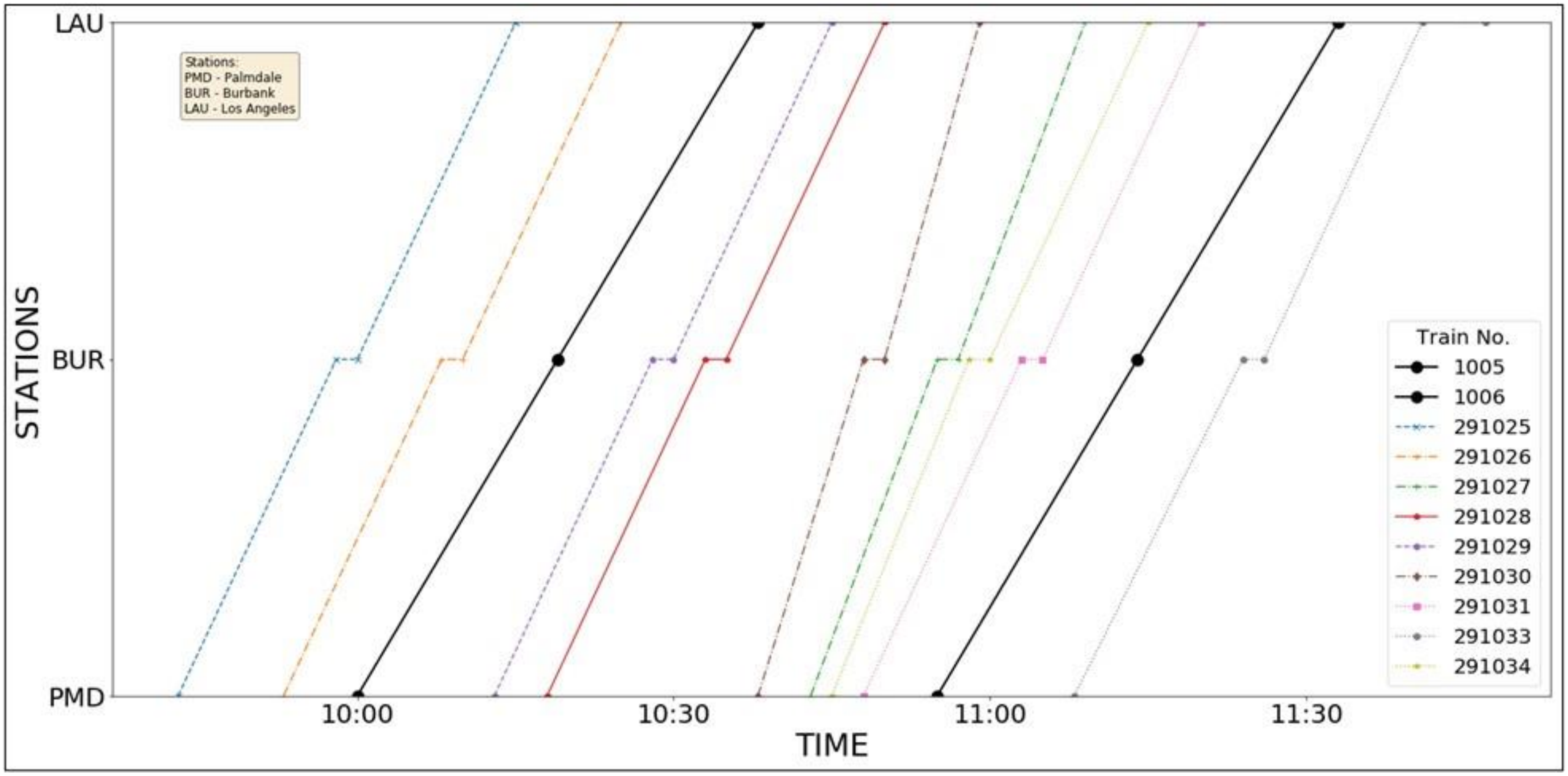


Figure 11: Capacity Allocation Model for Full Capacity 7:00 AM to 8:00 AM with 2 XpressWest Train from Palmdale to Los Angeles

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 Time	CAHSR	Adjusted Time	CAHSR	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:

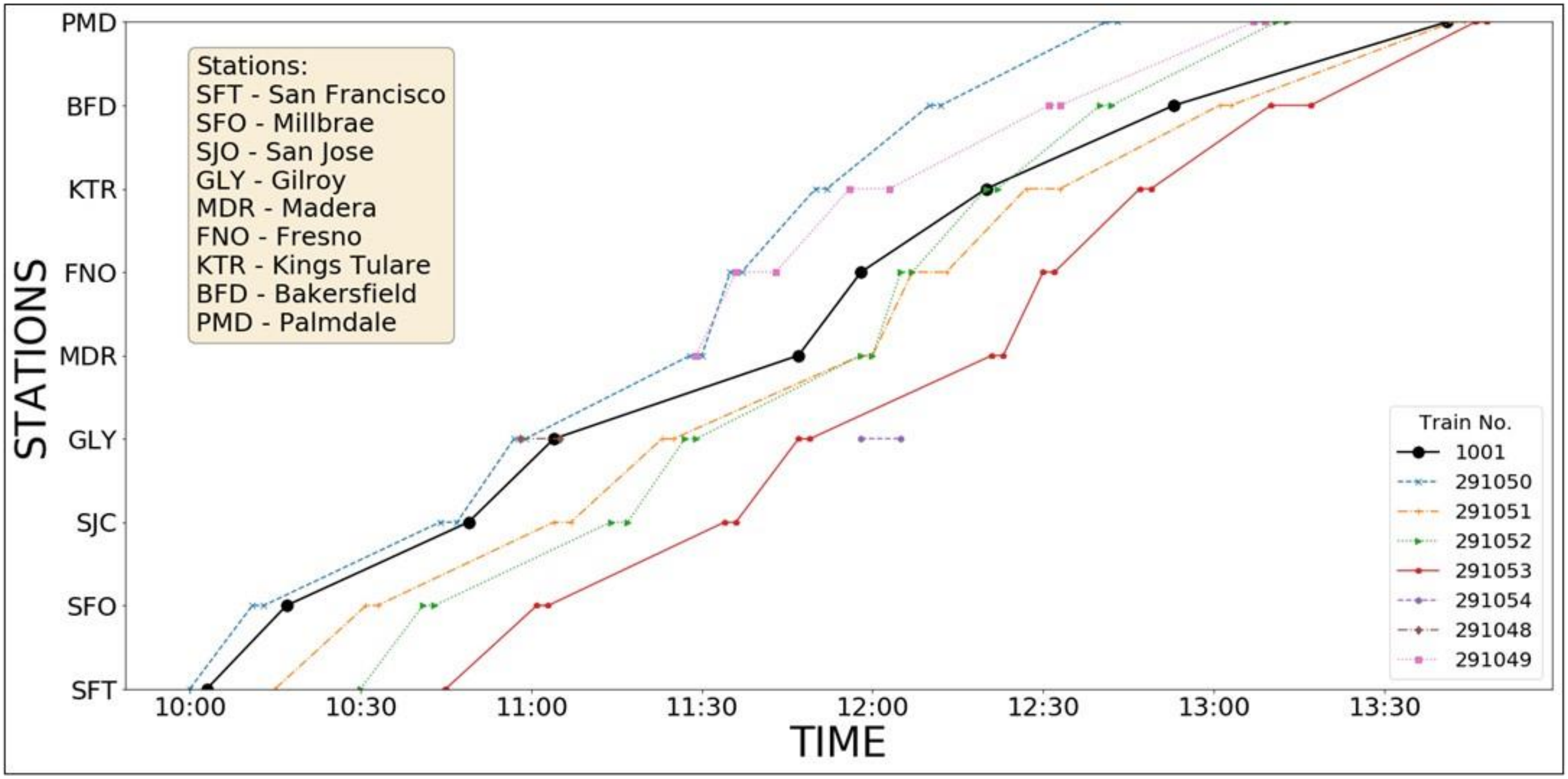


Figure 12: Capacity Allocation Model for Full Capacity 10:00AM to 11:00AM with 1 XpressWest Train from San Francisco to PalmdaleFrom Palmdale to Los Angeles

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:

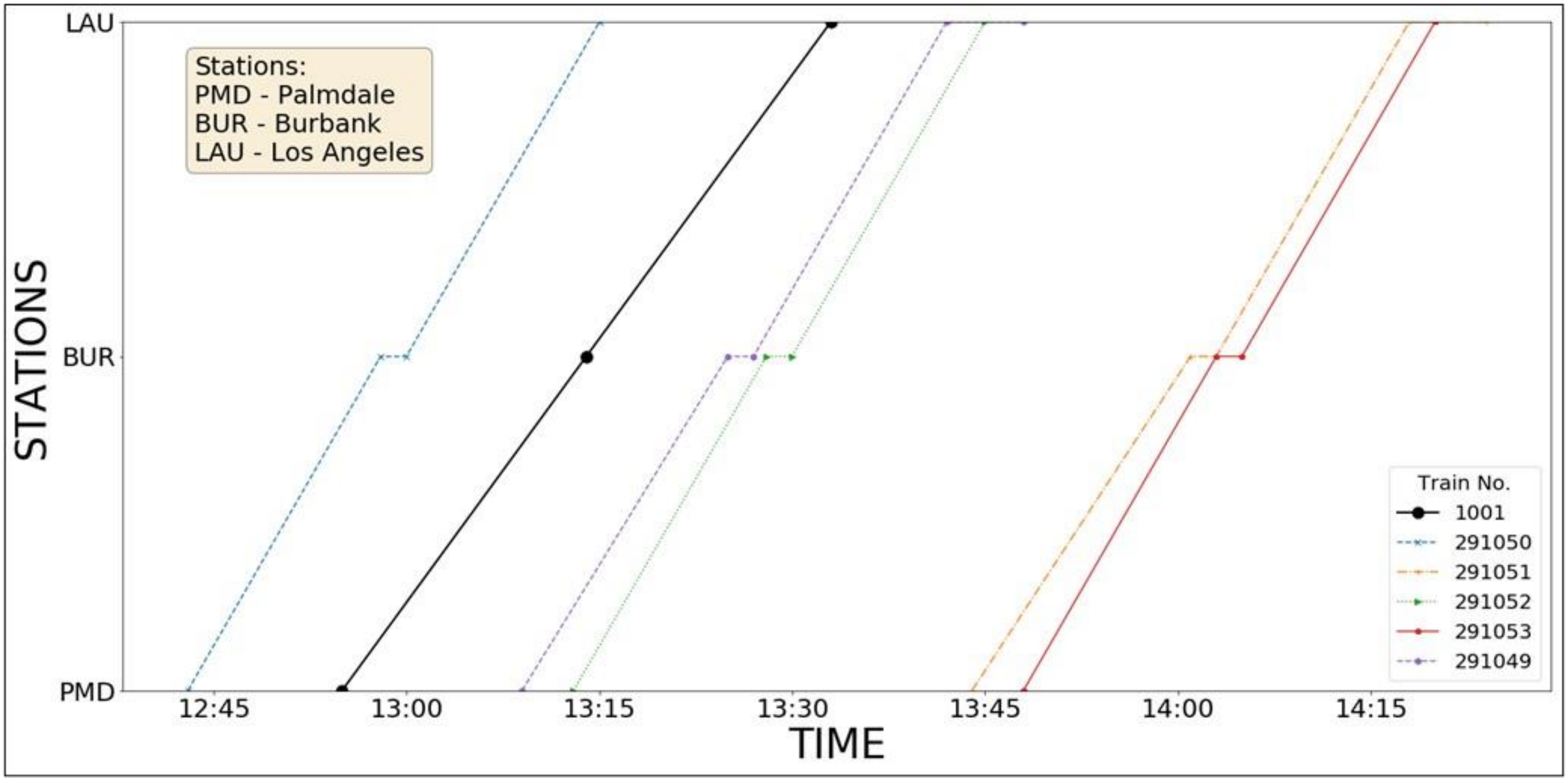


Figure 13: Capacity Allocation Model for Full Capacity 10:00 AM to 11:00 AM with 1 XpressWest Train from Palmdale to Los Angeles

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:

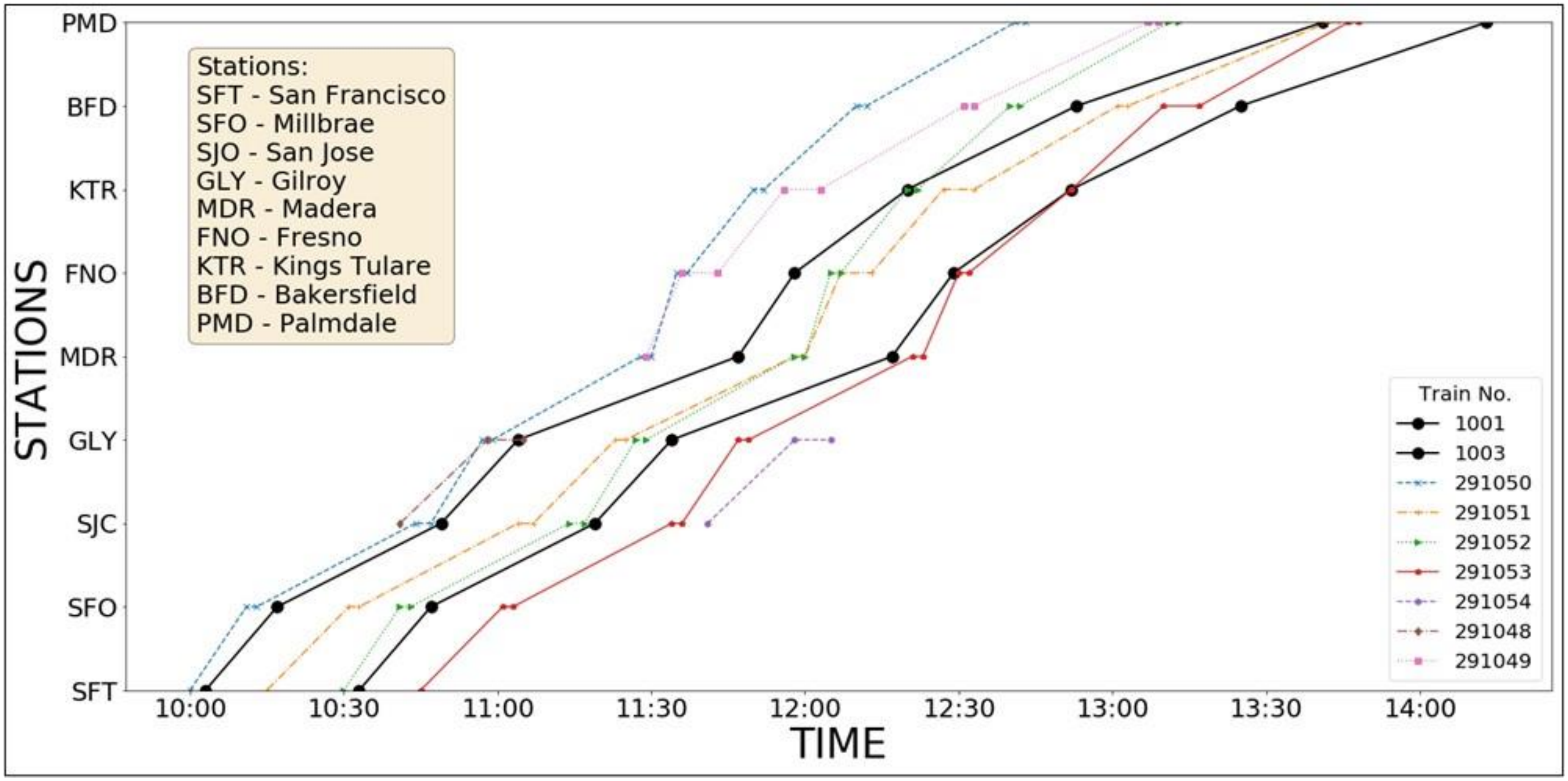


Figure 14: Capacity Allocation Model for Full Capacity 10:00 AM to 11:00 AM with 2 XpressWest Trains from San Francisco to PalmdaleFrom Palmdale to Los Angeles

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:

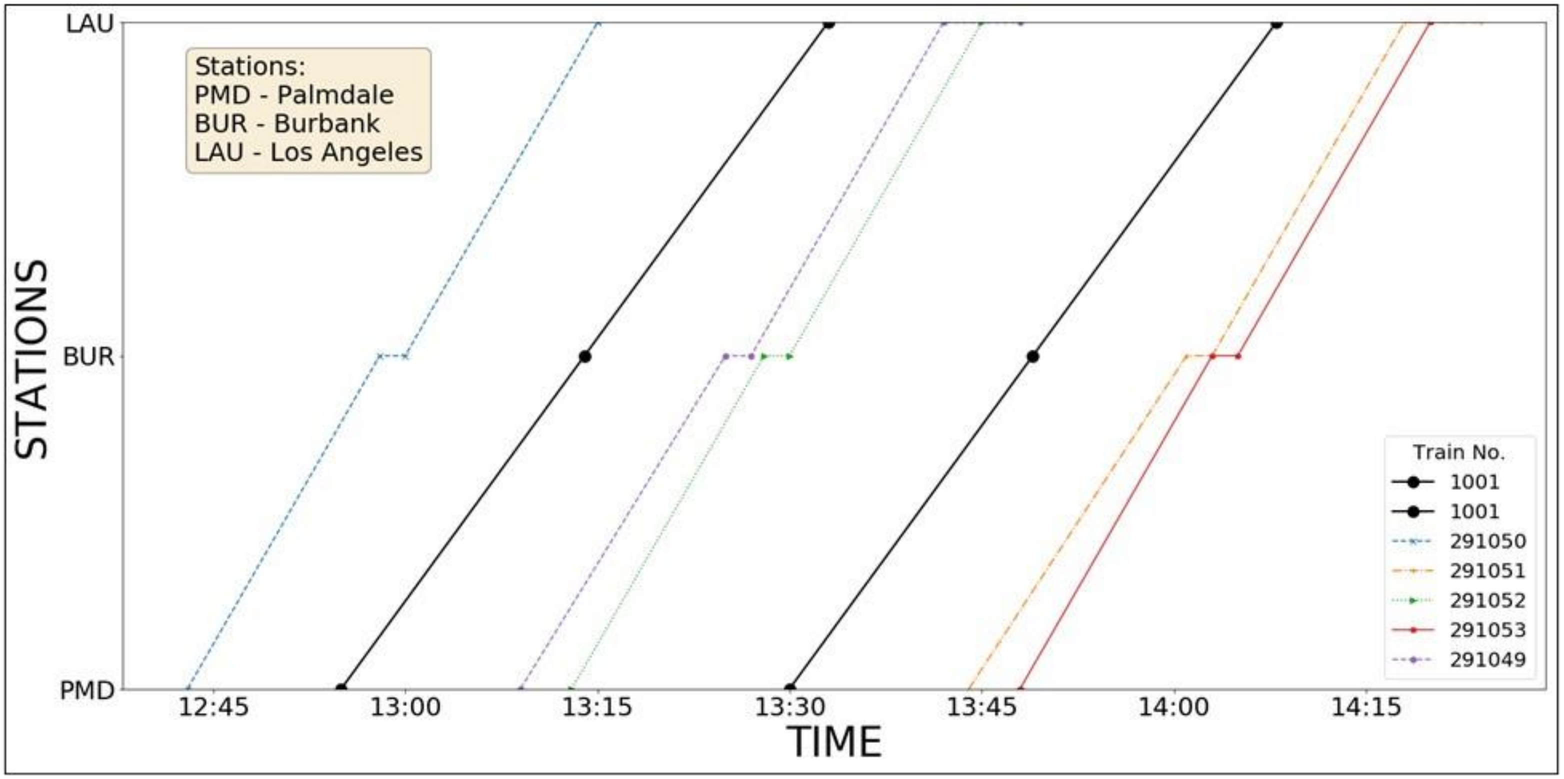


Figure 15: Capacity Allocation Model for Full Capacity 10:00AM to 11:00AM with 2 XpressWest Trains from Palmdale to Los Angeles

4.4: 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

4.5: Estimating Congestion Cost

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

From methodology,

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

4.6: 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 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
	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
	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

Country	Year	Inflation Rates (annual %)	Cost
	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

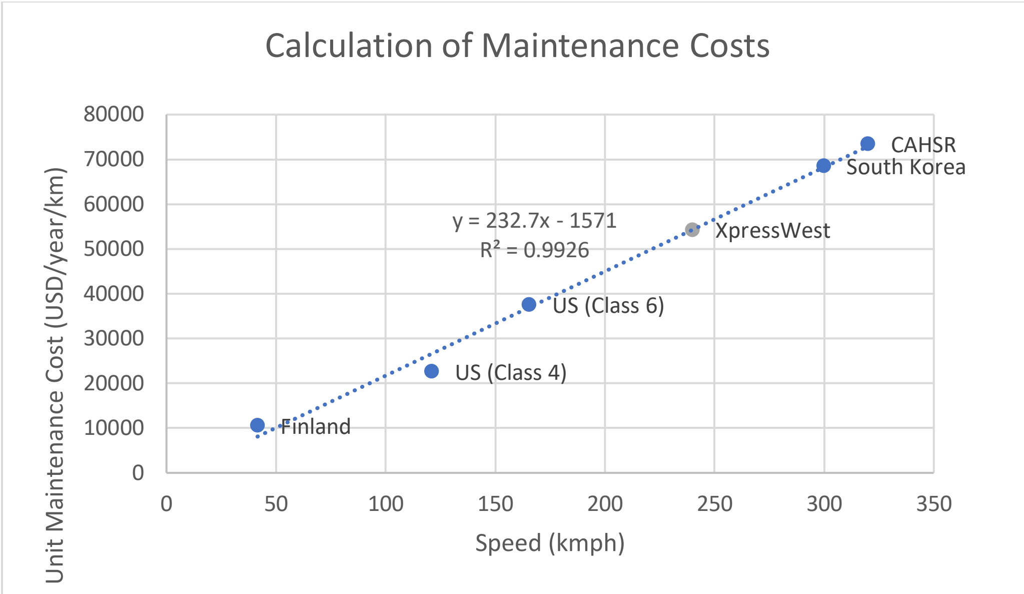


Figure 16: Calculation of Maintenance Cost by Unit Maintenance Cost VS Speed

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

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

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)

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

For XpressWest,

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

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

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

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

4.7: 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

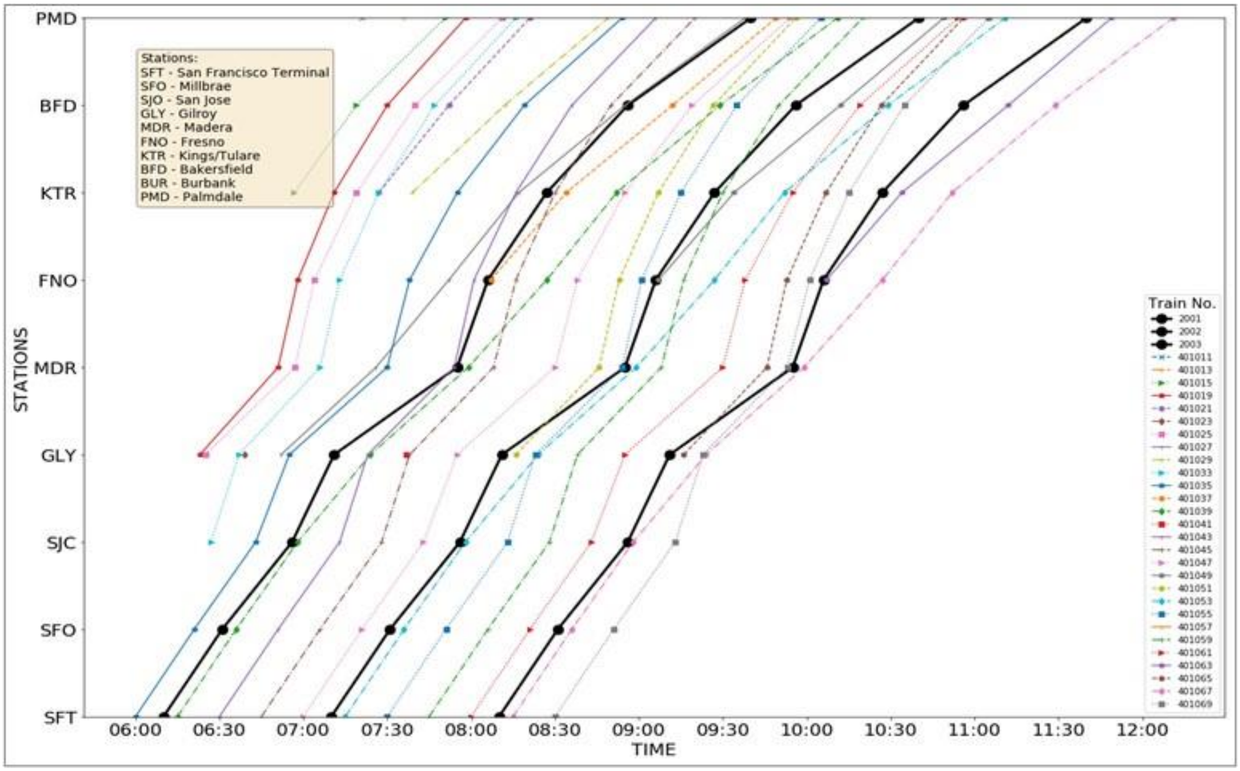


Figure 17: Calculation of Number of Side Tracks Using Baseline Capacity

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

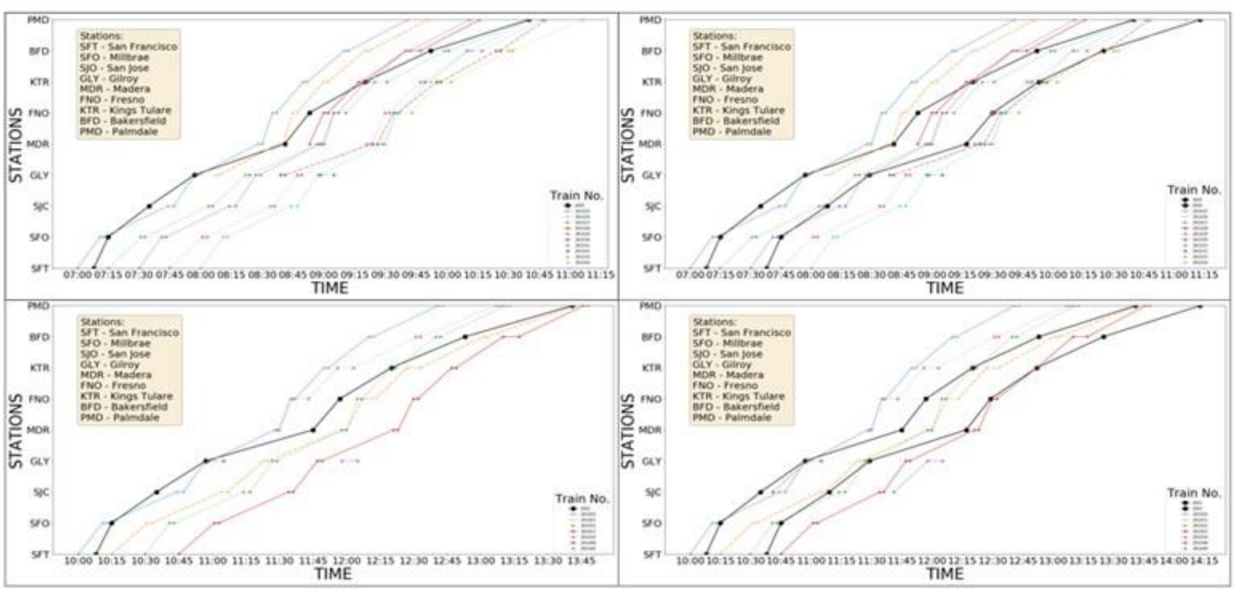


Figure 18: Calculation of Number of Side Tracks Using Full Capacity

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

4.8: 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

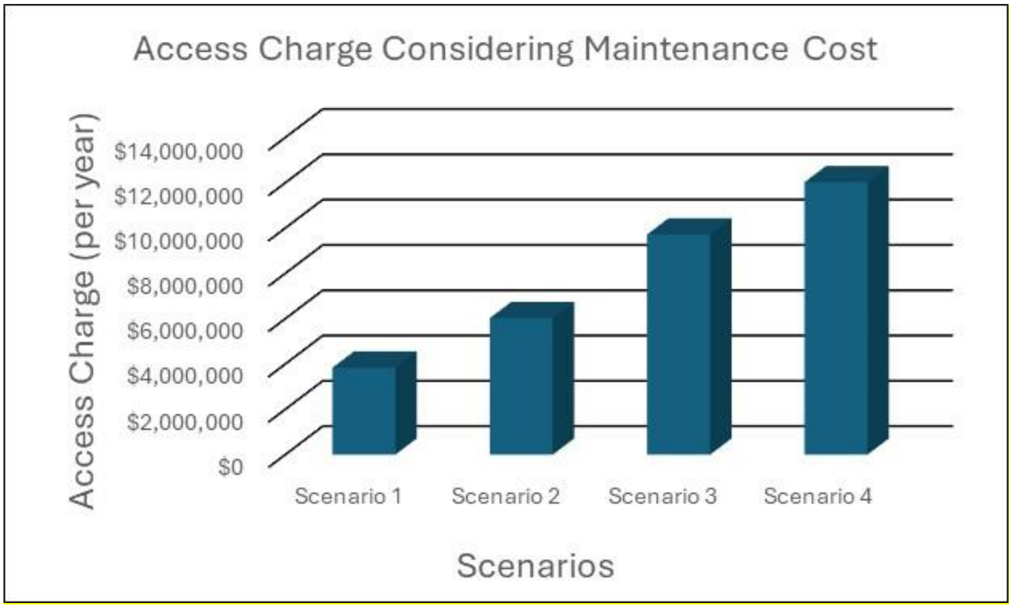


Figure 19: Calculation of Access Charge for Full Capacity Considering Maintenance Cost Only

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
4	2 Trains Every Hour	$12,027,780 / year	$112,362,000

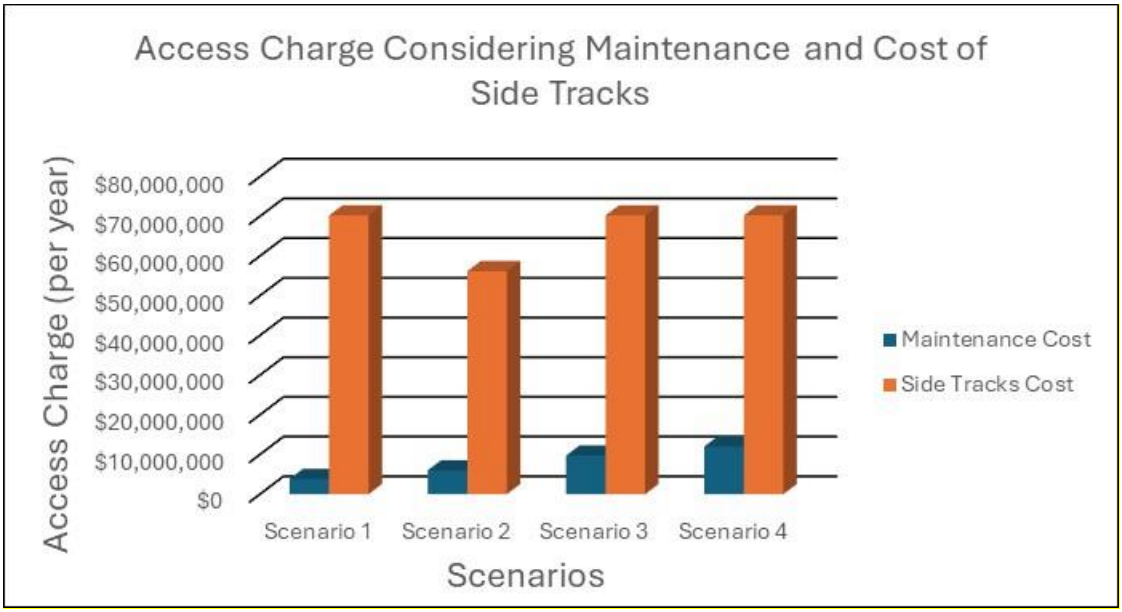


Figure 20: Calculation of Access Charge for Full Capacity Considering Maintenance Cost and Cost of Installing Side Tracks

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

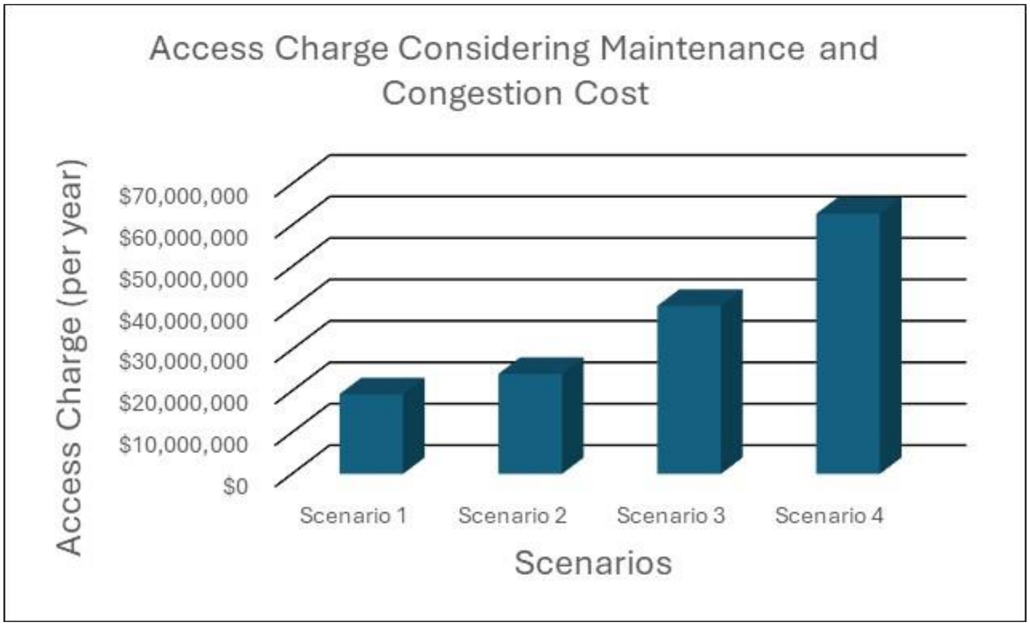


Figure 21: Calculation of Access Charge for Full Capacity Considering Maintenance and Congestion Costs

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

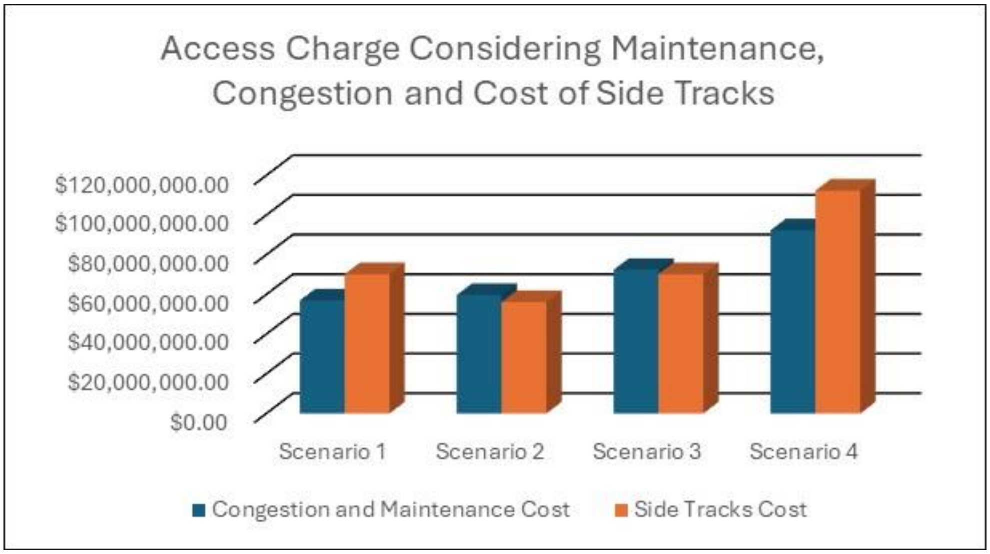


Figure 22: Calculation of Access Charge for Full Capacity Considering Maintenance, Congestion Costs and Cost of Installing Side-Tracks

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 the 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 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 providing a framework for the calculation of access charge in mixed flow passenger train operations. The need and of HSR is rising in the 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

1. 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
2. CAHSR. (2012). California High-Speed Train Project Design Criteria.
3. CAHSR. (2018a). 2018 Business Plan.
4. CAHSR. (2018b). Capital Cost Estimate Report.
5. CAHSR. (2018c). Operations and Maintenance Cost Forecasting.
6. CAHSR. (2018d). Service Planning Methodology Report.
7. 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
8. 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
9. 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
10. 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
11. 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
12. Korail (2013). Korail Info. Retrived from: http://www.letskorail.com/ebizbf/EbizbfForeign_pr16100.do;jsessionid=WaaZ1EmJwYgCAa1uPSUW4ggzZ0nyWQL4hGjvKe9V4KaZ8n1E0Mf9sysryp1JcyN6?gubun=1
13. Korea Train eXpress (KTX): Case Study. (2017).
14. 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
15. 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
16. Nash, C. (2005). Rail infrastructure charges in Europe. *Journal of Transport Economics and Policy*, *39*(3), 259–278. https://doi.org/10.2307/20053968
17. 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
18. 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
19. 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
20. 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
21. 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.
22. US Code Title. (2011). https://doi.org/10.1007/s00253-005-1916-3
23. Vidaud, M., & Tilière, G. De. (2010). Railway access charge systems in Europe. In *10th Swiss Transport Research Conference-STRC*.
24. VR Group (2018). Passenger Service. Retrieved from: https://www.vrgroup.fi/en/vrgroup/vr-group/
25. Zarembski, A. M. (1993a). Determining the Cost of Track Maintenance. *Railway Track and Structures*, (April).
26. Zarembski, A. M. (1993b). Track Maintenance Costing : Alternative Approaches.
27. 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).
28. 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).

PART 2 ANALYSIS OF HIGH-SPEED RAIL OPERATIONS USING VISSIM SIMULATION TO DETERMINE ACCESS CHARGES AND THE IMPACT OF INCIDENTS ON A SHARED NETWORK

By

Komal Sree Teja Boyapati, MSCE
Mohamed Kaseko, Associate Professor

Chapter 6: Part 2 Abstract

Shared High-Speed Rail (HSR) networks are networks where two or more railway operators use the same railway network infrastructure for train operations. The train operations in the shared HSR network can be composed of different types of trains operating at different speeds with varying stops at stations in a network. The interactions between different types of trains in the shared HSR network depends on the characteristics of the network's infrastructure and train operations and affect the capacity of the network. When a rail operator who owns the infrastructure allows other operators to access its infrastructure, the additional traffic will lead to an increase in the cost of operations and maintenance of the infrastructure. In such cases, it is common for the other operators to be required to pay a fee, generally referred to as "access charge". An access charge is a fee paid by a train operator to the owner of the infrastructure to compensate for the increased expenditure and other impacts of additional traffic such as additional delays due to congestion and incidents. The objective of this study is to develop a framework for the analysis of train operations including the impact of incidents on the operations and determining access charges for a shared HSR system using VISSIM traffic simulation software.

The California High-Speed Rail (CHSR), which is currently under construction, is used as a case study to analyze a potentially shared corridor from Palmdale to Los Angeles. XpressWest, a HSR system that plans to connect Las Vegas with Los Angeles through Palmdale, plans to utilize the CHSR network from Palmdale to Los Angeles for the California part of its operations. This study develops a VISSIM simulation model for analysis of train operations and evaluation of the impact of XpressWest operations on CHSR operations. The study also calculates what should be the access charges that may be levied to XpressWest for the right to operate on that part of the network. levied. Thus, a framework to calculate access charges for the shared CHSR corridor was developed in the study.

The analysis of train operations showed that the XpressWest can operate together with the planned operations of the CHSR on the shared corridor without causing any additional congestion for normal operations. Access charge pricing for the operation and maintenance of the Palmdale - Burbank corridor was calculated to be $16.47 per train-mile. A separate estimate is made for fees to be charged for each incident caused by XpressWest.

Chapter 7: Introduction

7.1: Background

7.1.1: High-Speed Rail and its Brief History

High-Speed Rail (HSR) is considered the fastest commercial ground transportation and is part of rail transport systems where the operational speeds of the trains exceed a certain speed limit. The train speeds that constitute HSR are different for different countries and railway organizations. Japan was the first country to build and operate HSR since 1964., Its HSR systems have operational speeds reaching up to 200 mph (Hornyak, n.d.). Significant decrease in travel times and high travel demand between Japan's interconnected cities contributed to the success of its HSR system and paved the way for HSR systems in the rest of the world.

The second country to inaugurate and introduce Europe to the HSR system was Italy in 1977 with operations speeds up to 155 mph by 1992 (Scordamaglia, 2015). France opened Europe's first dedicated HSR line in 1981 from Paris to Lyon with a maximum speed of 162 mph and prompted crucial development in Europe's HSR network (UIC, 2015). Germany and Spain launched their HSR sections in the early 1900s with their newer lines reaching up to 186 mph. Over time, comprehensive HSR networks were built in numerous European countries and as of the end-2017, Europe has 5,634 miles of HSR lines where speeds reach up to 199 mph with many cross-border international links (European Court of Auditors, ECA 2018).

In China, passenger dedicated HSR lines started operating in 2008 with a maximum speed of 217 mph and an average station-to-station speed of 149 mph (Ollivier et al., 2014). China's high population density, many well inter-spaced large cities, rapid urbanization, and economic development led to the swift expansion of its HSR system. By the end of 2017, China has opened 15,635 miles of HSR lines and is the largest and the most extensively used passenger dedicated HSR network in the world (Lawrence et al., 2019).

In the United States, a fully HSR line is yet to be built. The United States Code 49 U.S.C. § 26105 (2018), defines HSR as a rail transportation service that is "reasonably expected to reach sustained speeds of more than 125 mph". Under the definition, currently trains in two segments in Northeast Corridor (NEC), Boston, MA – New York City, NY, segment and New York City, NY – Washington, DC, segment reach a top speed of 150 mph and 135 mph respectively, and can be considered HSR service. In both segments, the top speeds are reached only in a small part of the segment and the average speed in the two segments is less than 85 mph. However, in 2009, the United States Congress during the Obama Administration proposed several new HSR corridors. (Peterman et al., 2013)

Figure 1-1 depicts the length of HSR lines in-operation, under-construction, planned, and in long-term planning for different countries. The data was obtained from a UIC, International Union of Railways 2020 report (UIC, 2020).

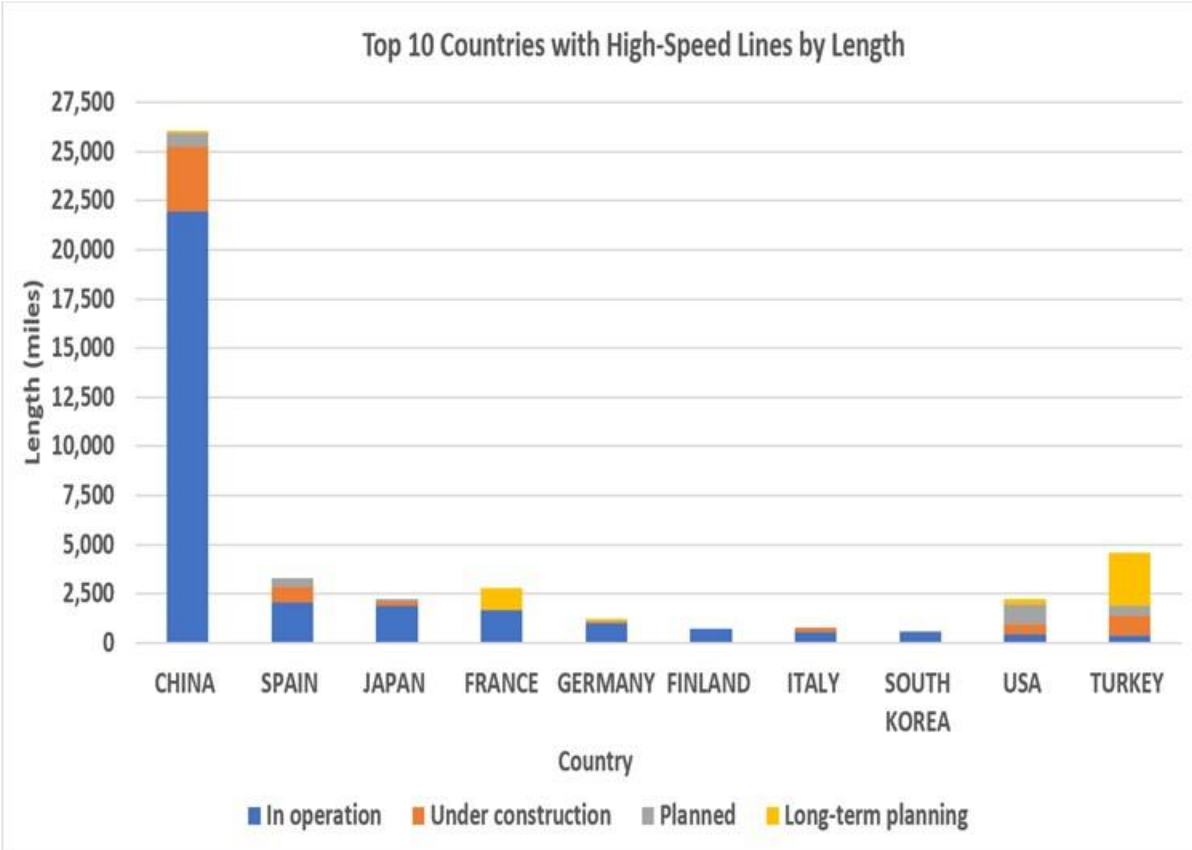


Figure 7-1: Top 10 Countries with High-Speed Lines by Length in the World (UIC, 2020)

It can be observed that China has more than 50 percent of the HSR lines in-operation compared with the HSR lines of the rest of the countries combined. The second country with the highest length of HSR lines in-operation is Spain followed closely by Japan. According to UIC, the USA has 457 miles of HSR lines in-operation which considers all of the NEC segment from Boston, MA to Washington, DC while only a small part of the segment being the HSR line. One project is under-construction which is the California High-Speed Rail and many other projects are planned which includes the XpressWest.

7.1.2: Shared HSR Systems

A shared HSR system is one where two or more rail operators use the same railway infrastructure. The sharing of infrastructure can be for full or partial segments of a network. There are several shared HSR network systems in the world with most of them in Europe. Operators can decide to share an HSR infrastructure due to several reasons. One of the reasons being when an operator is unable to build a new HSR track because of either high capital cost or due to geographical constraints, the operator can decide to share existing infrastructure owned by another operator. Shared HSR systems provide few benefits along with operational issues to the operators.

Shared HSR systems can be composed of different types of trains belonging to various operators that operate at different speeds with varying stops at stations. Based on the operating speed of the trains in the system, the trains can be divided into higher speed and relatively lower speed trains. A shared system's capacity, the total number of trains the system can operate in a unit time can depend on the composition of the number of higher-speed and lower-speed trains operating in the unit time. The speed of the trains that can travel at higher speeds trailing a lower speed train could be restricted to prevent the higher-speed train from catching up and colliding with the lower-speed train. A higher percent of low-speed trains in the shared system can decrease the system capacity (Yaghini et al., 2014). Usually, trains traveling with relatively higher speeds have a higher priority at stops and can overtake low-speed trains. Allowing overtaking between trains can decrease the overall passenger travel time in the system (Li et al., 2018). Depending on the characteristics of the shared HSR system's infrastructure such as the number of tracks, stations and stops, and train operations, the interactions between the higher-speed train and lower-speed trains differ and affect the capacity of the system accordingly (Abril et al., 2008). By understanding these interactions in a shared HSR system, train operations that are efficient and best suit the operators' needs can be devised.

7.1.3: Access Charges

Access charges are normally involved when two or more rail operators share the use of the same railway infrastructure. These charges are normally paid to the infrastructure manager and are designed to cover for operations and maintenance costs of the railway infrastructure, and often as well as the lifecycle capital costs. There are two alternate models for access charging that depend on the type of ownership of the infrastructure, namely

1. A government or private entity that owns or is responsible for maintenance and operation of the infrastructure, but does not itself conduct and train operations. It therefore imposes access charges to all the train operations for use of the infrastructure
2. A train operator and owner of the infrastructure imposes access charges to all guest operations for the incremental operations and maintenance costs of the infrastructure and congestion costs.

In either of the models, the charges may include recovery of lifecycle capital costs as well as congestion and incident impact costs.

This access charge practice is very common in European Railway Systems due do several railways operators with service across national boundaries and rail networks.

7.1.4: Incidents

Incidents occur on HSR infrastructure due to several factors. Some of the factors include environmental factors such as abnormal weather, human factors such as disobeying signals, track structure failure, track geometry defects, signal and communication systems failure, and rolling stock brake equipment failure (Lam and Tai, 2020; Lin et al., 2020). An incident's duration can range from short to long based on the severity of the incident. Incidents cause delay to train the train involved in the incident and this delay can be propagated to other trains based on the duration of the incident, the location of the incident on the network, the distance between stations, and headways between trains (Feng et al., 2019, Ye and Zhang, 2020). Understanding the impact of incidents on the network can aid in efficient train operations and dispatching methods during the time of incidents (Huang et al., 2019).

7.1.5: California High-Speed Rail and XpressWest

The California High-Speed Rail (CHSR) project is under construction in the state of California that will connect San Francisco in northern California to Los Angeles/Anaheim in southern California with extensions to Sacramento and San Diego also being planned. California High-Speed Rail Authority (CHSRA) owns and manages the CHSR project. The mission of the CHSR project is to build an HSR system that is capable of operating speeds over 200 mph (CHSRA, 2020a). The project will be completed in two phases, Phase 1 and Phase 2. The HSR operations in Phase 1 will be launched in three stages (CHSRA, 2020b):

1. Central Valley early service (Merced to Bakersfield)
2. Silicon Valley to Central Valley (San Francisco to Bakersfield)
3. Phase 1 (San Francisco to Los Angeles/Anaheim)

After the completion of Phase 1, CHSR will have more than 500 miles in track length with trains reaching a top speed of 220 mph and travel times between San Francisco and Los Angeles/Anaheim totaling less than 3 hours. In Phase 2, HSR services will be expanded to Sacramento in the north, and San Diego in the south, and by the end of Phase 2, the entire CHSR network will have approximately 800 miles in track length (CHSRA, 2020b). Figure 1-2 shows the phased implementation of CHSR as presented in the CHSRA, 2018.

7.1.6: XpressWest Las Vegas to Los Angeles HSR Service

XpressWest was a privately owned HSR project that planned to connect Las Vegas, Nevada with Victorville, California, and with possible extension to connect with the CHSR network at Palmdale, California. It was previously known as DesertXpress and was initially proposed in 2005. The goal of DesertXpress was to provide an HSR service as an alternative to highway and air travel between Los Angeles, California, and Las Vegas (FRA, 2020). Victorville was selected as the initial destination in California, instead of Los Angeles, due to the high construction cost for the segment to Los Angeles through Cajon pass. Later, DesertXpress was re-branded as XpressWest to reflect the expansion of plans to connect various cities in the western United States with Las Vegas. The project initially planned to run trains with operational speeds up to 150 mph. (Cox and Moore, 2012)

Figure 7-2: Phased California High-Speed Rail System Implementation (Source: CHSRA, 2018)

XpressWest planned to run its trains to Los Angeles through Victorville and Palmdale and utilize the CHSR network between Palmdale and Los Angeles (Steer Davies Gleave, 2017). For the right to share use of this part of the CHSR network, XpressWest may have to pay CHSRA an access charge.

Figure 7-3: Brightline West Plan and Alternatives for Las Vegas - Los Angeles High-Speed Rail. (Source: Brightline West, 2020)

XpressWest was later acquired by Brightline and was renamed Brightline West (Brightline, 2020; Brightline West, 2020). Brightline West proposes to connect Los Angeles with Las Vegas through two route expansions (Brightline West, 2020). The first route will connect Brightline West's Victorville station with CHSRA's station in Palmdale, California, and then to Los Angeles Union Station. The second route will involve construction through Cajon pass and will connect Los Angeles Union Station with Victorville station through the Metrolink station at Rancho Cucamonga, California (Scauzillo, 2020). Brightline West plans to run trains with operational speeds up to 200 mph. (Brightline West, 2020). The route that connects Brightline West's trains from Victorville to Palmdale is similar to the original XpressWest's proposed expansion.

7.2: Research Objective

The main objective of this research is to develop a framework for calculation of access charges for a shared corridor of a HSR network based on analysis of train operations using VISSIM traffic simulation software. As a case study, this research analyzes the train operations for the Palmdale

- Los Angeles shared HSR corridor of the CHSR system where CHSR and XpressWest are being planned to operate.

7.3: Research Scope and Limitations

The scope of the research is to use the VISSIM traffic simulation software to analyze the train operations in a shared HSR system. The research develops a VISSIM simulation model of the Palmdale - Los Angeles shared HSR corridor of the CHSR system. The simulation model replicates the infrastructure of the shared CHSR corridor and analyzes train operations based on the planned operations of CHSR and XpressWest. Various parameters such as HSR rolling stock characteristics including speed, acceleration, and deceleration profiles and characteristics of the signaling system are considered for modeling the simulation. Train operations are analyzed in terms of allowable minimum headways between the trains using the simulation model and for peak and off-peak services. The simulation does not model grades and curvature of the tracks but considers their effect on the trains' travel times by adjusting the speed, acceleration, and deceleration profiles of the trains to reflect travel times in proposed CHSR timetables.

The simulation model also evaluates the impact of incidents on train operations. A schedule of incidents is developed based on the incident data of a typical HSR system. Train operations on the shared corridor affected by incidents are analyzed taking into account the different priorities for the CHSR and XpressWest trains and considering for the overtaking of trains.

A framework to calculate access charges for the CHSR shared corridor is developed. Various cost elements involved in the operation and maintenance of the corridor that are affected by the addition of another rail operator, i.e., XpressWest, on the corridor is analyzed. Cost elements included in the calculation of the access charges include train operations costs, dispatch and control operations costs, Track and Systems, station operations and maintenance costs, as well lifecycle capital costs. Incident costs due to the incidents caused by the operator accessing the HSR system are also analyzed. The effect of train speed on the access charge is outside the scope of this research.

Chapter 8: Literature Review

8.1: Shared High-Speed Rail Networks

A simple definition of a shared HSR network can be given as the HSR network system where the network's infrastructure is shared by multiple operators. There are several shared HSR network systems in the world. The practice of using shared HSR network systems is highly prevalent in Europe. In Europe, there was no single dedicated HSR network as of 2018 (ECA, 2018). Several operational models for HSR networks exist in Europe and they differ from country to country. Rus, 2012, provides a comprehensive review of HSR networks around the world and describes the different types of operational models for HSR networks that are in practice. The operational models were primarily grouped into four different types based on the sharing practices:

1. Exclusive HSR networks
2. Mixed HSR networks
3. Mixed conventional HSR networks
4. Fully mixed HSR networks

Exclusive HSR networks are the HSR network systems where the high-speed trains are operated on dedicated tracks. These tracks are designed specifically for running high-speed trains with the capability of reaching high operational speeds. They are operated completely independent of conventional rail systems. Exclusive HSR network operations are primarily practiced by the HSR networks in Japan and China.

Mixed HSR networks are the HSR network systems where the high-speed trains are operated either on a dedicated track or on upgraded sections of conventional rail lines. In this case, conventional lines are upgraded to accommodate high-speed trains and their requirements. These upgraded conventional lines are generally used by various operators. Upgraded conventional lines are primarily used by high-speed trains when there is no possibility for constructing dedicated high-speed tracks due to either high construction costs or due to physical constraints. Mixed HSR networks are extensively practiced in countries in France, Italy, and Spain.

The maximum operating speed of a train depends on the characteristics of the rolling stock and the tracks. While high-speed trains are the fastest, some conventional trains can operate at higher speeds than other conventional trains. In this case, conventional trains that can run faster than the normal trains can do so on HSR tracks. The HSR network systems where conventional trains use HSR tracks along with HSR trains are referred to as Mixed conventional HSR networks. Few HSR lines in Spain are Mixed conventional networks and offer intermediary high-speed services.

In Fully mixed HSR networks, high-speed trains and conventional trains run interchangeably on HSR tracks and conventional tracks. In this case, several operators will be using both types of infrastructures. Germany, Austria, and two corridors in Italy use fully mixed HSR networks. Figure 2-1 depicts the pictorial representation of different HSR network operational models.

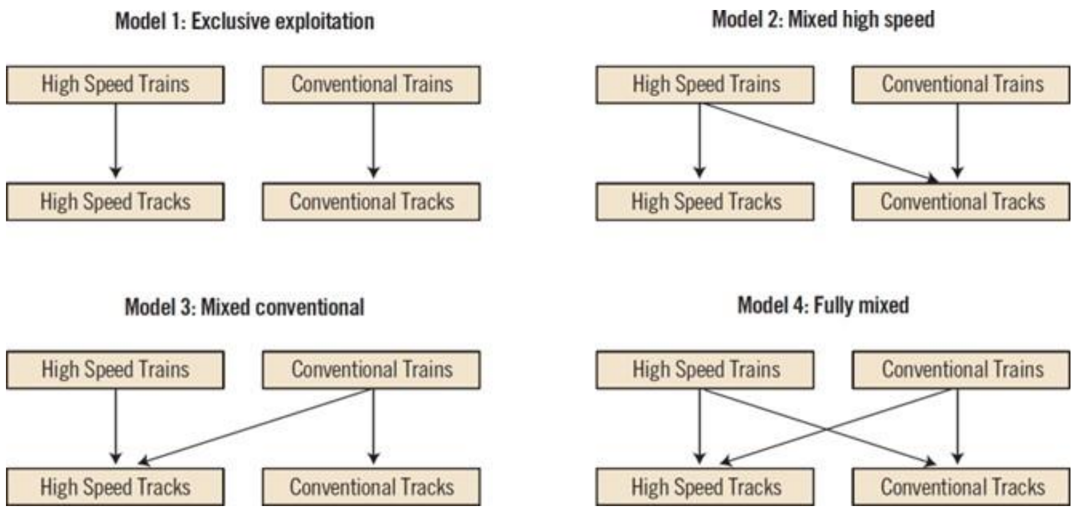


Figure 8-1: High-Speed Rail Network Models (Rus, 2012)

In the four types of HSR network practices discussed, the three types of mixed HSR network can be considered as shared use HSR networks. In shared use HSR networks, depending on the type, high-speed trains can reach their maximum speeds in only a few corridors. Therefore, defining HSR networks solely based on the maximum speed attainable is insufficient. To avoid this the International Union of Railways (UIC), the worldwide railway organization and the European Union (EU) provide multiple definitions of what can be considered an HSR network. Nash, 2003 describes types of shared HSR networks based on the extent of shared use HSR operations:

1. Total shared use HSR networks
2. Partial shared use HSR networks

Total shared use HSR networks are where the HSR systems share a track with conventional trains over the entire network. While partial shared use HSR systems are the HSR systems that share the track with conventional trains over a few sections of the network and operating mainly on the dedicated corridor. This grouping of shared HSR networks would be more relevant to the HSR network systems in the United States where the HSR systems have just begun to start.

Each type of shared HSR network has its benefits and issues. While exclusive HSR networks have the benefits of higher operational speeds, not all corridors require faster travel times (ECA, 2018). The report (Steer Davies Gleave, 2004) performed an analysis of the market competitiveness of HSR with other modes of transportation. On comparing the door-to-door journey time between HSR, conventional rail, and airway, the report analyzed that the HSR is the fastest mode of transportation for journeys between 100 - 500 miles and for the journeys between 230 - 500 miles HSR provides the most advantage compared to others. For journeys less than 100 miles conventional provides more comfort to passengers and for journeys greater than 500 miles airways provide faster door-to-door travel times. Figure 2-2 provides a graphical visualization of comparisons between HSR, conventional rail, and airways.

For the corridors that span less than 100 miles, HSR may be unnecessary and/or uneconomical. If the corridor is between two metropolitan cities, then most of the corridor could be in the city and high travel speeds of HSR could produce noise pollution and disturbance to the cities' population. For HSR to travel at high speeds they require a dedicated line which involves high construction costs in the cities and if the cities' rules require low noise operations, noise barrier construction needs to be done and this would increase the construction costs even more (Scordamaglia, 2015). In some cases, there could no physical space available in the city for a dedicated HSR track construction. In this case, the mixed HSR network model provides more benefits by HSR trains sharing conventional tracks and running at low speeds. For new HSR networks, such as the California HSR network, a mixed HSR network would be beneficial to assess the demand and market before building a dedicated corridor. Mixed conventional rail would also help in attracting more demand when the dedicated line is constructed later (Nash, 2003).

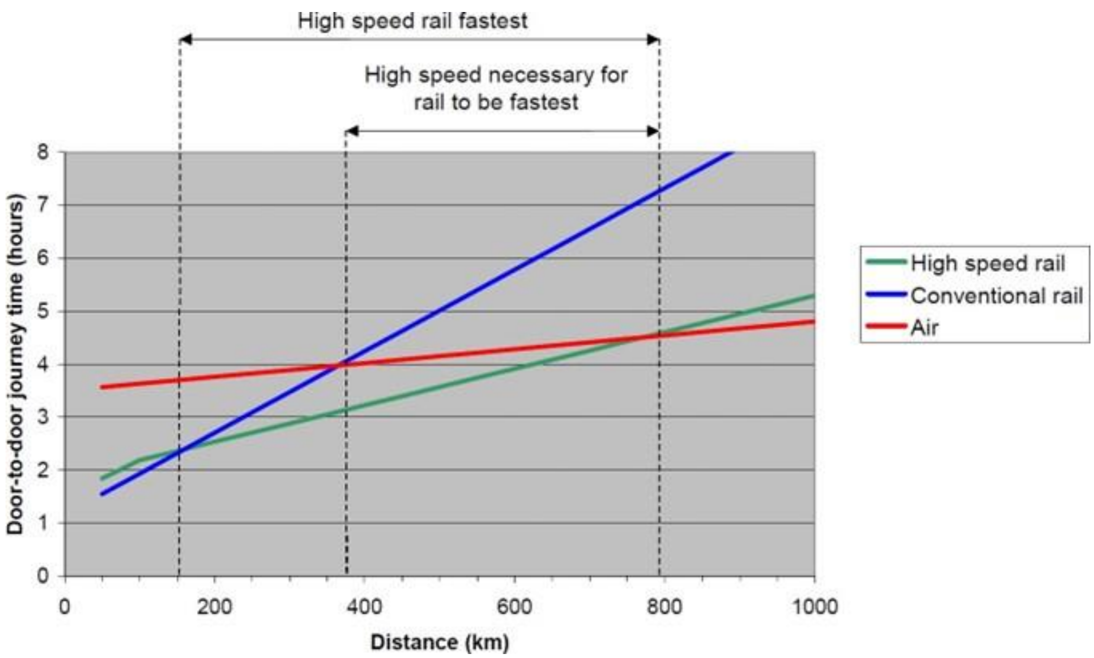


Figure 8-2: Comparison of Door-to-Door Journey Times between High-Speed Rail and Other Transport Modes (Steer Davies Gleave, 2004)

Revenue of running an HSR corridor depends on the market and the volume of the passengers it serves (Rus, 2012). For the corridors with the journey distance ranging from 100 - 230 miles, although HSR rail provides fewer travel times, depending on the corridor market, the cost of operating trains at high speeds could be more than the revenue. Instead by providing the intermediate high-speed services for these corridors, the operation costs of HSR could be mitigated. By allowing conventional trains that could travel at intermediate high-speeds at these corridors and HSR trains focusing on the corridors with high markets, the cost of operating HSR trains is decreased by improving travel times for the corridor that has high markets and by decreasing the energy and maintenance costs caused HSR trains braking and accelerating. In this case, a mixed conventional HSR network model is deemed to be beneficial.

In the countries like Germany and Austria where rail passenger service has a significantly higher demand, a fully mixed HSR network provides more benefits by providing higher capacity and flexibility by both HSR and conventional rails using the upgraded existing conventional lines and new lines to serve passengers. The main downside of this model is the significant increase in the maintenance cost of the tracks that are affected by both higher dynamic loads and static loads (Rus, 2012).

The problems of shared HSR networks were detailed in the work of Nash, 2003. By running two types of services with significantly different operational speeds the complexity of the signaling system increases. This brings a safety issue and may cause an increase in accidents and accident severity because of high speeds. Because of low-speed trains that take higher travel times between two locations, the capacity of the system is decreased, and a possible increase in congestion. The operators need to weigh the benefits and issues while planning a shared HSR network.

8.2: Access Charges

Figure 2-3 shows the different cost elements that an IM of an HSR network is normally faced with. The cost of operating and maintaining the infrastructure is directly proportional to the amount of traffic operating on the infrastructure. When an HSR operator accesses an infrastructure owned and/or operated by another IM, the additional rail traffic that is added to the existing traffic increases the cost of operations and maintenance of the infrastructure in several of the cost elements. The compensation paid by the operator to the IM for the increased expenditure is referred to as the access charge.

The practice of access charge in HSR networks is widespread in Europe where there are several shared HSR networks. With several shared HSR networks in different countries, each country has its own access charge system. Several EU directives provide the underlying principles on which the access charge system should be developed by each EU country (Prodan, 2011; IRG, 2018). An EU directive states that the access charge system should be based on the costs that are directly associated with the operating of train service. The directive also states that the access charge pricing system should be transparent and non-discriminatory against new operators. These directives and several others offer a wide scope for countries to develop their own access charging systems based on their operations and requirements.

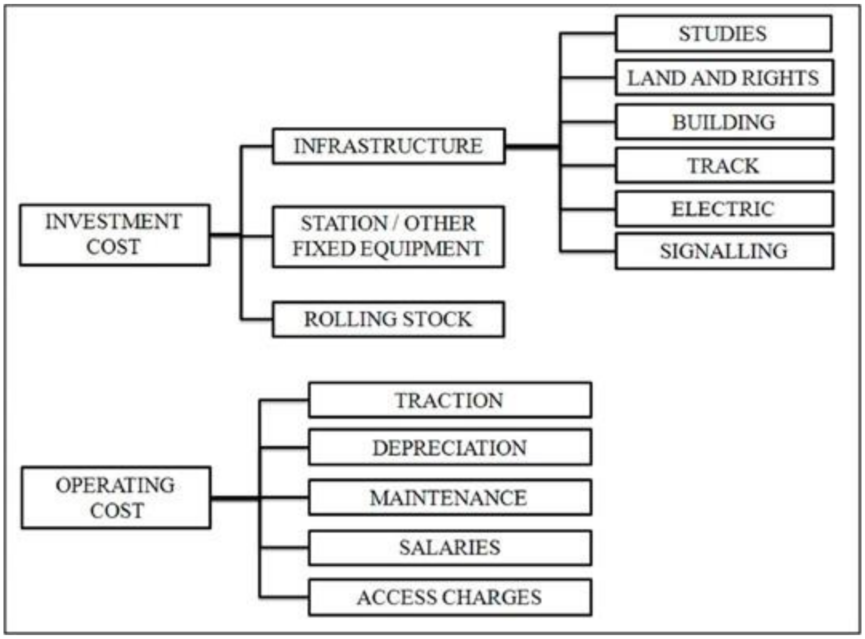


Figure 8-3: Cost Elements of Operating a Railway Infrastructure (Gattuso and Restuccia, 2014)

Several literature present and discuss access charge pricing philosophies of various EU countries. The access charge pricing systems are developed based on two major pricing principles (Prodan, 2011), namely, marginal cost pricing and full cost pricing:

1. Marginal cost (MC) pricing

   In this pricing system, the operators are charged for the additional cost incurred to the IM for running an additional train on the IM's infrastructure. The marginal costs include (Rothengatter, 2003):

   (a) Operating costs
   (b) Infrastructure wear and tear costs
   (c) Congestion and scarcity costs
   (d) Accident costs

   Marginal cost pricing system does not consider the investment costs of the infrastructure. In the EU countries where governments play a prominent role in managing the transportation system infrastructure, investment costs are generally funded by the country's government. The complexity of the marginal costs and the dependence of the IM on government funds are the major issues with this pricing system.

   In some cases, to relieve the IM's reliance on the government funds markup costs are considered. Markup costs are designed in such a way to recover a significant part of the financial cost/investment cost of an IM. Marginal costs coupled with markup costs are referred to as Marginal Costs Plus (MC+) pricing. When executed properly, the MC+ pricing system offers a balance between better efficient use of infrastructure and use of government budget (ECMT, 2005). The markup costs considered between countries vary. Two major markup costs considered are:

(a) Performance costs
(b) Reservation or cancellation costs

An issue with the MC+ pricing system is that some charges that are directly related to the cost of operating a train but may seem not related may not be considered which can lead to under-charging of operators and increased burden on an IM.

2. Full cost (FC) pricing

   In an FC pricing system, the full financial cost involved in operating a train on the IM's infrastructure is recovered from the operator in terms of marginal costs, investment costs, and capital recovery costs. The prices in the FC pricing system are significantly higher than the MC and MC+ pricing system. The primary benefit of the FC pricing system is that the full financial cost recovery is ensured. The high cost of the FC pricing system may discourage some operators from utilizing an IM's infrastructure and may lead to under-utilization of the infrastructure

Given the pricing system, the cost elements considered and the pricing structure varies widely between different countries, and the following charging units are generally considered:

1. Path-km: Distance between the origin and destination in kilometers.
2. Train-km: Total distance, in kilometers, traveled by trains between origin and destination. This is normally the product of the number of trains and the total distance, in kilometers, each train travels.
3. Gross-tonne-km: This is the product of the total number of trains operated, the average weight per train, and the distance traveled by each train.
4. Seats-train-km: This is the product of the total number of trains operated, the average number of seats per train, and the distance traveled by each train.

Three studies provide a detailed analysis of access charging systems of many EU countries. For all of the access charge pricing systems analyzed, a total of 46 different variable price components were identified in Maca´rio et al., 2007, and 48 components were identified in Teixeira and Prodan, 2014. These price components were charged based on various types and characteristics of:

1. Infrastructure
2. Allocation path and time
3. Market
4. Rolling stock
5. Services offered
6. Traction

The access charge prices varied significantly for different countries. Maca´rio et al. (2007) and Teixeira and Prodan (2014) compared the access charge prices of various countries and a high variance between them was found. Prices were high for new HSR lines compared to upgraded conventional lines. No correlation was found between the price level and length of an HSR line and a strong positive correlation was found between the price level and the amount of traffic on an HSR line (Teixeira and Prodan 2014) analyzed the HSR IM's revenue with their respective access charge prices and found that the IM's recover their maintenance costs and little to a significant part of their investment costs.

Since higher speeds cause higher wear and tear on tracks which leads to higher maintenance costs (ECMT, 2005), a positive relationship is expected between operational speed and access charges. However, studies have found their relationship to be complex. For example, the analysis done in Maca´rio et al., 2007 showed there was no direct relationship but that in general there was an increasing trend of charges with an increase in the operational speed. A similar analysis in Teixeira and Prodan, 2014 also concluded that the operational speed and price levels had a low positive correlation relationship. Sa´nchez-Borra`s and Lo´pez-Pita, 2011 analyzed the relationship between operational speed and price levels in Germany, France, Spain, and Belgium, and also similar results to Maca´rio et al., 2007 were obtained. Therefore, it can be concluded that access charge price levels do increase with the operational speed of an HSR line.

The literature review so far has presented an overview analysis of access charge prices and price systems in EU countries. To obtain a deeper understanding of access charge price systems, this study conducted a detailed review of access charges for 4 countries namely Spain, France, Germany, and Italy. These 4 countries were considered because of their high experience and extensive HSR networks. As per an EU directive, countries should provide 'Network statements' that contain all the information regarding access conditions and prices required for an operator to access an IM's infrastructure. Network statements from the 4 countries mentioned were obtained and reviewed.

Germany

German access charge pricing comprises a minimum access charge package which includes Direct Cost of Train Operations (DCTO) and full cost markup, and additional cost or discount elements (Deutsche Bahn, 2020a). The basic structure of the German access charge system can be given as:

Access Charge Pricing = DCTO + Full cost markup +/- additional elements

The services included in the minimum access charge are:

1. Capacity allocation and the right to use the allocated capacity
2. Use of rail infrastructure including tracks, signaling and communication systems, and overhead catenary system
3. Information required for the train operations.

Full cost markup is charged to recover the full financial cost of the IM for operating a train. Full cost markup is based upon the market segmentation. The minimum access charge is charged per train-km. The charge for operating a train of an operator can be given as:

Train Access Charge = (Minimum Access Charge) x (train-km)

The development of the minimum access charge package involved three stages:

1. Market segmentation

   The access charge prices are based on market segments and vary for each market segment. The market segments are formed based on:
   (a) Type of train service (HSR vs Conventional vs Freight)
   (b) The volume of passengers traveled between stations
   (c) Train allocation time (Peak vs Non-Peak and Day vs Night and Weekday vs Weekend)
   (d) Average Speed of the Train between two Stations
   Based on the above criterion various market segments are formed. The market segment with higher traffic and speed with more trains traveled during peak are charged higher.

2. DCTO

   The charges included in the DCTO are the costs that are directly associated with the operation of a train. The different charges included are:

   (a) Timetable Costs: The timetable costs are charged for the increased amount of time the staff spends on devising the train paths. This involves staff and staff related charges
   (b) Operation Costs: The operation costs are charged for the increased level of staff required to operate signal boxes, level crossing safety, and management of control centers.
   (c) Track Maintenance Costs: The track maintenance costs are charged for the increased level of staff and the amount of time the staff spends on the maintenance of track, signal and communication system structures. The track maintenance cost is calculated based on an equation that considers various maintenance elements and their weights of their drivers such as the number of trains, train weight, and train speed.
   (d) Track Depreciation Cost: Track depreciation cost is calculated based on the regression analysis with parameters as track depreciation and train-km from historic data.

3. Full cost markup

   The full cost markup is calculated based on the market segments' turnover, market share, operation costs, and the train service considered. Full cost markup is designed in such a way that it recovers the investment and capital recovery cost of the market segment.

Along with the minimum access charge package, additional costs or discounts are added depending on the individual situation. The additional costs or discounts involved in the German access charge pricing are:

1. New sector discount: Discount given on the newly built sectors to promote the use of the sector by operators. Discounted as a fixed percentage of train access charge

2. Scarcity charge: Additional cost charged for not using allocated capacity. This charge is to promote the efficient use of the infrastructure. Charged based on Timetable costs, train-km, and duration of scarcity.
3. Charge for movements outside operating hours: This charge is levied on operators that request for train movements outside operating hours. Charged fixed amount per additional time requested.
4. Performance cost/discount: Charged if the cause of an incident is an operator and discounted if the cause of an incident is the IM. Charged/discounted per
5. delay-minutes caused.

Figure 2-4 shows German access charge prices for the HSR market segment and all trains traveling above 100 mph.

Cost element	Charge price ($/train-mile)
Direct cost of train operation (A)	2.25
Full cost mark-up (B)	22.63
Timetable costs	0.04
Estimated total charge	24.92

Figure 8-4: German Access Charge Pricing for all Trains Traveling Above 100 mph (Deutsche Bahn, 2020b).

France

In the French HSR network along with IM and operators, the French government referred to as the State is also considered as primary stakeholder (SNCF Re´seau, 2019a). The market organization is done based on whether the State is involved or not. The rail operators where the State is involved are referred to as under contract operators. The international trains and freight trains where State is not involved are referred to as not covered by contract operators. The access charge system in France is developed based on the principles:

1. Update existing strategies for the market organization to ensure good economic standing of all stakeholders involved.
2. Enable IM to recover DCTO as marginal costs
3. Recover full or partial capital costs of IM
4. Promote efficient use of network

The French access charge system comprises various components that adhere to the above principles. The various charge components are:

1. Running charge

   Running Charge is the total marginal costs for the train operations, maintenance, and renewal of the tracks, track structures, signal, and communication systems. The marginal cost estimation is done based on the econometric analysis of historic data. The process for econometric analysis is detailed in (Silavong et al., 2014). Charging unit for train operations and maintenance of signal and communication systems is per train-km and for maintenance and renewal of all other activities is per Gross-tonne-km.

2. Electric traction charge

   Electric traction charge is the total marginal costs for the maintenance and renewal of the electrical facilities. Electrical facilities include catenaries and the European Association of Labor Economists (EALE). This charge is priced per train-km

3. Market charge

   The market charge is the markup cost to recover the fixed cost of the network depending on the allocated market segment. The segmentation of the market is based on:
   (a) Rail infrastructure performance in terms of speed, electrical systems, etc.
   (b) Characteristics of services and facilities provided
   (c) Amount of traffic on the path allocated
   (d) Characteristics and specifics of rolling stock
   The markup level is dependent on the market segment and is charged as the product of segment price and the length of the path allocated

4. Access charge

   An access charge is a fixed charge that is levied to recover the fixed cost of the infrastructure and is charged only for the operators under contract. This charge is paid by the State. The access charge is the difference between the total cost incurred to the IM and the sum of all the marginal costs discussed above. This charge is paid as a fixed price per year and is dependent on the number of trains running under contract.

5. Congestion charge

   The congestion charge is charged to promote efficient use of the network and to reconsider the needs of an operator. This charge is not well defined in the network statement and was not implemented in 2020 but discussions are in place for future implementation.

In addition to these charges, charges for individual operators are levied based on the service facilities they use of the French HSR IM. Figure 2-5 shows French access charge prices for the HSR market segment and for trains that are not under contract.

Cost element	**Cost driver**	**Charge price**
Running charges	Maintenance and renewal of track and track structures ($/1,000 Gross-tonne-miles)	10.51

	Train operations and maintenance of signaling and communications ($/train-mile)	0.43
Electric traction charge	($/train-mile)	0.51
Market charge	($/train-mile)	17.87 – 41.85
Estimated total charge ($/train) (assumes 500 tonnes/train)		**24.07 – 48.05**

Figure 8-5: French access charge prices for HSR market segment (SNCF Re´seau, 2019b)

Spain

Spain has the second-largest HSR network and it uses an extensive range of factors to divide its market segments. The access charge costs are dependent and vary between different market segments. Market segments are made based on railway line characteristics such as the maximum operational speed allowed on the line and the amount of traffic on the line, and train service characteristics such as long or short distance passenger services and freight services. The access charge pricing system in Spain can be divided into two main categories (ADIF, 2020):

1. DCTO

   The different cost drivers of DCTO considered by Spain are:

   (a) Capacity Allocation Cost
   These costs include allocating capacity, control and management of traffic, operation, and maintenance of traffic safety and its facilities. The capacity allocation cost can be increased or decreased based on the excess or lack of use of allocated capacity. This charge is priced per train-km.
   (b) Track Usage Cost
   These costs include the cost of maintenance and rehabilitation of all track infrastructure. This charge is priced per train-km. For market segments that have high traffic density, an extra charge is levied which is priced per 100 seat-km offered by the train.
   (c) Traction Cost
   These costs include maintenance and rehabilitation costs of all electrification facilities related to the railway infrastructure. This charge is priced per train-km

2. Charges for the use of the service facilities

   Charges for using various service facilities such as stations and maintenance facilities are included in the costs.

Cost element	Charge price
Capacity allocation cost ($/train-mile)	3.48

Track usage cost	Fixed price ($/train-mile)	8.64
	($/100 seat-mile)	0.36 – 3.17
Traction cost ($/train-mile)		1.44
Estimated total charge ($/train-mile) (assumes 450 seats per train)		**15.18 – 27.83**

Figure 8-6: Spain Access Charge Pricing for HSR market segment (ADIF, 2020)

Italy

The access charge pricing system in Italy is based on three principles (RFI, 2020):

1. To recover DCTO
2. FC pricing to recover more than 98 percent of DCTO costs
3. Use of efficient methods to compute capital costs.

The basic structure of the Italian access charge system can be given as the sum of two main cost components:

Access Charge Pricing = A + B

The cost components included in the minimum access charge are:

1. Cost Component A

   Cost component A is related to maintenance cost due to wear and tear caused by the use of rail infrastructure. This component is priced per train-km. The cost component A is further divided into three sub-components.

   A = A1 + A2 +A3

   (a) Sub-component A1
   This cost sub-component includes for wear and tear of track caused due to the weight class of the train. This sub-component is charged differently for different weight classes of the trains.
   (b) Sub-component A2
   This cost sub-component includes for wear and tear of track caused due to the operation speed of the train. This sub-component is priced based on the operating speed of the trains. The average speed of the train is calculated by dividing the total distance traveled by travel time minus the dwell time at stops.
   (c) Sub-component A3
   This cost sub-component includes for wear and tear of the over-head catenary line and charged based on the class of the overhead catenary line and if a train is electric or diesel.

2. Cost Component B

This cost component is dependent on the market segment the train is operated. The market segments are classified based on the operation speed of the train, the distances traveled by trains, and the types of service such as passenger and freight.

In addition to these charges, charges for the use of the service facilities are levied based on the types of passenger stations and the time of operation of the service. Figure 2-7 shows Italian access charge prices for the HSR market segment and for trains that are not under contract.

Charge component	**Charge sub-component**	**Charge price ($/train-mile)**
A (Wear and tear of infrastructure)	A1 (due to train weight)	1.55
	A2 (due to train speed)	1.90
	A3 (of the overhead catenary)	0.08
B (Market segment cost)	HSR	7.25 – 10.62
Estimated total charge		**10.78 – 14.18**

Figure 8-7: Italian access charge prices for the HSR market segment and all train traveling above 93 mph (RFI, 2020)

In the four European access charge systems considered, the incident cost was considered as an additional cost and was not part of the minimum access package. The incident cost was charged based on the amount of delay caused to the IM by the operators. Similarly, in this study incident cost will be considered as an additional cost to the access charge cost and will be calculated based on the amount of delay due to incidents caused by XpressWest to CHSR trains in a year.

8.3: California High-Speed Rail Blended System

It is anticipated that certain sections of the CHRS network will be shared or blended service corridors (CHRSA 2012). Vranich et al., 2013 discussed some of the impacts of the planned blended system on train operations. Under the blended system, the CHSR will be sharing tracks with conventional rail and freight trains and may therefore have to travel at reduced speeds. These reduced speeds would increase travel times by more than 2 times the intended travel time from San Francisco to Los Angeles

Levy (2015) discusses the capacity challenges involved in blended system corridors of CHSR and their impact on the operators involved. In a blended system, CHSR should share tracks with conventional and freight rail operators, and many institutional and operational challenges arise. The institution challenges involved would be the competition that arises between the passenger services, priority rules for the trains, and the necessary cooperation required to overcome the issues. The operating challenges that arise can be operating trains with various speeds and implementing a signaling system for different operators involved.

Similarly, Levy et al., 2016 discuss the challenges and implementation of blended corridors for CHSR. Challenges for each operator involved in the blended system corridor were analyzed. Levy et al., 2016 suggests that for a network that is economically profitable for all operators involved, all operators should aim for the best system-wide performance while relaxing individual goals where necessary. Where the operators' minimum goals cannot be met infrastructure improvements such as adding more tracks can be co-funded by all operators. A high level of cooperation and agreement should be involved between operators to implement a blended corridor system.

Sapkota, 2018 discusses and performs access charge calculation for XpressWest accessing the CHSR network. Theoretical capacity allocation for the CHSR and XpressWest from San Francisco to Los Angeles was performed considering baseline capacity and full capacity. Based on the capacity allocation models, congestion delays for the models were calculated and the operations were modified to minimize the delay of the network. Utilizing the modified allocation models' service plan various cost elements of access charges were calculated. The cost of installing side tracks for different allocation model scenarios was calculated. Finally, the access charge was presented in terms of cost per year.

The key differences between Sapkota, 2018, and this study are the consideration of the shared CHSR network segments, the allocation methodology of XpressWest in the CHSR network, and the analysis of HSR operations. The initially planned operations of XpressWest included operating trains from Palmdale to San Francisco along with the Palmdale to Los Angeles segment. Later, the planned operations from Palmdale to San Francisco were excluded from XpressWest. Sapkota, 2018 considers the XpressWest operations from San Francisco to Los Angeles. This study considers the XpressWest operations from Palmdale to Los Angeles. Sapkota, 2018 uses theoretical capacity allocation for the CHSR and XpressWest trains and considers the various frequency of XpressWest trains. This study develops a fixed timetable for the simulation model based on the planned operations of CHSR and XpressWest. Sapkota, 2018 performs theoretical analysis of the HSR operations while this study uses VISSIM simulation to analyze the HSR operations and also evaluate the impact of potential incidents.

8.4: Simulation Software for HSR Operations

The use of simulation software to analyze the HSR operations is fairly common in literature. To develop the estimated annual traffic of CHSR trains, Train Performance Calculator (TPC), simulation software developed specifically to simulate train performances was used (CHSRA, 2020c). TPC is part of Berkeley Simulation's Rail Traffic Controller (RTC) software package. RTC is used to simulate the dispatching pattern of trains. TPC is embedded in RTC and provides simulation results of various operational analysis in graphical plots. Inputs for TPC include characteristics and types of rolling stock, rolling stock equipment, terrain grades, and track characteristics (CHSRA, 2020c).

To perform capacity analysis in blended system operations, Caltrain used TrainOps® which is a proprietary simulation software by LTK which provides analysis on train operations, traction power, train control, and rail traffic modeling. TrainOps® accounts for all railway elements' characteristics and types, provides complex modeling techniques and results in customizable graphic plots.

For this study, PTV's traffic simulation software, VISSIM, was used. VISSIM is a microscopic traffic simulation software that can be used to model and analyze network performance of various surface transportation systems. VISSIM can analyze traffic operations composed of different types of vehicles from cars to trains considering for lane configuration, traffic composition, traffic signals, transit stops, etc. Applications of VISSIM include Traffic Impact Assessment and Traffic Management.

Chapter 9: Research Methodology

9.1: Overview of Research Methodology

This chapter discusses the steps involved in the approach to developing the study. The study consists of the following primary steps:

1. Data collection
2. Development and calibration of the network model in VISSIM
3. Development, running and analysis of simulation scenarios for train operations.
4. Development of the framework for o an access charge framework for the CHSR network.

9.2: Methodology

9.2.1: Data Collection

Data necessary to create a network model in VISSIM and intended operational parameters were obtained directly from the operators and through various sources available from the operator's official websites. Any data that was not available was assumed. Assumptions were made from our best reasoning based on the literature review. All data sources and assumptions made are detailed in further sections. The data is divided into three sections, namely, network characteristics, rolling stock characteristics, and train incident characteristics.

Network Characteristics

Network data included track geometry and location of stations, operational speeds and train timetables. California High-Speed Rail Authority provided AutoCAD plans of the entire CHSR network for Phase 1. The plans consisted of detailed track geometry, the number of stations, their relative positions on the track, and the length of the platforms at stations for the whole CHSR network.

Using the provided AutoCAD plans, the rail network model in VISSIM was developed. The CHSR network consists of two tracks. One track is for the north-bound service and the other for the south-bound service. Each track is 1.4 ft wide. For the simulation purpose, only south- bound service is modeled. The simulation does not model the grades of the tracks. However, train speeds and acceleration are adjusted such that the travel time of the trains between stations reflect the effect of grades on train travel time.

The Palmdale – Los Angeles network section consists of three stations at which CHSR trains stop. The 3 stations are Palmdale, Burbank, and Los Angeles. The distance between Palmdale and Burbank stations is 44 miles distance between Burbank and Los Angeles stations is 13 miles.

As required by the California law Public Utilities Code 185033, CHSRA publishes its Business Plan document every two years since 2008. The technical reports that are used to develop the Business Plan document include:

1. 50-Year Lifecycle Capital Cost Model Documentation
2. Capital Cost Basis of Estimate Report
3. High, Medium, and Low Cash Flow Analysis
4. Operations and Maintenance Cost Model Documentation
5. Ridership and Revenue Forecasting
6. Service Planning Methodology
7. Ridership and Revenue Risk Analysis
8. Ridership and Revenue Model

The latest published Business Plan is the 2018 Business Plan (CHSRA, 2018). The 2020 Business Plan (CHSRA, 2020a) is a draft report which is yet to be published. The study makes extensive use of these technical reports to support the research.

Service Planning Methodology reports include a base service plan that is designed to accommodate the ridership forecasts. The service plan is developed based on CHSRA's assumptions on operations. A baseline timetable that was used in the 2016 CHSR Service Planning Methodology report (CHSRA, 2016) was obtained for the study. This timetable consisted of the arrival and departures of CHSR trains at the stations during their revenue service period. The revenue service period is 18 hours a day with 6 hours of the peak period and 12 hours of the off-peak period. More trains are run during peak period to meet the demand.

The service plan reports also included assumptions for the operational speeds between stations, train fleet specifications, dwell times of trains at stations, and signaling system. From CHSR Service Planning Methodology 2020 draft report (CHSRA, 2020c), the maximum operating speed for Palmdale - Burbank section is 220 mph. While the maximum operating speed for the Burbank - LA section is 125 mph as it is a blended corridor where CHSR shares tracks with Metrolink and other rail operators. At intermediate stations, the minimum dwell time of 2 minutes was assumed. A minimum signaling headway of 165 seconds at 220 MPH was assumed to be provided by the signal system.

The CHSRA will implement an Automatic Train Control (ATC) system which provides automatic train protection, operation, and supervision. As part of the ATC system, CHSRA will enforce a moving block signaling system and Positive Train Control. ATC system includes the ability to automatically supervise and operate train movements such as throttle and braking commands according to the signaling system (CHSRA, 2010).

The train operations for the XpressWest in the Palmdale - Los Angeles shared corridor was assumed. The XpressWest trains were assumed to stop at Palmdale to allow passengers from Las Vegas or Victorville to travel to northern California. XpressWest trains travel from Palmdale to Los Angeles with no intermediate stop at Burbank. No stop was assumed at Burbank to not affect the ridership of the CHSR. The maximum operational speed for Palmdale to Burbank HSR section is 220 mph and the XpressWest trains reach a maximum operational speed of 180 mph (Akers, 2020). From Burbank - Los Angeles, XpressWest trains will share the tracks with CHSR, Metrolink, and other operators, and can travel at maximum operational speed for the section which is 125 mph.

Rolling Stock Specifications

Rolling stock specifications required for the simulation model included train set characteristics and performance data. These were obtained from the CHSRA Business Plan technical reports. The CHSRA, 2020c report assumed the length of a train-set to be approximately 660 feet with the capacity to carry 450 passengers. This study assumes similar train-set characteristics for XpressWest trains. The maximum attainable speed for CHSR trains is 220 mph while for XpressWest trains is 180 mph.

There was no source from the operators for acceleration and deceleration profiles for the trains. A base acceleration and deceleration profile principles for the high-speed trains were assumed based on the discussion from existing literature and to maintain smooth train operation. The principles for developing the profiles were:

1. Acceleration profile: Based on the acceleration profile discussed in Janic´, 2016, the trains were assumed to start from rest with a lower acceleration value. The acceleration increases linearly to its maximum over time and stays constant at the maximum value until it reaches approximately 90 percent of its maximum speed. The acceleration decreases linearly to 0 as it reaches the maximum speed. The maximum acceleration value for the CHSR trains was assumed to be 2 ft/s2 and for XpressWest trains was assumed to be 1.6 ft/s2
2. Deceleration profile: In Connor, 2014 a series of deceleration rates that vary over different speed ranges was discussed. Similarly, deceleration rates that vary with speed were assumed. The deceleration of the train from the maximum speed is minimum. The deceleration increases at a slower rate until approximately 80 percent of the maximum speed and increases at a higher rate to its maximum value until 60 percent of the maximum speed. The deceleration is constant till the train reaches to rest. The maximum deceleration value for both types of trains was assumed to be 2.6 ft/s2.

As the simulation does not model grades of the tracks, acceleration and deceleration profiles that depend on the grades were not considered. To reflect the assumed travel times between stations by the operators, the acceleration and deceleration profiles were developed based on the above principles

Incident Data

For the simulation of incidents, the first thing that was required was typical incident data for HSR service, which included incident frequency and duration characteristics. For this study, one year's worth of incident data was obtained from the Shanghai railway administration for its Shanghai-Jiangshan HSR line (Ye and Zhang, 2020). Timetable operations for a day for the HSR line were also obtained to calculate the amount of traffic on the line. This data was analyzed and was used to develop a schedule of incident scenarios that are most likely to occur on the Palmdale – Los Angeles section based on the network characteristics.

9.2.2: Development and Calibration of VISSIM Simulation Model

The simulation model reflected the geometry and station locations of the CHSR segment of interest, namely, Palmdale – Los Angeles, as well as train arrival and departure priorities at stations and operational control between stations.

VISSIM provides the Graphic User Interface (GUI) for creating the simulation model. VISSIM's GUI where the network model is created is called the "Network Editor". "Network Objects" are various objects which serve a specific purpose and are used to define the rules of the network. The characteristics of the network objects and their modeling is discussed in detail in Section 4.1.

To develop complex signal programs, VISSIM provides an add-on software called VisVAP. VisVAP provides GUI for Vehicle Actuated Programming (VAP) allowing users to create signal control logic in form of flow charts offering various signal group commands. This study used VisVAP to create signal controller programs for signal groups that control the behavior and priorities of trains at stations, train capacity at stations, and train behavior in case of an incident.

VISSIM does not have the inbuilt feature to create an incident during the simulation. This was achieved by using VISSIM Component Object Module (COM) interface. For this study, an incident is created by creating an unscheduled stop for a train in the middle of a block at a preset location, start time, and duration. COM interface provides the ability to describe VISSIM's binary components through a programming language. VSSIM's internal data and functions can be accessed through COM. COM runs VISSIM as an automation server and, simulation parameters and inputs can be provided during the simulation. The study selected Python as the preferred programming language. Various programming codes were developed in Python to perform multiple tasks in VISSIM.

After the simulation model was developed it was calibrated in such a way that the simulation travel times of the CHSR trains between Palmdale to Burbank and Burbank to Los Angeles matches the travel times of the respective sections in the 2016 CHSR baseline timetable and to fulfill the signaling system requirement specified in the 2020 service plan. The calibration essentially involved adjusting acceleration and deceleration rates while maintaining the maximum allowable operational speeds on the corridor.

Processing the Simulation Data

During a simulation, VISSIM generates data and writes them in a new text file after the simulation is completed. This data referred to here as "raw data", contains information of all the vehicles in the simulation generated at every simulation time step. Each row in the raw data specifies the time step and the vehicle's location, speed, and acceleration. To understand the behavior and the operations of the vehicles in the simulation, the raw data needs to be processed into an organized and more comprehensible format. This study uses Python and Microsoft Excel to perform data analysis on the raw data generated by VISSIM.

Free flow simulations to establish minimum allowable headways

Train operations were analyzed for both free flow and incident simulations. Using free flow simulations, minimum headway between successive trains were determined and were used to create service timetables.

9.2.3: Development of Simulation Scenarios for Train Operations

After successful development and calibration of the simulation model, the next task is creation and running of scenarios for normal train operations on the Palmdale – LA corridor. This involved simulation of 1 hour of peak period service and 1-hour off-peak period service based on the 2016 baseline timetable (CHSRA, 2016). Additional XpressWest trains operations have to be added to the mix carefully while ensuring that the minimum headways between successive trains, as established from the model calibration step, are adhered to. The CHRS trains are scheduled to stop at the intermediate station, Burbank, with dwell times of between 2 minutes and 3 minutes. However, it is assumed that XpressWest trains will not at the intermediate Burbank station, as they will not be allowed to serve internal California traffic. Two types of simulations:

Normal (non-incident) operations

These are simulations for normal train operating conditions, i.e., non-incident conditions. The objectives for these simulations are

- Ensure train operations as per timetables feasible (further validating the model
- Establish station arrival and departures time as well between station travel times.
- Essential information required for the second part of this task, which involves analysis of impact of train incidents.

Operations under incident conditions

In simulations where the rail traffic is interrupted by an incident are referred to as incident simulations. Trains that are affected by incidents experience a delay in travel times between stations and, arrival and departures of the trains at stations. Information from the free flow simulation is used to calculate the delay in an incident simulation.

Incident data obtained from the Shanghai railway administration for its HSR line, Shanghai - Jiangshan was used to determine the frequency and duration of incidents on an HSR network. The length of the Shanghai - Jiangshan HSR line is 265 miles with 15 stations and 14 sections over the length of the line. From November 1, 2016, to October 31, 2017, 54 incidents that caused delays to trains occurred between stations and 84 occurred at the stations. This study evaluated the impact of the incidents that occurred between stations. The incident duration data obtained for the Shanghai - Jianshan HSR line was analyzed using Python. Based on the analysis, several incident simulation scenarios were developed and simulated.

For the schedule of incident scenarios developed, the study simulated several incident simulations for off-peak hour timetable and for peak hour timetable. Data from the simulations were analyzed to determine the impact of incidents on each train in terms of various delays for all simulations. The types of delays considered for the study were:

1. Running Time Delay

The additional time took by a train between the stations which includes the time the train spent decelerating, accelerating, and the amount of time it stopped because of an incident is considered as the ’Running Time Delay’. It is the difference between the free-flow travel time of the train and the delayed travel time of the train due to an incident between two stations.

2. Station Delay

   Station Delay is the additional amount of time a train spent at the station due to an incident ahead. When an incident occurs, trains that are scheduled to depart at the station behind the incident position will be delayed at the station until the incident clears and the signal system allows them to depart. Station delay is the difference between the normal dwell time of a train with the dwell time of the train affected by an incident at the station.

3. Schedule Delay

   The study defines ’Schedule Delay’ as the difference between the normal schedule arrival and departure times with the respective arrival and departure time of a train affected by an incident. It measures how late a train arrived at the station compared to its scheduled arrival time. The total schedule delay for a train is equal to the sum of the total station delay and the running time delay of that train. Schedule delay best represents the total effect of an incident on a train.

These delays were calculated for each train affected by an incident. Tables summarizing each type of delay for all trains were created. The delays were also summarized by train type, i.e., CHSR and XpressWest.

9.2.4: Framework for Calculation of Access Charges for the Shared Corridor

The shared corridor in this case is the Palmdale - Los Angeles network section of CHSRA. For this corridor, XpressWest will be a guest operator and have to pay access charges. It should be noted that part of this corridor, namely Burbank - Los Angeles, is owned by Metrolink, and therefore both CHSRA and XpressWest will be considered as tenants and will have to pay access charge fees for Metrolink. This study estimates access charge fees for the Palmdale - Burbank service corridor, the fee XpressWest will have to pay for CHSRA. The Palmdale - Burbank blended corridor will primarily differ from the other corridors in the aspect of the allowed maximum operational speed. The maximum operational speed for this corridor is 220 mph and will be a high-speed rail only corridor. The access charge will consist of two components, namely

1. Infrastructure operations maintenance (O&M) costs
2. Infrastructure capital recover costs.

Infrastructure O & M Costs
Each service may include various costs related to personnel, supplies for personnel, vehicles, equipment, and energy depending on the service type. The O&M model provides the breakdown of all the related costs, including personnel, vehicles, equipment and energy supply.

The O&M model is developed based on the information provided by the service planning methodology (SPM) as reported in CHSRA (2020c). Based on the service timetable developed, the SPM report provides the number of train-miles for the CHSR network. The number of train-miles represents the level of complexity of the operations and maintenance required for the network. Based on this, the O&M report estimates the personnel and the amount of maintenance required. Mentions breakdown of O & Costs.

Infrastructure capital recovery costs

Capital recovery cost charge contains two components:

(a) Initial capital costs and
(b) Lifecycle capital rehabilitation and replacement costs

This study calculates capital cost recovery charge based on the CHSRA's Capital Cost Estimate (CCE) Reports of various sections of CHSRA and the 50 Year Lifecycle Capital Cost (LCC) Report. The CCE reports contain costs of all the construction components of the infrastructure and their materials for each section of CHSRA. The LCC report contains the cost of repair and replacement of infrastructure cost components over the span of 50 years of their usage. The study analyzes all the costs from these reports and based on the relative traffic of CHSRA and XpressWest on the Palmdale – Burbank blended corridor, calculates the capital cost recovery charge per mile for XpressWest.

The CCE report of the Palmdale – Burbank HSR section had not been published at the time of the study. Therefore, the capital and lifecycle cost data for this section was estimated based on per mile capital cost elements derived from other sections of the CHSR system, namely, Palmdale – Burbank HSR section is a new construction beginning from the land acquisitions. Two sections, San Francisco – San Jose and Burbank – Los Angeles already have the railway infrastructure and are being upgraded to support the HSR and the additional traffic associated with it. There are four other sections that are completely new constructions which are: San Jose – Merced, Merced – Fresno, Fresno – Bakersfield, and Bakersfield – Palmdale. CCE reports for these four sections have been published and were obtained in PDF format from CHSRA website and by contacting the CHSRA personnel. Each report contains huge amounts of capital cost data with costs for various infrastructure components and subcomponents. The data in the PDF format is not in a workable format. A python code was written to read the data from the PDF reports and then converted it into workable format in Excel. The data was then analyzed in Excel to calculate the cost per mile for each capital cost component in the respective HSR sections.

The capital cost data in three CCE reports belonging to San Jose – Merced, Fresno – Bakersfield, and Bakersfield – Palmdale sections have the similar table format in their PDF's and were readable by the Python code. Due to a very different and complex table format of the capital cost data in the Merced – Fresno section's CCE PDF report, the study was not able to analyze the data for the Merced – Fresno section.

Based on the rehabilitation and replacement cost information in the LCC report for infrastructure components and subcomponents, the study then calculated the 50-year lifecycle costs for the San Jose – Merced, Fresno – Bakersfield, and Bakersfield – Palmdale sections. These costs are then analyzed to obtain cost per mile and cost per station for the construction of a new HSR section and are then used to estimate the capital costs for the Palmdale – Burbank CHSR section.

Incident Costs

Incidents are another element that is considered in the development of access charges. Incidents cause train delays that can disrupt normal operations and cause increased operating costs and/or loss of revenue to the operator. To compensate for such potential losses, XpressWest may have to pay additional access charges for incidents that XpressWest trains will cause. This study develops a framework to calculate this access charge due to incidents caused by XpressWest trains on the corridor.

The incident cost per year depends on the number of incidents and the total delay incurred by all affected trains for each incident. The study calculates the incident cost by estimating the amount of delay caused to the CHSRA due to the incidents caused by the XpressWest and the cost incurred for CHSRA for a unit time of delay for a train. The estimation for the delay caused by the XpressWest incidents to CHSR trains is discussed in section 6.4.

Chapter 10: Implementation

10.1: Development of VISSIM Network Model Parameters

This section discusses the development of the VISSIM network model simulation parameters.

10.1.1: Tracks

The first step in developing a simulation network in VISSIM is to create “Links”. A link is a network object. Links are the roads or rails on which vehicles are simulated and serve as the base for defining paths and directions for the vehicles and other network objects. In the case of this study, a link serves as a rail track.

Using AutoCAD, the CHSR network plan was scaled to match the default Network Editor dimensions and saved as an image file. This image file was then imported to VISSIM and was used as a background image to create links while replicating the tracks. Since the study only considers south-bound traffic for the simulation, a single link serves as the south-bound track in between Palmdale - Burbank, and Burbank - Los Angeles stations and will be referred to as the main link.

Two links were created along the station length at the positions of stations in the network. These links serve as the tracks besides platforms. These two links were connected to the main link via links referred to as “Connectors” in VISSIM. Each link serves as the dedicated platform for CHSR and XpressWest trains at the three stations. These links will be referred to as “station links”.

Trains can be simulated in VISSIM through “Public Transport (PT) Vehicles” which are defined using the network object “Public Transport Lines”. PT lines specify a path for PT vehicles from origin to destination and which specific links to take among several links. The start-point and end-point of a PT line serve as the origin and destination points respectively for the PT Vehicles.

After creating the complete network of links, PT lines are defined along the network length. A dedicated PT Line is created for CHSR and XpressWest with start-point and end-point on their respective links at the position of Palmdale and Los Angeles stations. At Burbank station, PT lines of CHSR and XpressWest go through their assigned links.

10.1.2: Stations

Trains are scheduled to stop at stations for a certain duration to allow for passengers to get off or to board the train. The duration the train stops at a station is referred to as the dwell time. In VISSIM, station stops and dwell time for the PT vehicles are defined using the network object “Public Transport Stops”. The position of a PT stop determines where the PT vehicles stop in the network model. PT stops were added on all station links except for the XpressWest link at Burbank station as XpressWest trains do not stop at Burbank, as it may not be allowed to serve passengers within California. The AutoCAD station plans provided by CHSRA specified the length of platforms at stations. The lengths of the PT stops were given the platform lengths at respective stations provided in the AutoCAD plans. The study analyzes the train traffic operations from their departure at Palmdale station till their arrival at Los Angeles station. Dwell times for PT stops at Palmdale and Los Angeles stations do not influence the study. Dwell time for PT stop on CHSR link at Burbank station is given as 120 seconds as per the [CHSRA, 2020c].

At the Burbank station, XpressWest trains enter the station and travel through the stations at reduced speed. This was attained by using the network objects “Reduced Speed Areas”. Reduced speed areas can be added on a link and during the simulation, vehicles slow down before entering the reduced speed areas and move through the area with the defined speed.

10.1.3: Vehicle Models and Distributions

VISSIM requires to specify the vehicle model, vehicle type, and other operational characteristics. By default, VISSIM provides multiple models for different vehicle types. For the study, two vehicle models of the vehicle type “Tram” were used, one for CHSR and XpressWest. Using the vehicle model customization feature, the two tram models were customized to replicate the assumed train fleet as discussed in Section 3.2.1.

In VISSIM, to assign the operational speed, acceleration, and deceleration values to a vehicle model, individual profiles should be created and assigned. These profiles can be created in VISSIM features referred to as “Distributions”. For speed, acceleration, and deceleration, profiles can be created either as an empirical distribution or a normal distribution. An empirical distribution, VISSIM uses the exact values assigned during the simulation of vehicles. When a normal distribution is provided, VISSIM selects a range of values from the distribution profiles for different vehicles. As HSR operations are precise, the study used empirical distributions for the speed, acceleration, and deceleration profiles for the trains. The principles for the development of the profiles were discussed in Section 3.2.1. For the CHSR trains, these profiles were created to replicate the travel times between the stations provided in the 2016 baseline timetable. For the XpressWest trains, similar acceleration and deceleration profiles to CHSR trains over the XpressWest trains’ operational speeds.

10.1.4: Signaling Systems

The signaling system can be modeled on the VISSIM network simulation using the network object “Signal Heads”. To add a signal head on a link, a signal program is required which can be created using the “Signal Controller” feature. Multiple signal heads can be grouped as a “Signal Group”. Signal programs can be used to control multiple signal groups. Actuated signal programs use detectors to activate signal heads. This can be achieved by using the network object “Detectors”.

A detector can be added on a link and used to detect vehicles during a simulation and collect information such as occupancy, occupied time, number of front ends, and rear ends of vehicles that passed the detector among many others. A group of detectors can be linked to a signal group and programmed to work with signal heads. Multiple signal programs are necessary for attaining the level of signaling required to control various parts of the network.

This study simulates the Fixed Block Signaling System (FBSS) for control of train operations between stations. In FBSS, train movements are governed by automatic signals that are placed at equal distances along the length of the track. The length of the track section between two signals is called a block. A block length should be at least equal to the safe stopping distance of a train. Safe stopping distance is the braking distance plus the distance traveled by train during the reaction time of the driver to recognize the signal and applying the brake. When the FBSS detects a vehicle in a block, the rear signal of the block is switched to red and the signal behind it is switched to amber. The red signal prevents the following train from entering the block where a train is already present and ensures that there is only one train in the block at any given time. The amber signal is a caution to the following train to enter the block at a reduced speed in preparation for a possible following red signal that will require the train to stop. As the train moves forward into the next block, the new block rear signal turns red and the previous, the red signal and the amber signal of the previous blocks turn to amber and green, respectively. This happens continuously as the train travels throughout the length of the track. The capacity of a rail network is dependent on the block length of FBSS. Higher block lengths lead for the trains to travel with increased headways and therefore decreasing the capacity.

However, it has to be noted that CHSRA will implement the Moving Block Signaling System (MBSS). In MBSS, trains communicate their positions with each other actively and are separated by the safe stopping distance. If a train is stopped, the following train immediately recognizes the stopped train, and breaks are applied automatically. The rear ends of the trains are treated as the red block signals. As the MBSS relies on train-to-train communication and automatic braking system it eliminates the necessity for the trains to travel at reduced speed before reaching a red block signal and allows for trains to travel much closer compared to FBSS. As a result, rail networks with MBSS have lesser headways between trains and have higher capacity than a network with FBSS. As VISSIM does not have the feature to enforce the MBSS, modified FBSS is enforced in this study.

VISSIM provides the option to specify a signal head as a block signal head and the reduced speed to enforce on the trains when the block signal head is amber which is referred to as "Amber speed". Block signal heads were then added on the main link with the spacing of a block length between each signal head. During the simulation, VISSIM automatically enforces the FBSS on the main link. The look-ahead distance of the driver of a simulated vehicle can be specified in VISSIM. When the look-ahead distance of the driver is greater than the block length, it allows for the driver to recognize the signal head before-hand and eliminates the necessity to consider the distance traveled by train during the driver reaction time. This allows for lesser block lengths and the ability to simulate train headways slightly closer to the MBSS. Therefore, only the braking distance instead of the safe stopping distance was considered for the block lengths and, look-ahead distance of drivers was given higher than the block length.

To determine the braking distance of the simulated trains in VISSIM, the braking distance was calculated using the speed and deceleration profiles of the trains. The deceleration profile was determined during network calibration. The calculations are shown in Table 4-1 and Table 4-2 for Palmdale - Burbank, and Burbank - Los Angeles sections respectively.

Table 10-1: Braking Distance Calculation for HSR and XpressWest trains for Palmdale - Burbank Section Model

Speed (mph)	Deceleration (ft/s^2)	Distance (miles)
220 - 185	2.4	1.20
185 - 140	2.5	1.19
140 - 0	2.62	1.52
Breaking Distance of CHSR train		3.92

Speed (mph)	Deceleration (ft/s^2)	Distance (miles)
180 - 140	2.5	1.04
140 - 0	2.62	1.53
Breaking Distance of XpressWest train		2.57

The analysis of preliminary simulations showed similar results to the calculations. The braking distance of CHSR trains from 220 mph to a complete halt was determined to be approximately 4 miles. The braking distance of XpressWest trains from 180 mph to rest was approximately 3 miles. The higher value determines the block length. Therefore, a block length of 4 miles was used in the network for the Palmdale - Burbank section and an amber speed of 100 mph was assumed.

Table 10-2: Braking Distance Calculation for CHSR and XpressWest trains for the Palmdale - Burbank Section Model

Speed (mph)	Deceleration (ft/s^2)	Distance (miles)
95-0	2.62	0.70
Breaking Distance of CHSR and XpressWest trains		0.70

For the network section of Burbank - LA, after the network calibration (discussed in section 4.2), the operational speed for both train operators is determined to be 95 mph. The braking distance for both train types from 95 mph to rest was approximately 1 mile. A block length of 1 mile allows for very short headways between trains which may be unsafe for the train operations. Therefore, a block length of 2 miles for the Burbank - LA section and an amber speed of 45 mph were assumed.

10.2: Network Development and Calibration

The VISSIM network model was developed in various stages with additions of the discussed network parameters in Section 4.1, and VisVAP logics of the signaling system for train operations and priorities in the network. During the development, several simulations were run with and without incidents to check if there are errors in trains' operation behavior such as trains not stopping at the stations and trains not following the priority rules. At each stage of development, speed and acceleration profiles of the trains, train stopping and priority behavior at stations, their dwell time, trains' obeyance of signals, and the behavior of block signal system were inspected. If any errors were found, investigations were done using a bottom-up approach investigating from basic network parameters to the programmed VisVAP logics to find the cause for it. On estimating the cause for the error, such as the modeling of a network parameter or the code of the VisVAP logic, it was modified and simulations were run to check if the problem persisted. If the problem persisted, different causes were investigated until the problem was solved.

Calibration was done by changing the train characteristics such as maximum speed, acceleration, and deceleration profiles, and accordingly the block lengths. After the simulation model is calibrated, the maximum operating speed for the CHSR trains for the Burbank to Los Angeles section is determined to be 95 mph to match the simulated CHSR train travel times with those in the baseline timetable. In the 2020 CHSR service plan (CHSRA, 2020c), the maximum operating speed for the Burbank to Los Angeles section is stated as 125 mph. The determined maximum operational speed for the section of the simulation model was less than 125 mph because the trains in reality only reach the speed of 125 mph at a small part of the sections. At grades, curves, and in the city of Los Angeles the trains travel at much lower speeds. As the simulation does not model these details and to match the travel times of the section in the draft timetable, the maximum operational speed for the section was determined to be 95 mph.

10.2.1: Free Flow Train behavior

In the free flow simulation, CHSR and XpressWest train departure from the Palmdale station at specified headways. From Palmdale to Burbank, CHSR trains reach a top speed of 220 mph and XpressWest trains reach a top speed of 180 mph. Arriving CHSR trains at Burbank station travel on its respective station link and stop for 2 minutes, which is the designated station dwell time. XpressWest trains do not stop at the Burbank station and continue to travel at 20 mph till they leave the station. From Burbank to LA, both train types travel at 95 mph. Both train types enter the Los Angeles station at their respective station links and stop at their designated stops.

10.2.2: Simulation of Incidents

In VISSIM, required network objects to create incidents were added to the network model. Then these network objects are controlled during the simulation through Python to create incidents. Signal heads and detectors were placed on the main link at specific locations where incidents were to be created. These signal heads and detectors were assigned to a signal group. This signal group can be used to control the required signal head to switch it to red and turn it off. The detector at the signal head detects the incident and relays information to the rest of the network affecting their behavior.

Primary inputs for the Python code to create an incident are the start time in the simulation, duration of the incident, and the location of the incident by giving the respective signal head. When the Python program is initiated, the VISSIM file of the CHSR network model is opened as an automation server, and simulation is started. At the specified start time, the Python program switches the signal head to red and turns it off after the duration specified. The effect of the incident on the simulation is then analyzed through the data collected.

10.2.3: Train Operations and Priorities at Stations affected by an incident

When an incident occurs, the train affected by it which will be referred to as the “incident train” stops at the incident signal head. When the detector at the incident signal head is occupied by the incident train for more than 15 seconds the incident is observed by the simulation. When the incident is detected, trains that are scheduled to depart at the immediate upstream stations of the incident location are stopped from departing the station. Any trains that are trailing behind the incident train and are already past the immediate upstream station will proceed and, will be stopped at the red block signal heads as specified by FBSS based on the block the incident train is present.

After the designated incident duration, the incident signal head turns off and, the incident train resumes moving. The occupancy of the incident detector will be '0' when the incident train completely moves away from it and the incident will be cleared off. The trains trailing behind the incident train will resume moving following the normal rules of the block signals as the FBSS specifies. However, in the Palmdale - Burbank section, a stopped CHSR train will only start moving when the train ahead of it crosses the first two blocks and when the blocks are empty. This ensures that there is safe headway between two successive CHSR trains and between a CHSR train trailing an XpressWest train such that the high-speed CHSR train does not catch up to the slow-moving XpressWest train avoiding any possibility of a collision happening. An XpressWest train stopped at this section will resume operations according to the rules of the FBSS. Within the Burbank - Los Angeles section, both train types stopped at the stations will resume operations as the FBSS specifies.

At stations, depending on the incident duration many trains may be stopped. Priorities for train departures after an incident are necessary to prevent excess delay for any vehicle type. CHSR trains have higher priority over XpressWest trains. All CHSR trains that are scheduled to depart before an XpressWest train will depart before it. CHSR trains that are scheduled to depart after the XpressWest train will depart before the XpressWest train depending on the time the XpressWest train is delayed at the station. If an XpressWest train is delayed for less than 10 minutes, a CHSR train will overtake the XpressWest train. If the XpressWest train is delayed for more than 10 minutes, no CHSR train is allowed to overtake and will be departed in the scheduled order. This priority system ensures that the delay caused by XpressWest trains to CHSR trains is minimized while not delaying XpressWest trains excessively.

If an incident happens at the main link between Burbank and Los Angeles stations, the train scheduled to depart at Burbank will stop at Burbank. This includes XpressWest trains that do not stop at Burbank during normal operations. The two links that act as platforms at the stations were programmed to contain a maximum of 5 trains, 3 CHSR trains, and 2 XpressWest trains at their designated links. If the incident is long enough, the trains arrive at Burbank and are stopped at their respective links. If the capacity of either of the links at Burbank is filled, the next train stops behind the Burbank station. This train is detected by the network and any trains that are scheduled to depart from Palmdale will be stopped at the station. Any trains that have already departed before the detection will be stopped at the block signal heads by FBSS. After the incident clears, the trains depart from Burbank with minimum possible headways as directed by the FBSS. As the trains depart from Burbank, the trains stopped behind the Burbank station are allowed into links. Trains at Palmdale are allowed to depart if no train is stationary on the main link before Burbank.

10.3: Processing the Simulation Data

A Python program code is written to process raw data, perform initial data analysis, generate graphs to visualize data, and write the processed data into an Excel file for further data analysis and data presentation. The raw data generated by VISSIM is loaded into Python. The data is saved as a data frame. Python program then sorts the data by time and creates a data frame for each train.

Data analysis is performed on each train data frame and for each train, a timetable is generated. This timetable consists of information on the stations, arrival and departure times at stations. Later it compiles the timetables of all trains into a 'Network Timetable" data frame. Each data frame is then written into a sheet in an excel file. Along with the excel file, plots of distance vs time, speed vs distance, speed vs time, and headway vs time for the whole network are generated and stored as a PDF file.

For performing analysis on incident simulation data, along with the raw data file and a free flow data file is loaded into Python. The free flow data file consists of information of all vehicles at free flow. The timetable for each vehicle generated by Python for incident simulations also consists of information comparing the incident times with the free flow time and on various delays. The types of delays considered were discussed in detail in Section 3.2.3. Tables consisting of delay information of all vehicles for each type of delay are generated. These tables are written to the excel file in the same sheet as the network timetable. A summary table with information on which train is affected by the incident, incident location and duration, all the trains that are affected, and total delays for all trains and each train type is generated and written to a new sheet in the excel file.

10.4: Development of Simulation Scenarios for Normal and Incident Operations

10.4.1: Development of Network Timetable for Normal Operations

The baseline timetable for Phase 1 operations that was reported in the 2016 CHSR Service Planning Methodology report (CHSRA, 2016) was the basis for scheduling of the simulation for train service under normal (i.e., non-incident) conditions. This timetable consisted of the arrival and departures of CHSR trains at the stations during their revenue service period and only the timetable for the Palmdale to Los Angeles section was extracted. The revenue service period is 18 hours a day with 6 hours of the peak period with 7 trains per hour and 12 hours of the off-peak period with 5 trains per hour. The timetable was modified to accommodate 3 XpressWest trains per hour during the peak period and two trains per hour during the off-peak period. This was done while making sure that the minimum headway requirements are not violated. Only one hour of the peak period and one hour of the off-peak period were simulated. The resulting timetables for the peak and off-peak period are shown in Tables 4-3 and 4-4.

Table 10-3: Peak Hour Timetable for the Simulation Model

Train name numbered by the sequence of departure from Palmdale station	Timetable	Headway between all trains	Headway between CHSR trains only (Generated Headways)	Headway between XpressWest trains only
CHSR 1	0:00			
XpW1	0:07	0:07		
CHSR 2	0:18	0:11	0:18	
CHSR 3	0:24	0:06	0:06	
CHSR 4	0:29	0:05	0:05	
XPW2	0:34	0:05		0:27
CHSR 5	0:40	0:06	0:11	
CHSR 6	0:45	0:05	0:05	
XPW3	0:49	0:04		0:15
CHSR 7	0:55	0:06	0:10	

Table 10-4: Off-Peak Hour Timetable for the Simulation Model

Train name numbered by the sequence of departure from Palmdale station	Timetable	Headway between all trains	Headway between CHSR trains only (Generated Headways)	Headway between XpressWest trains only
CHSR 1	0:00			
CHSR 2	0:05	0:05	0:05	
XPW 1	0:11	0:06		
CHSR 3	0:19	0:08	0:14	
CHSR 4	0:24	0:05	0:05	
XPW 2	0:35	0:11		0:24
CHSR 5	0:47	0:12	0:23	

For the peak hour simulation, there were a total of 10 trains, 7 CHSR trains, and 3 XpressWest trains. The average headway between CHSR trains and between XpressWest train was 9 minutes and 21 minutes respectively. Between all the trains the average headway was 6 minutes. In the off-peak hour network timetable, there were 5 CHSR trains and 2 XpressWest trains. The average headway between all the trains is 8 minutes while it is 12 and 24 minutes between CHSR trains and XpressWest trains, respectively. These schedules result in train-miles of service summarized in Table 4-5.

Table 10-5: Train-miles of Service for the Palmdale to Los Angeles Service

Parameter	Peak Period	Off-peak Period	Total
Hours of operation per day	6	12	18
Number of CHSR trains per hour	7	5	
Number of XpressWest trains per hour	3	2	
Total length of section one-way (miles)	57	57	
CHSR train-miles per day	4,788	6,840	11,628
XpressWest train-miles per day	2,052	2,736	4,788
CHSR train-miles per year	1,747,620	2,496,600	4,244,220
XpressWest train-miles per year	748,980	998,640	1,747,620
Total train-miles per year	2,496,600	3,495,240	5,991,840

10.4.2: Development of Simulation Scenarios for Operations under Incident Conditions

The data used to determine the frequency and characteristics of incidents to be simulated was based on data from the Chinese Shanghai – Jiangshan HSR line. The data showed that there was an average of 3 incidents per million train-miles of operation, and the average duration of the incidents was 23.3 minutes (Table 4-6). This value is then used to compute the number of incidents that might occur for the Palmdale - Los Angeles network section.

Table 10-6: Timetable Analysis of Shanghai – Jiangshan High-Speed Rail line

Number of trains	337
Train-miles per day	48,711
Train-miles per year	17,779,515
Number of incidents per year	54
Number of incidents per million train-miles	3

The average number of incidents that may occur per year is then calculated based on the estimated total number of train-miles of combined service (CHSR and XpressWest) per year (Table 4-7). The result is 18 incidents per year, broken down into 7 and 11 during the peak and off-peak periods, respectively. Also, based on the proportional train-miles of service, 13 of the incidents will be caused by CHSR trains, and the remining 5 by XpressWest trains.

Table 10-7: Estimated annual number of incidents for the Palmdale – Los Angeles section.

Parameter	Peak Period	Off-peak Period	Total
CHSR train-miles per year	1,747,620	2,496,600	4,244,220
XpressWest train-miles per year	748,980	998,640	1,747,620
Total train-miles per year	2,496,600	3,495,240	5,991,840
Total number of incidents per year	7	11	18
Incidents caused by CHSR trains	5	8	13
Incidents caused by XpressWest trains	2	3	5

To estimate the average impact of each incident, 60 and 42 incident scenarios were randomly generated and simulated for the peak and off-peak periods, respectively. Each incident scenario had randomly generated parameters including the location, time of occurrence, duration of the incident, and the train causing the incident. The incident durations were randomly generated so as to produce a similar statistical distribution (i.e., mean, std deviation, maximum and minimum durations) as observed in the Shanghai - Jianshan incident data (Table 4-8). Only incidents that occur between stations were considered. The impact of each incident in terms of the number of trains affected and the resulting schedule delays were calculated and were the basis for estimating the overall average impact of each incident.

Table 10-8: Summary Statistics of Incident Durations for Shanghai – Jiangshan High-Speed Rail line and Generated Random Incident Durations for the Simulation Model.

Parameter	Shanghai-Jiangshan High-Speed Rail line	Palmdale-Los Angeles California High-Speed Rail network section (Generated Durations)			
Service hours	24 hours	Peak Hours		Off Peak Hours	
Train type	High-speed trains	CHSR	XPW	CHSR	XPW
Number of incidents	54	42	18	30	12
Maximum duration of an incident	2:11	2:25	2:00	1:52	1:30
Minimum duration of an incident	0:01	0:01	0:01	0:01	0:01
Average incident duration	0:23	0:24	0:24	0:23	0:23
Standard deviation of incident durations	0:30	0:30	0:30	0:29	0:30
Note: All durations are in H:MM					

10.5: Analysis of Incident Simulation Output Data

Below is a discussion of the outputs of five selected incident simulations, two for the off-peak period and three for the peak period., i.e.,

Off-peak hour service

1. Simulation 1: Incident caused by the train CHSR 1 with a duration of 6.5 minutes
2. Simulation 2: Incident caused by the train XpressWest 1 with a duration of 90.25 minutes

Peak hour service

3. Simulation 3: Incident caused by the train XpressWest 1 with a duration of 6.5 minutes
4. Simulation 4: Incident caused by the train CHSR 3 with a duration of 16.82 minutes
5. Simulation 5: Incident caused by the train XpressWest 1 with a duration of 23.13 minutes

To distinguish between CHSR and XpressWest trains in the plots, trajectories of all CHSR trains were colored red, and trajectories of all XpressWest train were colored blue.

10.5.1: Off-Peak Hour Incident Simulations

Table 4-9 shows the timetable of off-peak hour service with arrival and departure times of all trains at all the stations. Figure 4-3 shows the distance vs time plots of all the trains under normal operations for off-peak period.

Table 10-9: Free Flow Timetable of Off-Peak Hour Service Timetable

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5
Palmdale	DEP	0:00	0:05	0:11	0:19	0:24	0:35	0:47
Burbank	ARR	0:15	0:20	0:28	0:34	0:39	0:52	1:02
Burbank	DEP	0:17	0:22	0:28	0:36	0:41	0:52	1:04
Los Angeles	ARR	0:27	0:33	0:39	0:47	0:52	1:03	1:15
Note: All times are in H:MM								

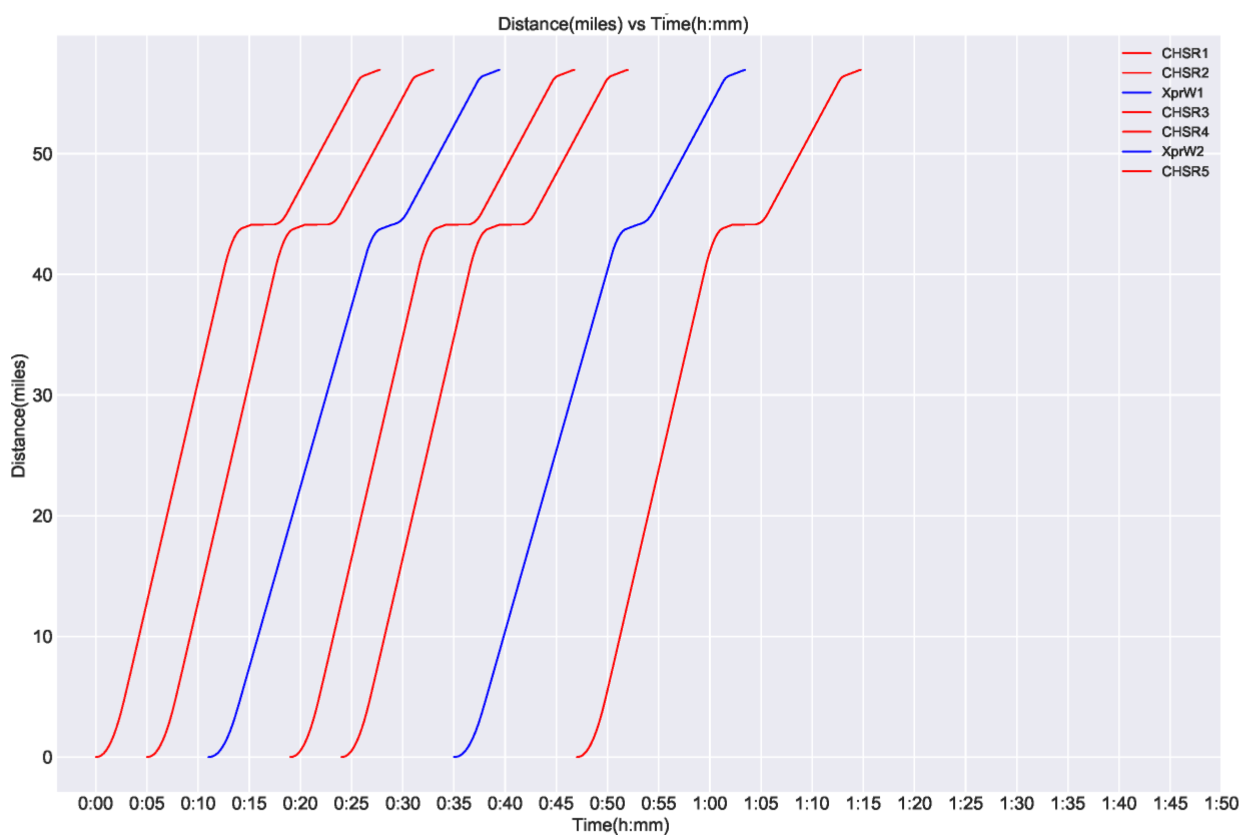


Figure 10-1: Distance vs Time Plot for Free-Flow Simulation of Off-Peak Hour Service Timetable (Red – CHSR; Blue – XpressWest)

Incident Simulation 1

The train CHSR 1 caused the incident for a duration of 6.5 minutes at the location 6, 10.5 miles from Burbank station. The timetable and delay summaries for the simulation are shown in Table 4-10. The distance vs time plot shown in Figure 4-4 for all the trains in this simulation depicts the effect of the incident on the network.

Table 10-10: Schedule Delay Summaries under Incident Simulation 1

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5
Palmdale	DEP	0:00	0:05	0:11	0:19	0:24	0:35	0:47
Burbank	ARR	0:15	0:20	0:29	0:34	0:39	0:52	1:02
Burbank	DEP	0:17	0:22	0:33	0:36	0:41	0:52	1:04
Los Angeles	ARR	0:35	0:38	0:43	0:47	0:52	1:03	1:15
Note: All times are in H:MM								

(a) Departure-Arrival times under Incident Simulation 1

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5	Network Total
Palmdale	DEP	-	-	-	-	-	-	-	
Burbank	ARR	-	-	0:01	-	-	-	-	
Burbank	DEP	-	-	0:05	-	-	-	-	
Los Angeles	ARR	0:08	0:05	0:05	-	-	-	-	
Total Schedule Delay		0:08	0:05	0:05	-	-	-	-	0:18
Note: All times are in H:MM									

(b) Schedule Delays for Incident Simulation 1

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5	Network Total
Palmdale	DEP	-	-	-	-	-	-	-	
Burbank	DEP	-	-	0:05	-	-	-	-	
Total Station Delay		-	-	0:05	-	-	-	-	0:05
Note: All times are in H:MM									

(c) Station Delays for Incident Simulation 1

Between Stations	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5	Network Total
Palmdale - Burbank	-	-	-	-	-	-	-	
Burbank - Los Angeles	0:08	0:05	-	-	-	-	-	
Total Running Time Delay	0:08	0:05	-	-	-	-	-	0:13
Note: All times are in H:MM								

(d) Running Time Delays for Incident Simulation 1

Train CHSR 2 was trailing the CHSR 1 between the stations Burbank and Los Angeles when the incident was caused by CHSR 1. When the CHSR 1 was stopped at the incident location, the FBSS stopped the CHSR 2 a block behind the block CHSR 1 was present. XpressWest 1 was stopped at the Burbank as there was an incident at the link. Once the incident was cleared, CHSR 1 resumes moving and when the block ahead of CHSR 2 was empty, it was allowed to resume moving with a restricted speed of 45 mph by FBSS. This can be observed in the plot and depicted by the difference in the slope of the CHSR 2 movement. The change in the slope to a steeper slope represents the train accelerating to its operational speed of 95 mph on the Burbank - Los Angeles section. Both CHSR 1 and CHSR 2 experienced running time delays as they were delayed between the stations. The XpressWest 1 leaves the Burbank station after CHSR 2 resumes moving and experienced station delay as it was delayed at the Burbank station.

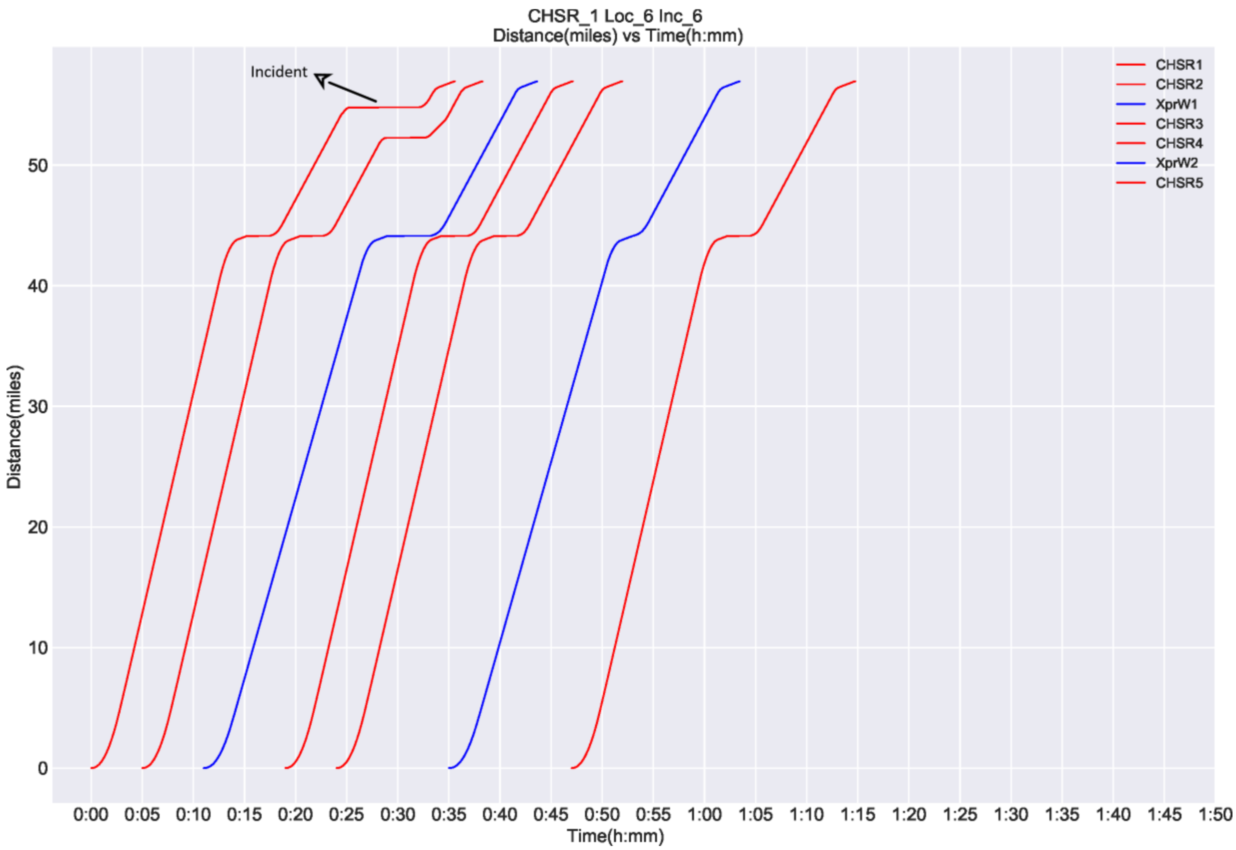


Figure 10-2: Distance vs Time Plot for Incident Simulation 1

Incident Simulation 2

In this scenario, the first XpressWest train in the timetable was the cause of an incident with a duration of 90.25 minutes. The location of the incident is location 1, 10 miles from the Palmdale station. The effect of this incident on the network is shown in the incident timetable and delay summaries in Table 4-11 and the space-time plot in Figure 4-5.

Table 10-11: Schedule Delay Summaries under Incident Simulation 2

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5
Palmdale	DEP	0:00	0:05	0:11	1:49	1:53	1:56	2:02
Burbank	ARR	0:15	0:20	2:01	2:05	2:09	2:15	2:17
Burbank	DEP	0:17	0:22	2:01	2:07	2:11	2:15	2:19
Los Angeles	ARR	0:28	0:33	2:12	2:17	2:22	2:26	2:30
Note: All times are in H:MM								

(a) Departure-Arrival times under Incident Simulation 2

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5	Network Total
Palmdale	DEP	-	-	-	1:30	1:29	1:21	1:15	
Burbank	ARR	-	-	1:33	1:31	1:30	1:22	1:15	
Burbank	DEP	-	-	1:33	1:31	1:30	1:22	1:15	
Los Angeles	ARR	-	-	1:33	1:31	1:30	1:22	1:15	
Total Schedule Delay		-	-	1:33	1:31	1:30	1:22	1:15	7:11
Note: All times are in H:MM									

(b) Schedule Delays for Incident Simulation 2

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5	Network Total
Palmdale	DEP	-	-	-	1:30	1:29	1:21	1:15	
Burbank	DEP	-	-	-	-	-	-	-	
Total Station Delay		-	-	-	1:30	1:29	1:21	1:15	5:35
Note: All times are in H:MM									

(c) Station Delays for Incident Simulation 2

Between Stations	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5	Network Total
Palmdale - Burbank	-	-	1:33	0:01	0:01	0:01	-	
Burbank - Los Angeles	-	-	-	-	-	-	-	
Total Running Time Delay	-	-	1:33	0:01	0:01	0:01	-	1:36
Note: All times are in H:MM								

(d) Running Time Delays for Incident Simulation 2

By the time XpressWest 1 was affected by the incident between Palmdale and Burbank station, no train departed from Palmdale station. Therefore, for the duration of the incident, no train was departed from the Palmdale station. After the incident was cleared and the XpressWest 1 resumed operation, CHSR 3 which was scheduled next was allowed to depart. The trains later departed with the minimum headways possible between the trains by the FBSS. The train XpressWest 2 was delayed for more than 10 minutes at the Palmdale station. Therefore, train CHSR 5 following it doesn't overtake the XpressWest 2. Since all affected trains except for the incident train were delayed at Palmdale station they experienced station delay and minor running time delay due to the signaling system.

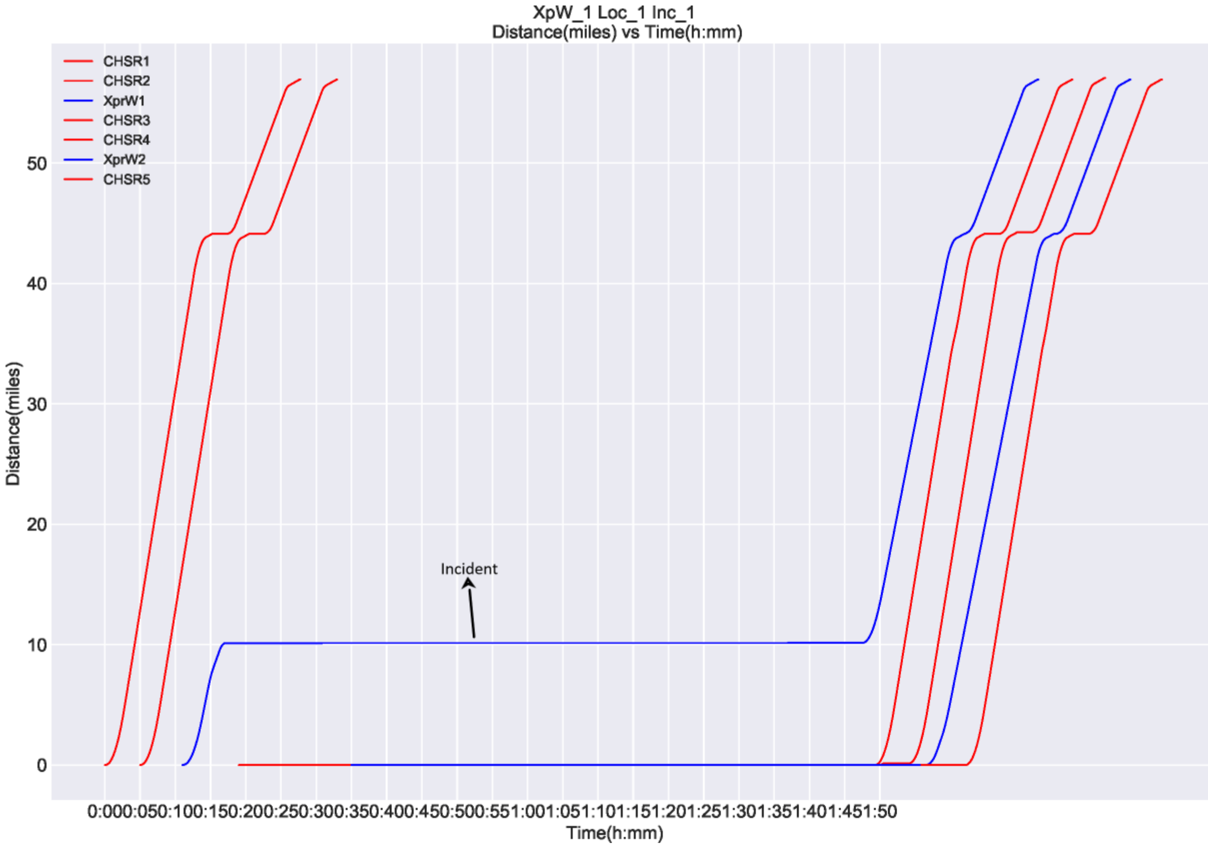


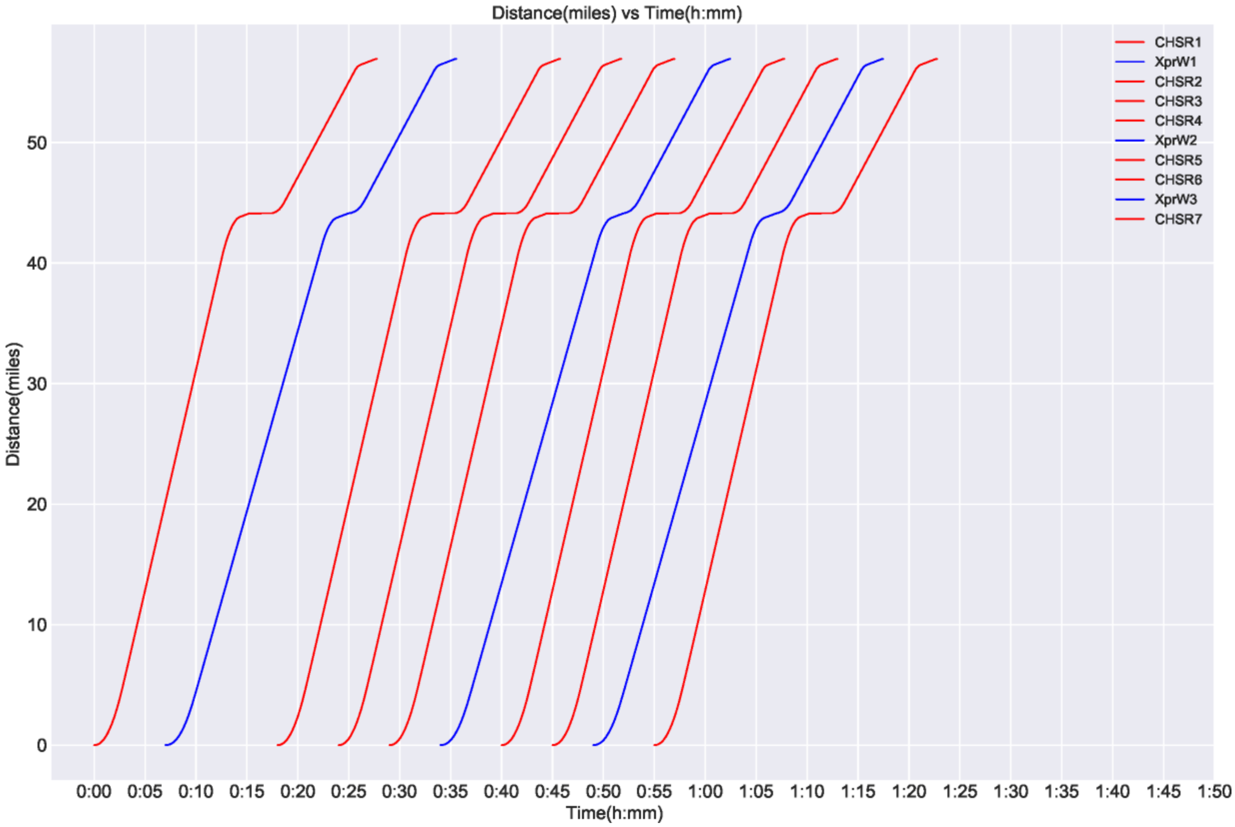
Figure 10-3: Distance vs Time Plot for Incident Simulation 2

10.5.2: **Peak Hour Incident Simulations**

The peak hour schedule with arrival and departure times of all trains at all the stations is shown in Table 4-12. The distance vs time plots of all the trains in the free flow simulation of the peak hour timetable is shown the Figure 4-6.

Table 10-12: Free Flow Timetable of Peak Hour Service Timetable

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7
Palmdale	DEP	0:00	0:07	0:18	0:24	0:29	0:34	0:40	0:45	0:49	0:55
Burbank	ARR	0:15	0:24	0:33	0:39	0:44	0:51	0:55	1:00	1:06	1:10
Burbank	DEP	0:17	0:24	0:35	0:41	0:46	0:51	0:57	1:02	1:06	1:12
Los Angeles	ARR	0:28	0:35	0:46	0:52	0:57	1:02	1:08	1:13	1:17	1:23
Note: All times are in H:MM											



– CHSR; Blue – XpressWest)

Figure 10-4: Distance vs Time Plot for Simulation of Incident-free Peak Hour Service (Red)

Incident Simulation 3

The incident occurred at the location 3.5 miles from Burbank station for a duration of 32.92 minutes and was caused by XpressWest train 1. All the trains scheduled to depart after the XpressWest train were affected. The incident schedule and delay summaries of the affected trains are shown in Table 4-13 and the effect of the incident on these trains are in Figure 4-7.

Table 10-13: Schedule Delay Summaries under Incident Simulation 3

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7
Palmdale	DEP	0:00	0:07	0:18	0:24	0:29	0:34	0:40	0:45	0:49	1:12
Burbank	ARR	0:15	0:24	0:33	0:39	0:44	0:52	1:12	1:15	1:18	1:27
Burbank	DEP	0:17	0:24	1:03	1:05	1:08	1:13	1:34	1:19	1:24	1:29
Los Angeles	ARR	0:28	1:10	1:14	1:18	1:21	1:24	1:45	1:31	1:35	1:40
Note: All times are in H:MM											

(a) Departure-Arrival times under Incident Simulation 3

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale	DEP	-	-	-	-	-	-	-	-	-	0:17	
Burbank	ARR	-	-	-	-	-	-	0:17	0:15	0:12	0:17	
Burbank	DEP	-	-	0:28	0:26	0:24	0:22	0:37	0:17	0:18	0:17	
Los Angeles	ARR	-	0:35	0:28	0:26	0:24	0:22	0:37	0:18	0:18	0:17	
Total Schedule Delay			0:35	0:28	0:26	0:24	0:22	0:37	0:18	0:18	0:17	3:45
Note: All times are in H:MM												

(b) Schedule Delays for Incident Simulation 3

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale	DEP	-	-	-	-	-	-	-	-	-	0:17	
Burbank	DEP	-	-	0:28	0:26	0:24	0:22	0:20	0:02	0:06	-	
Total Station Delay				0:28	0:26	0:24	0:22	0:20	0:02	0:06	0:17	2:25
Note: All times are in H:MM												

(c) Station Delays for Incident Simulation 3

Between Stations	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale - Burbank	-	-	-	-	-	-	0:17	0:15	0:12	-	
Burbank - Los Angeles	-	0:35	-	-	-	-	-	0:01	-	-	
Total Running Time Delay	-	0:35	-	-	-	-	0:17	0:16	0:12	-	1:20
Note: All times are in H:MM											

(d) Running Time Delays for Incident Simulation 3

All trains that were scheduled to depart after CHSR 2 from Burbank were halted at the station. The platform dedicated to the CHSR trains allows for a maximum of 3 trains and this can be observed in the figure. The XpressWest train arrived at its designated link at Burbank and was stopped. The trains CHSR 2, 3, 4, and XpressWest 2 experienced station delay at Burbank. The CHSR 5 was stopped behind the Burbank station as the CHSR platform was at capacity. CHSR 5 was detected by the simulation and the CHSR 7 was stopped at Palmdale. CHSR 6 and XpressWest 3 were trailing CHSR 5 and were stopped between Palmdale and Burbank at the block signal heads specified by FBSS. As XpressWest 1 cleared the incident and resumed moving, all trains were departed from Burbank with minimum possible headways specified by FBSS. No CHSR train was allowed to overtake XpressWest 2 as it was delayed for more than 10 minutes. The trains behind the Burbank started to move as the vacancy was created at the platforms at Burbank. The trains CHSR 5, 6, and XpressWest 2 experienced running time delay between Palmdale and Burbank and station delay at Burbank. CHSR 7 was departed from Palmdale after XpressWest 3 resumed operation. CHSR 7 experienced station delay at Palmdale.

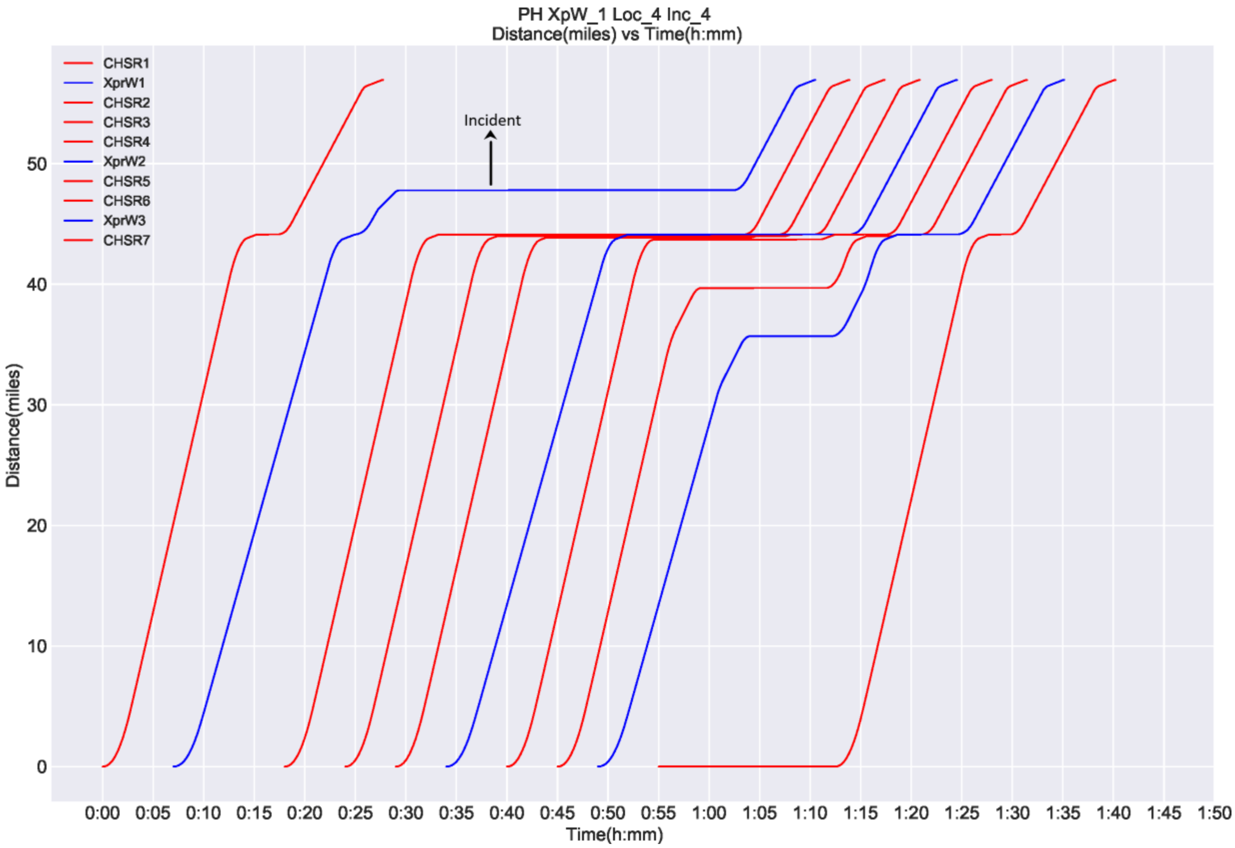


Figure 10-5: Distance vs Time Plot for Incident Simulation 3

Incident Simulation 4

An incident with a duration of 16.82 minutes was caused by the CHSR 3 train at a location 7 miles from Burbank station. Six trains were affected by the incident. The incident timetable and delay summaries are shown in Table 4-14 and their trajectories were portrayed in Figure 4-8.

Table 10-14: Schedule Delay Summaries under Incident Simulation 4

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7
Palmdale	DEP	0:00	0:07	0:18	0:24	0:29	0:34	0:40	0:45	0:49	0:55
Burbank	ARR	0:15	0:24	0:33	0:39	0:44	0:52	0:55	1:00	1:07	1:10
Burbank	DEP	0:17	0:24	0:35	0:41	0:46	1:07	1:09	1:13	1:21	1:16
Los Angeles	ARR	0:28	0:35	0:46	1:10	1:13	1:18	1:20	1:24	1:32	1:27
Note: All times are in H:MM											

(a) Departure-Arrival times under Incident Simulation 4

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale	DEP	-	-	-	-	-	-	-	-	-	-	
Burbank	ARR	-	-	-	-	-	-	-	-	-	-	
Burbank	DEP	-	-	-	-	-	0:15	0:12	0:11	0:14	0:04	
Los Angeles	ARR	-	-	-	0:18	0:16	0:15	0:12	0:11	0:14	0:04	
Total Schedule Delay		-	-	-	0:18	0:16	0:15	0:12	0:11	0:14	0:04	1:30
Note: All times are in H:MM												

(b) Schedule Delays for Incident Simulation 4

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale	DEP	-	-	-	-	-	-	-	-	-	-	
Burbank	DEP	-	-	-	-	-	0:15	0:12	0:11	0:14	0:04	
Total Station Delay		-	-	-	-	-	0:15	0:12	0:11	0:14	0:04	0:56
Note: All times are in H:MM												

(c) Station Delays for Incident Simulation 4

Between Stations	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale - Burbank	-	-	-	-	-	-	-	-	-	-	
Burbank - Los Angeles	-	-	-	0:18	0:16	-	-	-	-	-	
Total Running Time Delay	-	-	-	0:18	0:16	-	-	-	-	-	0:34
Note: All times are in H:MM											

(d) Running Time Delays for Incident Simulation 4

The incident by CHSR 3 occurred near the rear end of a block. CHSR 4 can be observed slowing down to the restricted speed by amber block signal head two blocks before the incident block. CHSR 4 which immediately behind the incident train and had already left the station was stopped at the red block signal head at the block before the incident block. Al the other following trains were held at Burbank until the incident was cleared.

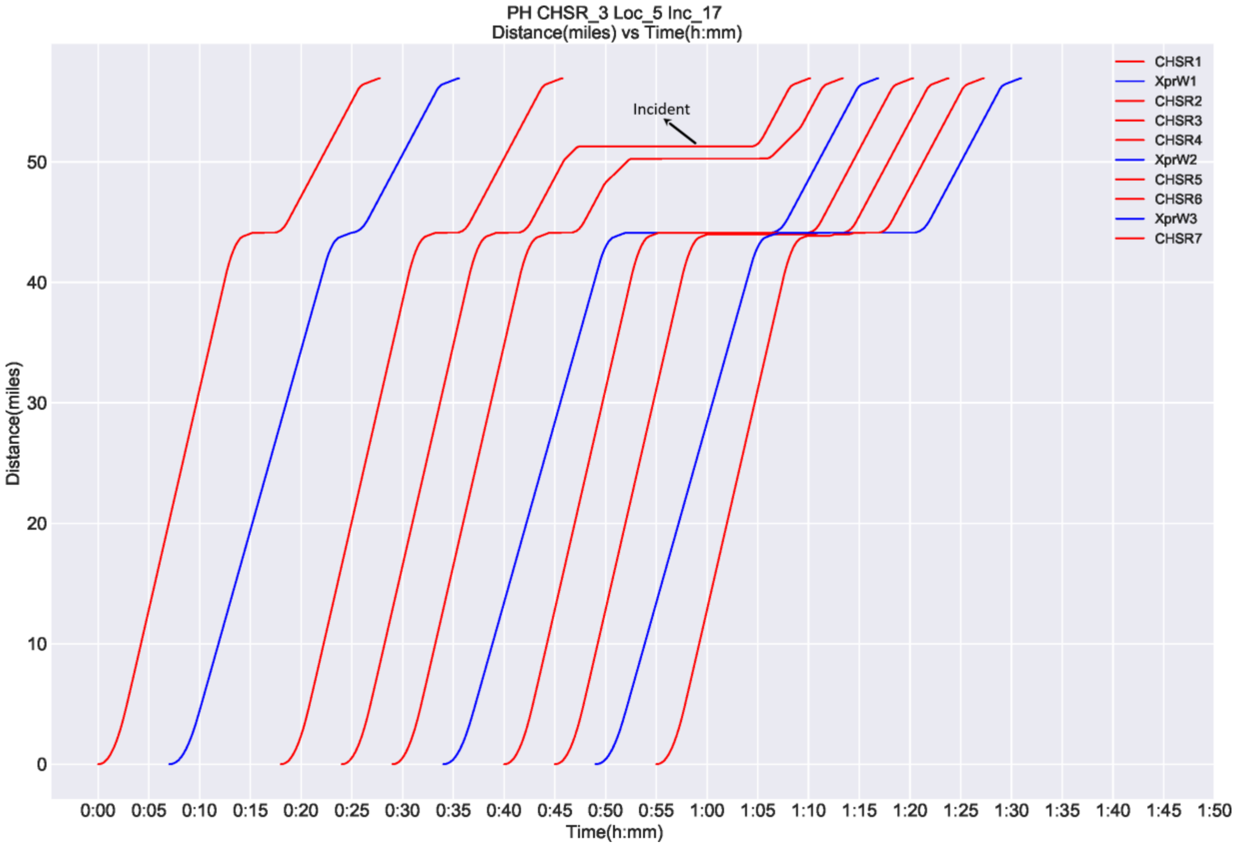


Figure 10-6: Distance vs Time Plot for Incident Simulation 4

Incident Simulation 5

In this case, the incident, caused by the XpressWest 2 train, occurs 10 miles from Palmdale station and last for 23.13 minutes. Five trains were delayed. The schedule delay summaries are shown in Table 4-15 and the corresponding distance-time plots are shown in Figure 4-9.

Table 10-15: Schedule Delay Summaries under Incident Simulation 5

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7
Palmdale	DEP	0:00	0:07	0:18	0:24	0:29	0:34	1:05	1:10	1:12	1:18
Burbank	ARR	0:15	0:24	0:33	0:39	0:44	1:17	1:20	1:25	1:31	1:33
Burbank	DEP	0:17	0:24	0:35	0:41	0:46	1:17	1:22	1:27	1:31	1:35
Los Angeles	ARR	0:28	0:35	0:46	0:52	0:57	1:28	1:34	1:39	1:42	1:46
Note: All times are in H:MM											

(a) Departure-Arrival times under Incident Simulation 5

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale	DEP	-	-	-	-	-	-	0:25	0:25	0:23	0:23	
Burbank	ARR	-	-	-	-	-	0:26	0:25	0:25	0:23	0:23	
Burbank	DEP	-	-	-	-	-	0:26	0:25	0:25	0:23	0:23	
Los Angeles	ARR	-	-	-	-	-	0:26	0:25	0:25	0:23	0:23	
Total Schedule Delay		-	-	-	-	-	0:26	0:25	0:25	0:23	0:23	1:30
Note: All times are in H:MM												

(b) Schedule Delays for Incident Simulation 5

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale	DEP	-	-	-	-	-	-	0:25	0:25	0:23	0:23	
Burbank	DEP	-	-	-	-	-	-	-	-	-	-	
Total Station Delay		-	-	-	-	-	-	0:25	0:25	0:23	0:23	0:56
Note: All times are in H:MM												

(c) Station Delays for Incident Simulation 5

Between Stations	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7	Network Total
Palmdale - Burbank	-	-	-	-	-	0:26	-	-	-	-	
Burbank - Los Angeles	-	-	-	-	-	-	-	-	-	-	
Total Running Time Delay	-	-	-	-	-	0:26	-	-	-	-	0:34
Note: All times are in H:MM											

(d) Running Time Delays for Incident Simulation 5

The incident was detected by the signaling system before any of the following trains departed from the Palmdale station. The trains were held at the station until the incident was cleared and the XpressWest 2 resumed traveling. The delayed trains at the Palmdale station departed with the minimum possible headways.

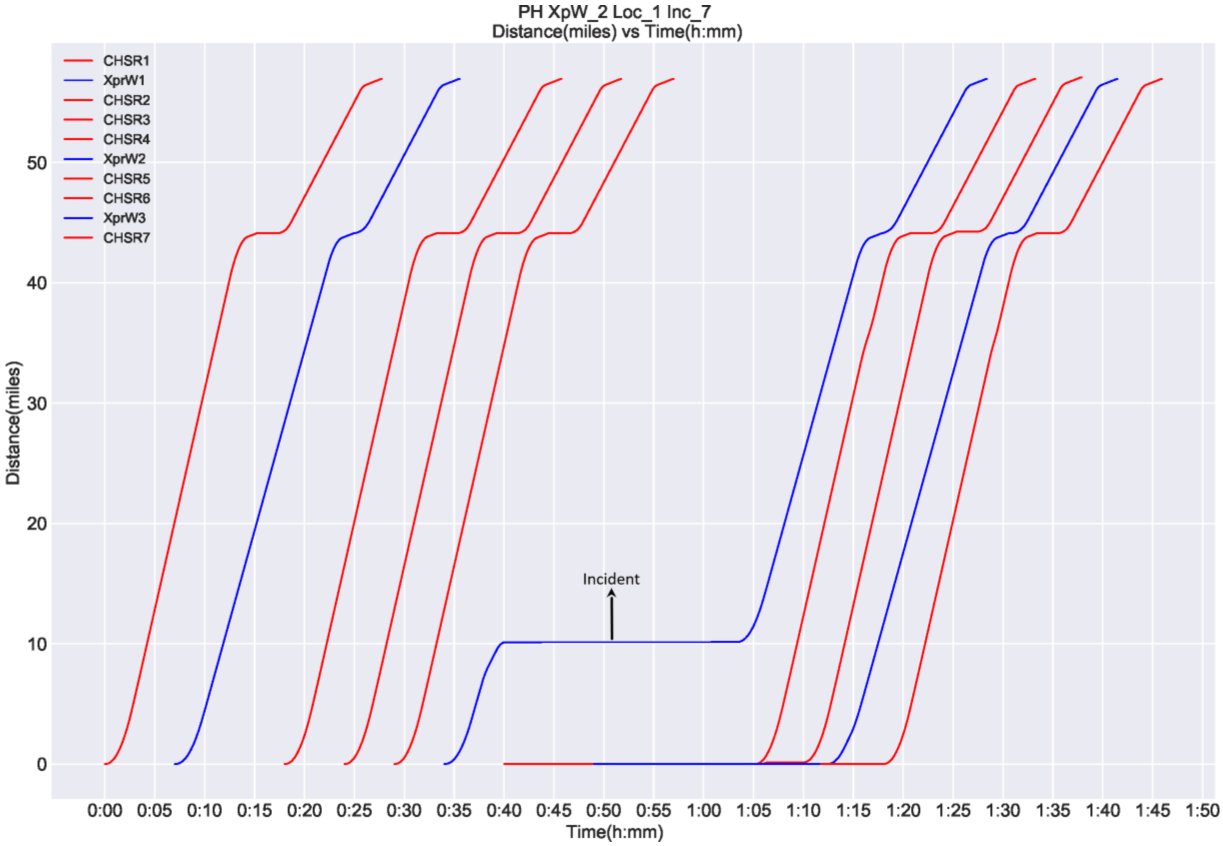


Figure 10-7: Distance vs Time Plot for Incident Simulation

Chapter 11: Analysis of Results

11.1: Free-flow Travel Times and Shortest Allowable Headways

Table 5-1 below shows the free-flow travel times from Palmdale to Los Angeles for both trains.

Table 11-1: Free-Flow Travel Times of the Train Types in the Simulation Model

		CHSR Train		XpressWest Train	
Station	Arrival (ARR) / Departure (DEP)	Time	Travel time	Time	Travel time
Palmdale	DEP	0:00		0:00	
Burbank	ARR	0:15	0:15	0:17	0:17
Burbank	DEP	0:17		0:17	
Los Angeles	ARR	0:28	0:11	0:28	0:11
Note: Times are denoted in H:MM					

From Palmdale to Burbank, travel times for CHSR and XpressWest trains are 15 minutes and 17 minutes respectively. CHSR has a dwell time of two minutes at Burbank station while XpressWest has no scheduled stopping at Burbank, as it may not be allowed to pick up local passengers. Travel times for CHSR and XpressWest train from Burbank to Los Angeles are 10 minutes and 11 minutes respectively as they both have the same operational speeds at this link. Hence, the total time for both CHSR and XpressWest trains from Palmdale to Los Angeles, including the dwell time at Burbank, is 28 minutes (Table 5-1).

To determine the shortest allowable headways between successive trains, the following cases were analyzed, namely,

1. For a CHSR train trailing a CHSR train
2. For an XpressWest train trailing a CHSR train
3. For a CHSR train trailing an XpressWest train

The study did not consider the scenarios for an XpressWest trailing an XpressWest train because XpressWest service will not be frequent enough to generate successive trains. To determine the minimum allowable headways, simulations at various headways between each train types were run. The minimum allowable headway is the shorted headway that allows a following train to travel at its free-flow travel time without being slowed down by catching-up to the leading train. Based on the simulation results, the study determined the minimum headways between train types as:

1. Five (5) minutes headway for a CHSR train trailing a CHSR train
2. Four (4) minutes headway for an XpressWest train trailing a CHSR train
3. Six (6) minutes headway for a CHSR train trailing an XpressWest train

The following equations gives the relationship between the number of CHRS and XpressWest trains when the corridor is operating at capacity, i.e.,

$$N_{CHSR} = \frac{60}{h_1} - \frac{N_{Xwest}(h_2+h_3-h_1)}{h1}$$

where N_{CHSR} = the maximum number of CHSR trains/hour
N_{Xwest} = the number of XpressWest trains/hour
h_1 = minimum headway between CHSR trains
h_2 = minimum headway when XpressWest trails CHSR
h_3 = minimum headway when CHSR trails XpressWest

Since h_1 = 5 minus, h_2 = 4 minutes and h_3 = 6 minutes, the formula translates to $N_{CHSR} = 12 - N_{XWest}$,

This means that when the corridor is running at full capacity, for each XpressWest train to be included in the schedule, one CHSR train will have to be removed. However, based on the published timetable for Phase 1, CHSRA plans to run seven (7) trains per hour during the peak period, XpressWest can operate on the corridor without impacting CHSRA operations.

11.2: Simulation Results for Normal Train Operations

Simulations for normal (i.e., incident-free) train operations were done for both the peak and off-peak period, based on the CHSRS proposed timetables for Phase 1 Operations.

11.2.1: **Peak Period Operations**

CHSR Phase 1 operations for the peak period involved 7 CHSR and 3 XpressWest trains per hour each direction. The peak period has a total of six hours per day, from 6 am to 9 am and 3 pm to 6 pm. One hour of the of the peak period operations in one direction, Palmdale to Los Angeles, was simulated based on the developed timetable in Table 5-2. The resulting time-space diagram is shown in Figure 5-1.

Table 11-2: Peak-period timetable with free-flow travel times

Station	Arrival (ARR) / Departure (DEP)	CHSR1	XprW1	CHSR2	CHSR3	CHSR4	XprW2	CHSR5	CHSR6	XprW3	CHSR7
Palmdale	DEP	0:00	0:07	0:18	0:24	0:29	0:34	0:40	0:45	0:49	0:55
Burbank	ARR	0:15	0:24	0:33	0:39	0:44	0:51	0:55	1:00	1:06	1:10
Burbank	DEP	0:17	0:24	0:35	0:41	0:46	0:51	0:57	1:02	1:06	1:12
Los Angeles	ARR	0:28	0:35	0:46	0:52	0:57	1:02	1:08	1:13	1:17	1:23
Note: All times are in H:MM											

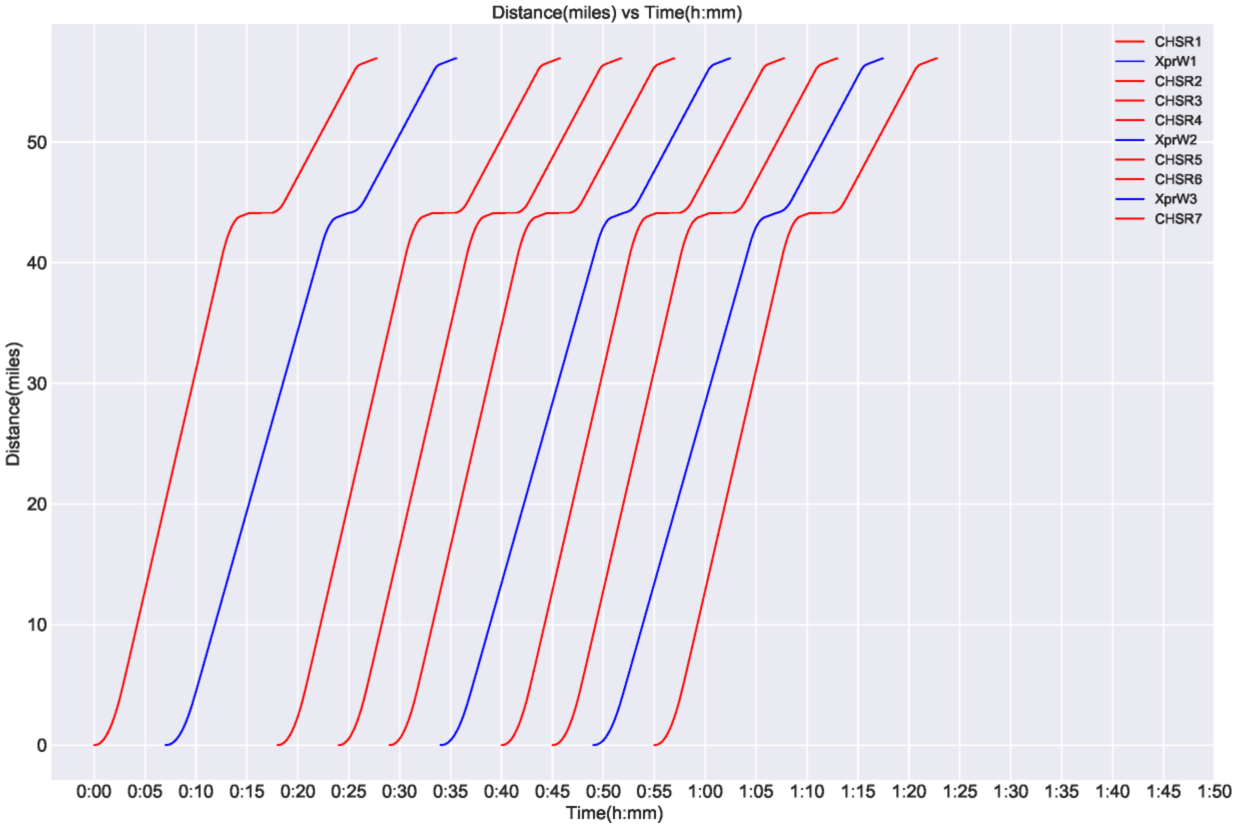


Figure 11-1: Peak-period time-space diagram

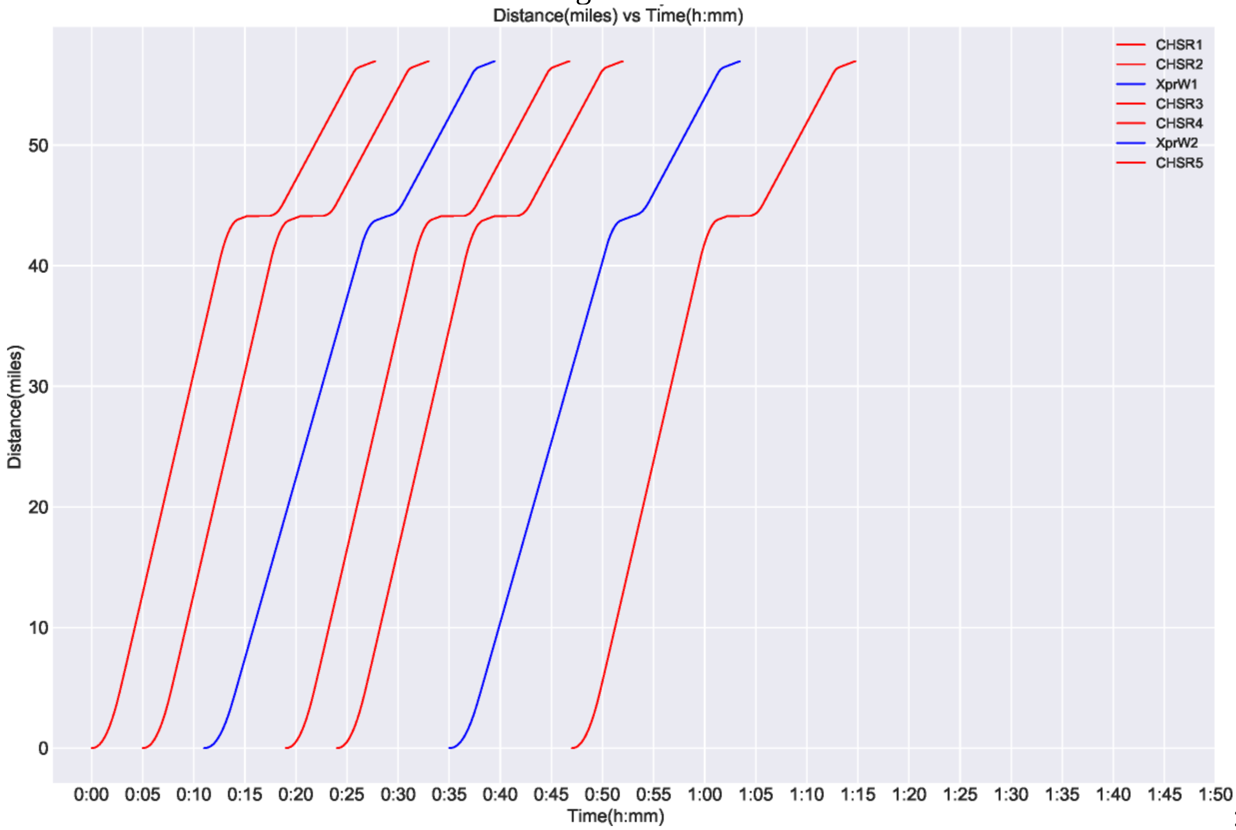
11.2.2: Off-peak Period Operations

The off-peak period is from 9 am to 3 pm and 6 pm to midnight, for a total of 12 hours per day. CHSR Phase 1 operations for the peak period involved 7 CHSR and 3 XpressWest trains per hour each direction. The peak period has a total of six hours per day, from 6 am to 9 am and 3 pm to 6 pm. One hour of the of the peak period operations in one direction, Palmdale to Los Angeles, was simulated based on the developed timetable in Table 5-3. The resulting time-space diagram is shown in Figure 5-2.

Table 11-3: Peak-period timetable with free-flow travel times

Station	Arrival (ARR) / Departure (DEP)	CHSR1	CHSR2	XprW1	CHSR3	CHSR4	XprW2	CHSR5
Palmdale	DEP	0:00	0:05	0:11	0:19	0:24	0:35	0:47
Burbank	ARR	0:15	0:20	0:28	0:34	0:39	0:52	1:02
Burbank	DEP	0:17	0:22	0:28	0:36	0:41	0:52	1:04
Los Angeles	ARR	0:27	0:33	0:39	0:47	0:52	1:03	1:15
Note: All times are in H:MM								

Figure 11-2



Off-peak-period time-space diagram

Table 5-4 below summarizes the annual train service parameters. CHSR and XpressWest will run 4,244,220 and 1,747,620 train-miles of service per year, respectively. This will be the basis for determination of the access charge for XpressWest's use of the corridor.

Table 11-4: Annual train-miles of service

Parameter	Peak Period	Off-peak Period	Total
Hours of operation per day	6	12	18
Number of CHSR trains per hour	7	5	
Number of XpressWest trains per hour	3	2	
Total length of section one-way (miles)	57	57	
CHSR train-miles per day	4,788	6,840	11,628
XpressWest train-miles per day	2,052	2,736	4,788
CHSR train-miles per year	1,747,620	2,496,600	4,244,220
XpressWest train-miles per year	748,980	998,640	1,747,620
Total train-miles per year	2,496,600	3,495,240	5,991,840

11.3: Analysis of Impact of Incidents on the Network Model

11.3.1: Impact of Incidents during the off-peak period

As presented in Chapter 4, to evaluate the impact of off-peak incidents, 42 simulations of randomly generated off-peak incidents were run and their results analyzed. Only incidents caused by trains and occurring between stations were analyzed, i.e., incidents at stations and those that are due to infrastructure problems were not analyzed. Each incident was on a randomly selected train, at a randomly selected location for a randomly generated incident duration. The impact of each incident was measured by how many trains were impacted and the average and total schedule delays experienced by all the impacted trains.

Table 5-5 provides a summary of the impacts of the 42 incidents in terms of the average delays per incident, per train and the average number of trains affected, including the incident train. The results show that an off-peak incident affects an average of 3.60 trains for a total of 109.1 train-minutes of schedule delays per incident and 30.31 minutes per affected train. The impacts are further broken down by train type as shown in the table. Figure 5-3 shows the distributions of these impact measures

Table 11-5: Summary of the average impact of an off-peak period incident

Train Group	Average Delay Per Incident (minutes)	Average Number of Affected Trains Per Incident	Average Delay Per Train Per Incident (minutes)
All Affected Trains	**109.11**	**3.6**	**30.31**
Affected CHSR Trains	**72.6**	**2.34**	**31.03**
Affected XPW Trains	**36.52**	**1.26**	**28.98**

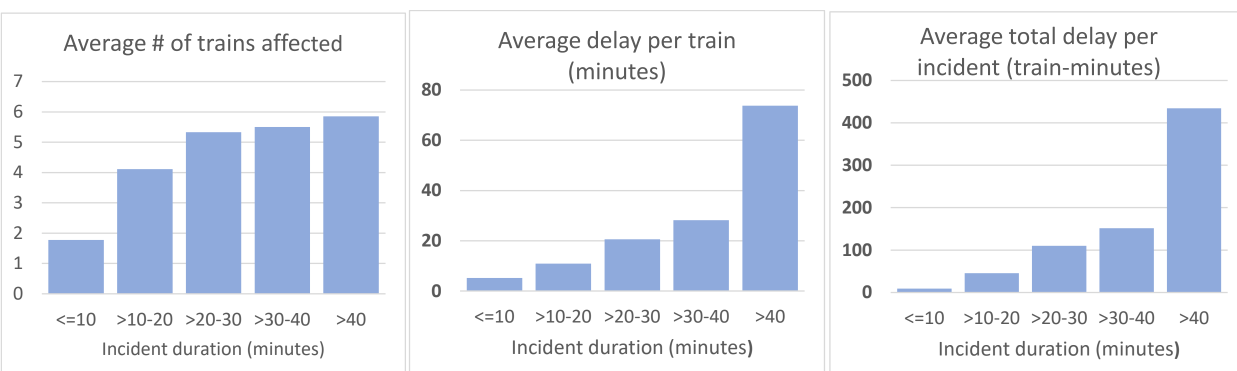


Figure 11-3: Distributions of the impacts of off-peak period incidents.

Tables 5-6 and 5-7 is a further breakdown of the incident impacts, showing how incidents caused by XpressWest trains affect CHSR trains, and vice-versa. Table 5-6 shows that a typical XpressWest incident during the off-peak period will affect an average 1.5 CHSR trains at an average of 38 minutes of delay per train and a total of 57 train-minutes of delay per incident. On the other hand, Table 5-7 shows that an incident caused by a CHSR train will affect an average of

1.17 XpressWest trains at an average of 29.07 minutes of delay per train and a total of 33.91 train-minutes per incident. This data forms a basis for determination of how much each train service may have to compensate the other for each incident caused.

Table 11-6: Impacts of off-peak incidents caused by XpressWest trains

Trains Affected	Average # of trains affected per incident	Average delay per train per incident (min)	Average total delay per incident (train-min)
All trains	3.0	33.34	100.03
CHSR	1.5	38.00	57.0
XpressWest	1.5	28.69	43.03

Table 11-7: Impacts of off-peak incidents caused by CHSR trains

Trains Affected	Average # of trains affected per incident	Average delay per train per incident (min)	Average total delay per incident (train-min)
All trains	3.83	29.41	112.75
CHSR	2.67	29.56	78.84
XpressWest	1.17	29.07	33.91

11.3.2: Impact of Incidents during the peak period

As presented in Chapter 4, sixty (60) incident simulations were run for the peak period. The schedule delays and the number of affected trains of the train groups for all the peak hour incident simulations are shown in Table 5-8. On the average, each incident during the peak period would affect 5.43 trains for an average of 33.93 minutes of delay per train and a total of 184.24 train-minutes for all the affected trains combined. The impacts are further broken down by train type as shown in the table. Figure 5-4 shows the distributions of these impact measures.

Table 11-8: Summary of the average impact of a peak period incident

Train Group	Average Delay Per Incident (minutes)	Average Number of Affected Trains Per Incident	Average Delay Per Train Per Incident (minutes)
All Affected Trains	184.24	5.43	33.93
Affected CHSR Trains	126.71	3.73	33.94
Affected XPW Trains	57.53	1.70	33.84

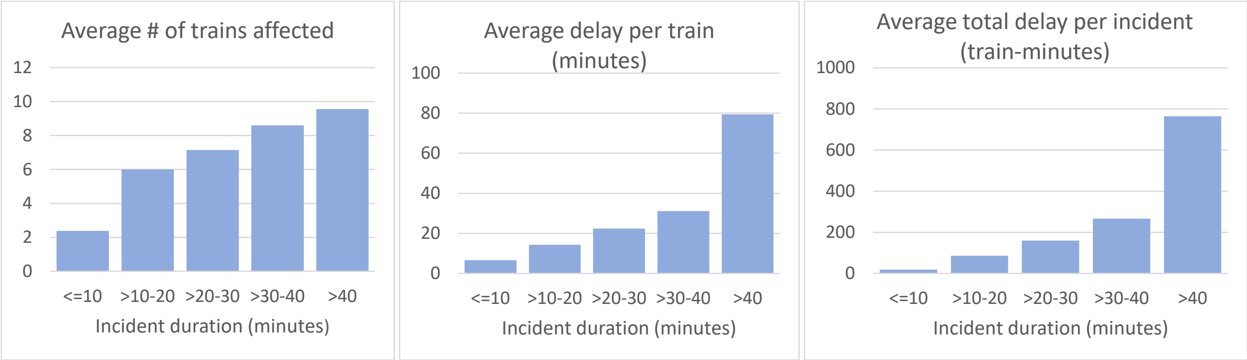


Figure 11-4: Distributions of the impacts of peak period incidents.

As expected, the impacts of the incidents during the peak period are more severe than those during the off-peak. This is due to the shorter headways during the peak periods. Tables 5-9 and 5-10 are a further breakdown of the incident impacts, showing how incidents caused by XpressWest trains affect CHSR trains, and vice-versa. Table 5-9 shows that a typical XpressWest incident during the peak period will affect an average 3.11 CHSR trains at an average of 37.22 minutes of delay per train and a total of 115.8 train-minutes of delay per incident. On the other hand, Table 5-10 shows that an incident caused by a CHSR train will affect an average of 1.57 XpressWest trains at an average of 34.82 minutes of delay per train and a total of 54.72 train-minutes per incident.

Table 11-9: Impacts of peak period incidents caused by XpressWest trains

Trains Affected	Average # of trains affected per incident	Average delay per train per incident (min)	Average total delay per incident (train-min)
All trains	5.11	35.19	179.87
CHSR	3.11	37.22	115.80
XpressWest	2.0	32.04	64.07

Table 11-10: Impacts of peak period incidents caused by CHSR trains

Trains Affected	Average # of trains affected per incident	Average delay per train per incident (min)	Average total delay per incident (train-min)
All trains	5.57	33.40	186.11
CHSR	4.0	32.85	131.39
XpressWest	1.57	34.82	54.72

Chapter 12: Determination of Access Charges

12.1: Introduction

To calculate access charges, estimates of the infrastructure operations, maintenance, capital and rehabilitation costs for the Palmdale to Burbank section are required. This chapter presents these costs estimates which are derived from the CHSR Phase 1 cost estimates extracted and compiled from several CHSRA reports.

12.2: Operations, maintenance and rehabilitation costs for Phase 1

The estimates of train and infrastructure operations and maintenance costs, summarized in Sections 6.2.1 to 6.2.6, were mainly obtained and complied from CHRSA (2020b).

12.2.1: Train operations costs

Train operations costs are those costs that are directly associated with the operation of the train sets. These include the cost of personnel and various equipment and supplies. Personnel include the Train Operations Director as the head of the Train Operations division of CHSRA and Road managers who oversee the on-board employees and ensure the operation quality of train services and emergency operation management. The O&M model states that the number of road managers employed depends on the number of on-board personnel and the complexity of train operations. The study assumed that the addition of XpressWest trains would increase the complexity of the train operations and therefore would increase the number of road managers employed and the workload of the train operations director. On-board personnel and energy consumption for trainsets and protect trains were not considered as these would not be impacted by the addition of XpressWest trains to the network.

Cost estimates presented in this study were acquired from several CHSRA reports and are for Phase 1 operations for the entire system. The total cost will be estimated and divided by the train-miles of service to obtain cost per train-mile, which then forms the basis for determination of the access charge. The cost breakdown and estimation for the personnel and other costs considered are shown in Tables 6-1 and 6-2. The total cost for train operation is shown in Table 6-3. The average cost of train operations per trainset-mile considered for access charge calculation for the CHSR network during Phase 1 was $0.55.

Table 12-1: Train Operations Personnel Cost

Management Train Operations	Wage Per Year Per Employee	Fringe Benefits	Total Wage Per Year Per Employee	Number of Positions (Phase 1)	Wage Per Year Per Phase 1 ($/Year)
Train Operations Director	130,000.00	52,897	182,897	1	$182,897
Road Managers	130,000.00	52,897	182,897	69	$12,619,885
Total					$12,802,782
Unallocated Contingency	5%				$640,139
Allocated Contingency	21.25%				$2,856,621
Total Train Operations Personnel Cost (A)					$16,299,541

Table 12-2: Equipment and other costs required for Train Operations Personnel

Other Costs	Cost Per Year	Number of Positions (Phase 1)	Cost Per Year Per Phase 1 ($/Year)
Road Manager Office Supply	457	69	$31,533
Cell phones	756	70	$52,920
Uniform Costs	326	70	$22,820
Total			$107,273
Unallocated Contingency	5%		$5,364
Allocated Contingency	18.33%		$20,646
Total Other Cost for Train Operations (B)			$133,283

Table 12-3: Total Cost of Train Operations

Total Cost of Train Operation per Year (A + B)	**$16,432,824**
Total CHSR Train-miles per Year (Phase 1)	**29,940,950**
Average Cost of Train Operation per Train-mile	**$0.55**

12.2.2: Electric Traction Costs

Trainsets will require energy for electric traction and will use the overhead catenary system. The OM report estimates that an average traction energy consumption of an Electric Multiple Unit high-speed trains is 37 kWh per trainset mile. The estimated cost for electric traction energy for a high-speed train was $6.08, as summarized in Table 6-4.

Table 12-4: Energy Cost for Electric Traction

Electric Traction	kWh/trainset mile	Cost/kWh	Cost/trainset-mile
Avg power consumption of trainset	37	0.13	$4.85
Unallocated Contingency			$0.24
Allocated Contingency			$0.99
Total Energy Cost for Electric Traction			$6.08

12.2.3: Train Dispatch and Control Costs

Dispatch and control costs are costs associated directly with the Planning Department of CHSRA. The tasks of the Planning Department include the construction of timetables, directing, and controlling train operations. The cost elements associated with Dispatch and Control Costs are personnel and supply/other costs.

In the access charge calculation for XpressWest, all the cost elements of Dispatch and Control costs were considered. The addition of XpressWest trains to the CHSR network would increase the workload of the Planning Department as they would also have to consider XpressWest trains in addition to the CHSR trains for constructing timetables, directing and controlling train operations. The cost breakdown and estimation for the involved personnel and other costs are shown in Tables 6-5 and 6-6 respectively. The total cost for the dispatching and control is shown in Table 6-7. The average cost of dispatch and control per trainset-mile considered for access charge calculation for the CHSR network during Phase 1 was $0.31.

Table 12-5: Dispatch and Control Personnel Costs

Dispatching and Control Costs	Wage Per Year Per Employee	Fringe Benefits	Total Wage Per Year Per Employee	Number of Positions (Phase 1)	Wage Per Year Per Phase 1 ($/Year)
Operation Control Director	150,000	58,107	208,107	1	$208,107
Chief line Dispatcher	106,598	46,801	153,399	5	$766,993
Line Dispatcher	102,056	45,617	147,673	15	$2,215,102
Depot Dispatcher	81,786	40,337	122,123	30	$3,663,694
Information Controller	60,000	34,662	94,662	4	$378,648
Planning Director	60,000	34,662	94,662	1	$94,662
Scheduler	60,000	34,662	94,662	2	$189,324
Performance and Data Manager	60,000	34,662	94,662	1	$94,662
Total				59	$7,611,191
Unallocated Contingency	5%				$380,560
Allocated Contingency	16.25%				$1,298,660
Total Dispatching and Control Personnel Cost (A)					$9,290,410

Table 12-6: Equipment and other costs required for Dispatch and Control Personnel

Other Costs	Cost Per Year	Number of Positions (Phase 1)	Cost Per Year Per Phase 1 ($/Year)
Office Supply	457	59	$26,963
Cell phones	756	59	$44,604
Total			$71,567
Unallocated Contingency	5%		$3,578
Allocated Contingency	18.33%		$13,774
Total Other Cost for Dispatching and Control (B)			$88,919

Table 12-7: Total Cost of Dispatch and Control Operations

Total Cost of Dispatch and Control per Year (A + B)	**$9,379,330**
Total CHSR Train-miles per Year (Phase 1)	**29,940,950**
Average Cost of Train Operation per Train-mile	**$0.31**

12.2.4: Infrastructure Maintenance Costs

Maintenance of Infrastructure Costs refers to the costs associated directly with the maintenance of the tracks, systems, structures, and facilities of CHSRA. The cost elements associated with the Maintenance of Infrastructure are personnel, materials, tools, equipment/other, and subcontract services. The personnel of maintenance of infrastructure are divided into three units. The three units and the responsibilities of the personnel in each unit are:

1. Track and Systems - The responsibilities of the personnel in this unit include maintenance of track, signal and communications, overhead catenary system, and electric traction.
2. Structures - The responsibilities of the personnel in this unit include maintenance of civil structures such as tunnels, bridges, drainage systems, culverts, etc.
3. Facilities - The responsibilities of the personnel in this unit include maintenance of stations, facilities for train maintenance, and maintenance of way.

The addition of XpressWest train to the CHSR network would increase the maintenance activities of CHSRA. The additional traffic would produce more wear and tear on tracks, overhead catenary systems, and electric traction. The increased traffic would also contribute to higher maintenance of the bridge, tunnels, etc., and the facilities for the maintenance of way. The additional passengers from XpressWest would increase the maintenance of station areas for the Palmdale and Los Angeles stations. The study does not consider the cost of maintenance of Burbank station and train maintenance facilities. The cost of maintenance personnel for all the units considered is shown in Table 6-8.

The O&M model considers the cost for materials required for maintenance as 15 percent of the total maintenance personnel cost. An additional 5 percent of the total personal cost was assumed for tools required for maintenance. The details of all the vehicles and their cost were included in the O&M model report and this study takes the cost of maintenance vehicles from the report. These costs and the supply costs are shown in Table 6-9 and Table 6-10. The total average cost for maintenance of infrastructure was $2.19 per train-mile for a year is shown in Table 6-11.

Table 12-8: Maintenance of Infrastructure Personnel Cost

Maintenance of Infrastructure (MI)	Wage Per Year Per Employee	Fringe Benefits	Total Wage Per Year Per Employee	Number of Positions (Phase 1)	Wage Per Year Per Phase 1 ($/Year)
Chief Engineer	223,696	77,305	301,001	1	$301,000
Deputy Chief Engineer	200,000	71,132	271,132	1	$271,132
Administrative Assistant	60,000	34,662	94,662	2	$189,3234
Stores Manager	85,000	41,174	126,174	1	$126,174
Stores Clerk	69,068	37,024	106,092	1	$106,092
Stores Handling	69,068	37,024	106,092	3	$318,276
Procurement Specialist	75,975	38,823	114,798	1	$114,798
Track Manager	130,000	52,897	182,897	2	$365,794
Track Engineer	100,000	45,082	145,082	2	$290,164
Track Supervisor	100,000	45,082	145,082	3	$435,246
Track Inspector/ Foreman	75,235	38,631	113,866	15	$1,707,984
Track Laborer	62,183	35,231	97,414	14	$1,363,790
Equipment Operator	71,372	37,624	108,996	18	$1,961,933
Welder	69,872	37,234	107,106	8	$856,844
Mechanic	71,935	37,771	109,706	11	$1,206,765
Systems Manager	150,000	58,107	208,107	3	$624,321
Systems Inspector	87,687	41,874	129,561	10	$1,295,613
Systems Tech.	81,255	40,199	121,454	43	$5,222,514
Systems Engineer	130,000	52,897	182,897	8	$1,463,175
Power/OCS Manager	150,000	58,107	208,107	2	$416,214
OCS Supervisor	130,000	52,897	182,897	2	$365,794
Power/OCS Inspector/Foreman	85,474	41,298	126,772	7	$887,403
Power Techs	77,748	39,285	117,033	10	$1,170,332
OCS Tech.	77,748	39,285	117,033	29	$3,393,964
OCS Tech. (CDL License)	83,588	40,807	124,395	7	$870,762
Structures Manager	130,000	52,897	182,897	1	$182,897
Structures Engineer	130,000	52,897	182,897	2	$365,794
Bridge Inspector	130,000	52,897	182,897	4	$731,588
Structures Foreman	76,360	38,924	115,284	5	$576,418
Structures Laborer	68,409	36,852	105,261	10	$1,052,614
Facilities Manager	150,000	58,107	208,107	1	$208,107
Asst. Facility Manager	130,000	52,897	182,897	2	$365,794
Facilities Foreman (Stations)	85,474	41,298	126,772	13	$1,648,034
Facilities Technician (Stations)	77,748	39,285	117,033	13	$1,521,432
Train Engineer	99,050	44,834	143,884	1	$143,884
Train Conductor	83,433	40,766	124,199	1	$124,199
Total				257	$32,246,170
Unallocated Contingency	5%				$1,612,308
Allocated Contingency	22.50%				$7,618,158
Total MI Personnel Cost (A)					$41,476,636

Table 12-9: Cost of Materials, Tools, and Vehicles required for Maintenance of Infrastructure

Equipment and Other Costs	Cost Per Year	Number of Positions (Phase 1)	Cost Per Year Per Phase 1 ($/Year)
Uniform	326	257	$83,782
Cell Phones	756	257	$194,292
Information Tech	5,816	257	$1,494,712
Total			$1,772,786
Unallocated Contingency	5%		$88,639
Allocated Contingency	18.33%		$341,199
Total Equipment and Other Cost for MI (E)			$2,202,625

Table 12-10: Equipment and Other Cost required for Maintenance of Infrastructure Personnel

Materials for MI	Cost Per Year Per Phase 1 ($/Year)
15% of Total MI Personnel Cost	$6,221,495
Unallocated Contingency (5%)	$311,075
Allocated Contingency (22.50%)	$1,469,828
Total Materials Cost for MI (B)	$8,002,398
Tools for MI	
5% of Total MI Personnel Cost	$2,073,832
Unallocated Contingency (5%)	$103,692
Allocated Contingency (20.63%)	$449,223
Total Tools Cost for MI (C)	$2,626,746
Maintenance Vehicles for MI	$8,703,274
Unallocated Contingency (5%)	$435,164
Allocated Contingency (22.50%)	$2,056,148
Total Maintenance Vehicles Cost for MI (D)	$11,194,586

Table 12-11: Total Cost of Maintenance of Infrastructure

Total Cost of MI (A+B+C+D+E)	**$65,502,991**
Total CHSR Train-miles per Year (Phase 1)	**29,940,950**
Average Cost of Station Operations per Train-mile	**$2.19**

12.2.5: **Costs of Subcontract Services**

The subcontract services included in the maintenance of infrastructure for tracks were rail grinding and weed spraying. The costs for these services are charged per track mile and were calculated for the Palmdale - Burbank corridor. The cost breakdown for these services is shown in Table 6-12.

Table 12-12: Cost of Subcontractor services, Maintenance of Infrastructure

Subcontract services	**Cost per year per track-mile**	**Track miles**	**Cost per year**
Rail grinding	**7,000**	**44**	**$308,000**
Weed Spraying	**500**	**44**	**$22,000**
Total Subcontract Cost			**$330,000**
Total CHSR Train-miles per year (Palmdale – Burbank)			**3,276,240**
Average Cost of Subcontract Service per Train-mile			**$0.10**

12.2.6: Station Operations Costs

Station Operation costs refer to costs associated directly with the operation of passenger stations. The operations of the station include station cleaning and passenger services. The cost elements associated with the Station Operations are station personnel, energy, water and sewer, security, equipment, and other costs.

The O&M report states that stations have two types of station elements, Trackside Station Elements and Landside Station Elements. Trackside station elements are considered as part of Track and Systems while landside station elements are considered as part of operational spaces of stations. Trackside station elements are the minimum elements built in a station such that the station can be operated without any staff. Landside station elements include operational spaces and utility areas for staff and passengers. Each station in the network was grouped into the elements it includes. Group I stations are the end of line stations which includes the Los Angeles station and have both trackside and landside elements. Group II stations have landside elements and Group III stations have trackside elements. The Palmdale and Burbank stations include both trackside elements and landside elements. Based on this Palmdale and Burbank stations are considered as both Group II and Group III. The staffing at stations is based on the groups. Group I stations have the highest staffing while Group II stations higher staffing than Group III stations. The responsibilities of the staff at stations are to provide information and assist people as required.

The O&M model states that the CHSRA will hire subcontractors for station maintenance and cleaning. The O&M model estimates the rates for subcontracting services based on the data from the International Facility Management Association. These services are charged per unit area and per track mile depending on the individual service. The O&M model provides the information of the trackside area and the landside area at the stations.

At Palmdale and Los Angeles station both trackside and landside elements were considered for access charge calculation. While at Burbank station only trackside elements were considered. The access charge calculation includes all the cost elements for the considered station elements. For the station personnel cost calculation, staffing for Palmdale stations was considered as Group II staffing because of its higher staffing level than Group III. And Burbank was not considered in the cost calculation. Only the security personnel were considered for Burbank station as the report considers security as a trackside element. Los Angeles station was considered as a CHSRA station and was included in all calculations. The cost breakdown for station personnel and security are shown in Tables 6-13 and 6-14 respectively.

Table 12-13: Station Personnel Cost

Station Operations	Wage Per Year Per Employee	Fringe Benefits	Total Wage Per Year Per Employee	Number of Positions (Phase 1)	Wage Per Year ($/Year)
Palmdale -Group II	73,270	38,119	111,389	19	$2,116,386
LA - Group I	73,270	38,119	111,389	26	$2,896,107
Total				45	$5,012,492
Unallocated Contingency	5%				$250,625
Allocated Contingency	22.5%				$1,184,201
Total Station Personnel Cost (A)					$6,447,318

Table 12-14: Security Personnel Cost

Station Operations	Wage Per Year Per Employee	Fringe Benefits	Total Wage Per Year Per Employee	Number of Positions (Phase 1)	Wage Per Year ($/Year)
Palmdale -Group II	73,270	38,119	111,389	19	$2,116,386
LA - Group I	73,270	38,119	111,389	26	$2,896,107
Total				45	$5,012,492
Unallocated Contingency	5%				$250,625
Allocated Contingency	22.5%				$1,184,201
Total Station Personnel Cost (A)					$6,447,318

Table 12-15: Station Energy Cost

Energy	Station Area (Sq. Ft)	Consumption (kWh)/Sq. Ft	Cost Per Year ($/Year)
Palmdale	85,406	14.3	$1,221,306
Burbank	41,924	14.3	$599,513
LA	84,966	14.3	$1,215,014
Total			$3,035,833
Unallocated Contingency	5%		$151,792
Allocated Contingency	22.50%		$717,215
Total Station Energy Cost (C)			$3,904,840

The O&M report provides the average consumption of energy, water, and sewer per unit area for a year for a station. Using this information and the areas of the respective stations considered, consumption for energy, water, and sewer for the stations were calculated. Table 6-15 shows the estimation of total energy cost for the stations and Table 6-16 shows the breakdown of water and sewer cost estimation.

Table 12-16: Water and Sewer Cost

Water and Sewer	Station Area (Sq. Ft)	Cost Per Year Per Sq. Ft	Cost Per Year ($/Year)
Palmdale	85,406	0.392	$33,479
LA	84,966	0.392	$33,307
Total			$66,786
Unallocated Contingency	5%		$3,339
Allocated Contingency	24.17%		$16,949
Total Water and Sewer Cost (D)			$87,074

The supply/other costs required for the station personnel and security personnel were calculated based on the personnel specific needs provided in the O& M report. Table 6-17 shows the total cost estimation for the other costs. For the subcontractor services janitorial, roads and landscaping, station areas of both Palmdale and Los Angeles stations were considered. For the general maintenance service, in addition to the two stations, Burbank station's trackside area is also considered the cost breakdown of the subcontractor services are shown in Table 6-18.

Table 12-17: Equipment and Other Cost of Station and Security Personnel

Equipment, Other Costs	Cost Per Year	Number of Positions (Phase 1)	Cost Per Year ($/Year)
Uniforms	326	45	$14,670
Supplies	457	90	$41,130
Cell Phones	756	90	$68,040
IT	5,816	90	$523,440
Total			$647,280
Unallocated Contingency	5%		$32,364
Allocated Contingency	18.33%		$124,579
Total Other Costs (E)			$804,223

Table 12-18: Cost of Subcontractor Services, Station Operations

Subcontract services	Cost Per Year Per Sq. Ft	Total Station Area in Sq. Ft	Cost Per Year ($/Year)
Janitorial-Stations	4.74	170,372	$807,563
Roads-Stations	0.46	170,372	$77,519
Landscaping-Stations	0.15	170,372	$25,760
General Maintenance Services-Stations	3.50	212,296	$743,036
Total Subcontract Cost (F)			$1,653,879

Combining all the costs discussed above total cost for the station operations for the access charge calculation was estimated. Ridership at the stations from the operators is a way to estimate the station usage of the train operator. Since information on the ridership is not available, it was assumed that the train traffic is in proportion with the ridership of the trains within the corridor considered. This assumption was made based on the SPM report which states that the baseline timetable was developed based on the ridership forecasts for the train types. Therefore, similar to the costs of other service elements, the cost of station operations was also estimated in terms of cost per train-mile. The total cost estimation is shown in Table 6-19. The total average cost for station operation per train-mile per year is $4.29.

Table 12-19: Total Cost of Station Personnel

Total Cost of Station Operations per Year (A+B+C+D+E+F)	**$18,189,967**
Total CHSR Train-miles per Year (Palmdale – Los Angeles)	**4,244,220**
Average Cost of Station Operations per Train-mile	**$4.29**

12.2.7: Capital and Rehabilitation Costs of the Infrastructure

This section provides estimates of capital and rehabilitation costs for the Palmdale to Burbank section. It is not clear how the Burbank to Los Angeles will factor in, since it is going to coincide with the MetroLink network. The following are the different infrastructure capital cost components and their numbering category as reported in the in CHSRA reports:

10 - Track Structures and Track
20 - Stations, Terminals, Intermodal
30 - Facilities, Yards, Shops and Administration Buildings
40 - Sitework, Right-of-Way, Land, and Existing Improvements
50 - Communications and Signaling
60 - Electric Traction
80 - Professional Services
90 - Unallocated Contingency

For the future rehabilitation costs, CHSRA (2020d) report outlines rehabilitation schedules and costs for the relevant capital cost items. According to this report, for example, ballast, which is under cost category 10 (Track Structures and Track), requires two future rehabilitation costs, each equal to 6% of the initial cost. The first is to be spread over five years starting year 16, and the second one also to be spread over 5 years starting year 33. Similar information is provided for other costs elements in cost categories 20 (Stations, terminals, intermodal), 50 (Communications and signaling) and 60 (Electric traction). These future costs are then converted into equivalent present worth.

However, capital cost data for the corridor of interest, i.e., Palmdale – Burbank, had not been produced at the time this study was being conducted. Therefore, estimates for both capital and rehabilitation costs for this section were based on the available cost data for three sections, namely, San Jose to Merced (CHSRA 2020e), Fresno to Bakersfield (CHSRA 2017), and Bakersfield to Palmdale (CHSRA 2020f). The estimates were calculated in the following steps:

1. Calculation of the total capital and rehabilitation costs for each cost category for each section. The future rehabilitation costs are converted into equivalent present worth based on the discount rate of 5% per year, i.e.,

   $$\text{PW} = \sum_{j \in k} RC_j (1+i)^{-j}$$

   Where RC_j = the rehabilitation cost in year j, for all k years with rehab costs
   i = discount rate per year (5%)

   These costs are summarized in Tables 6-20, 6-21 and 6-22.
2. Since cost estimates for the different sections were based of different years, this step involved converting all the costs to year 2021 USDollars based on the industry recognized Construction Cost Index (CCI) published by Engineering News-Record (Table 6-23).
3. Calculation of the average costs in 2021 US$ per mile or per station for each cost category from these three sections (Table 6-24).
4. Using the average costs from step 2 to estimate the total capital and rehabilitation costs for the Palmdale to Burbank section based on the section length (41 miles) and number of stations (2) (Table 6-25).
5. The costs are converted to equivalent uniform annual costs based on a discount rate of 5% and a service life of 50 years (Table 6-25), i.e.,

   $$\text{Equivalent annual cost, EVAC} = \text{(Total Initial or PW Cost)} \text{x} \left[\frac{i(1+i)^N}{(1+i)^N - 1}\right]$$

   Where i = discount rate (5% per year)

N = service life (50 years)

Table 12-20: Summary of capital and rehabilitation costs for the San Jose to Merced Section (CHRSA 2020e)

	San Jose to Merced (with 2 stations) - 2018 Q3 USD			
Cost Component	Capital Costs	PW(Rehab Costs)	Miles	Stations
10 - Track Structures and Track	$8,678,041,612	$13,744,811	84	
20 - Stations, Terminals, Intermodal	$698,398,748	$29,405,433		2
30 - Facilities, Yards, Shops and Administration Buildings	$262,779,068		84	
40 - Sitework, Right-of-Way, Land, and Existing Improvements	$3,282,675,193		84	
50 - Communications and Signaling	$387,037,757	$118,319,422	84	
60 - Electric Traction	$597,758,906	$18,883,284	84	
80 - Professional Services	$1,981,345,574		84	
90 - Unallocated Contingency	$590,573,617		84	
TOTAL	**$16,478,610,475**	**$180,352,950**		

Table 12-21: Summary of capital and rehabilitation costs for the Fresno to Bakersfield Section (CHSRA 2017)

	Fresno to Bakersfield (with 4 stations) - 2012 USD			
Cost Component	Capital Costs	PW(Rehab Costs)	Miles	Stations
10 - Track Structures and Track	$8,487,938,340	$28,004,056	114	
20 - Stations, Terminals, Intermodal	$701,384,210	$4,619,358		4
30 - Facilities, Yards, Shops and Administration Buildings	$395,047,145		114	
40 - Sitework, Right-of-Way, Land, and Existing Improvements	$7,029,877,027		114	
50 - Communications and Signaling	$491,634,904	$145,076,553	114	
60 - Electric Traction	$1,620,769,257	$79,491,757	114	
80 - Professional Services	$2,193,572,152		114	
90 - Unallocated Contingency	$859,889,106		114	
TOTAL	**$21,780,112,141**	**$257,191,724**		

Table 12-22: Summary of capital and rehabilitation costs for the Bakersfield to Palmdale Section (CHSRA 2020f)

	Bakersfield to Palmdale (with 2 stations) - 2016 Q4 USD			
Cost Component	Capital Costs	PW(Rehab Costs)	Miles	Stations
10 - Track Structures and Track	$7,348,602,169	$11,709,481	79	
20 - Stations, Terminals, Intermodal	$627,481,423	$16,258,958		2
30 - Facilities, Yards, Shops and Administration Buildings	$245,890,851		79	
40 - Sitework, Right-of-Way, Land, and Existing Improvements	$3,065,806,057		79	
50 - Communications and Signaling	$174,825,447	$51,779,729	79	
60 - Electric Traction	$473,662,438	$23,401,423	79	
80 - Professional Services	$1,360,189,051		79	
90 - Unallocated Contingency	$575,734,262		79	
TOTAL	**$13,872,191,698**	**$103,149,591**		

Table 12-23: Multiplication factors to convert the costs to 2021 US Dollars

San Jose to Merced (2018 Q3 USD to May 2021 USD)	
Aug-2018	11,124
May-2021	11,990
Mult factor	1.078

Fresno to Bakersfield (2012 USD to May 2021 USD)	
2012	9,291
May-2021	11,990
Mult factor	1.290

Bakersfield to Palmdale (2016 Q4 USD to May 2021 USD)	
Nov-2016	10,443
May-2021	11,990
Mult factor	1.148

Table 12-24: Average Capital and Rehabilitation per-mile and per-station Costs.

	Averages			
Cost Component	Cap.Cost/Mile	Reh.Cost/mile	Cap.Cost/Sta	Reh.Cost/Sta
10 - Track Structures and Track	$103,756,551	$232,435		
20 - Stations, Terminals, Intermodal			$297,251,019	$7,040,414
30 - Facilities, Yards, Shops and Administration Buildings	$3,881,478	-		
40 - Sitework, Right-of-Way, Land, and Existing Improvements	$58,219,533	-		
50 - Communications and Signaling	$4,520,344	$1,350,687		
60 - Electric Traction	$11,837,332	$540,669		
80 - Professional Services	$23,563,522	-		
90 - Unallocated Contingency	$8,688,947	-		

Table 12-25: Estimated Capital and Rehabilitation Costs for the Palmdale to Burbank Section

	Total Costs		Equiv Annual Costs	
Cost Component	Capital Costs	PW(Reh costs)	EVAC (CC)	EVAC(Rehab)
10 - Track Structures and Track	$4,254,018,588	$9,529,854	$233,021,251	$522,014
20 - Stations, Terminals, Intermodal	$594,502,039	$14,080,828	$32,564,881	$771,302
30 - Facilities, Yards, Shops and Administration Buildings	$159,140,590	-	$8,717,202	-
40 - Sitework, Right-of-Way, Land, and Existing Improvements	$2,387,000,843	-	$130,752,114	-
50 - Communications and Signaling	$185,334,112	$55,378,155	$10,151,998	$3,033,435
60 - Electric Traction	$485,330,606	$22,167,439	$26,584,826	$1,214,260
80 - Professional Services	$966,104,408	-	$52,920,046	-
90 - Unallocated Contingency	$356,246,815	-	$19,514,038	-
Totals	$9,387,678,000	$101,156,276	$514,226,355	$5,541,011

Table 6-25 provides a summary of the final estimates for the lifecycle capital and rehabilitation costs for the Palmdale to Burbank section, and, together with the operations and maintenance costs, form the basis for estimation of the access charges.

12.3: Estimation of access charges

All the costs for infrastructure and train operations and maintenance presented in the previous sections were based on projected Phase 1 CHSR operations only, excluding XpressWest. These costs should generally be split between fixed costs, i.e., costs that are fixed and do not very by the quantity or level of service, and variable costs which vary by the level of service in terms of train-miles, train frequency or track mileage. For example, one would expect that track maintenance cost would consist of fixed costs plus variable costs that are a function of trains-miles of service, while station operations costs would consist of fixed costs plus variables costs that may be a function of train frequency. Then depending on the access charge policy, the access charge may be a function on only the variable costs, since the fixed cost components would remain the same, whether or not the guest operator is allowed to operate on the network, or it may-be a function of the total cost. However, the data available for this study did not have enough detail to enable estimate such breakdowns. As such, all these total costs were simply divided by the estimated train-miles of service to get the cost per train-mile. This also means that this may be an overestimate of the access charge.

Based on the total costs presented in Section 6.2, the resulting unit costs per train-mile are summarized in Table 6-26 below. Note that the top four costs in the table are total costs based on entire network for Phase 1 CHRS operations, while the bottom four are estimates only for operations on the Palmdale to Burbank section. Hence, the use of different train-miles for calculation of costs/train mile.

Table 12-26: Summary of the Capital, Operations, Maintenance and Rehabilitation Costs

		Total Costs	CHSR Phase 1 (train-miles)	Cost per train-mile
1	Train Operations Cost per year	$16,432,824	29,940,950	$0.55
2	Electric traction (cost per train-mile)			$6.08
3	Train Dispatch and Control Costs per year	$9,379,330	29,940,950	$0.31
4	Infrastructure Maintenance Costs per year	$65,502,991	29,940,950	$2.19
5	Station Operations Costs (Palmdale - Burbank)	$18,189,967	3,276,240	$5.55
6	Subcontractor Services Costs (Palmdale - Burbank)	$330,000	3,276,240	$0.10
7	Equiv Annual Rehabilitation Costs (Palmdale - Burb	$5,541,011	3,276,240	$1.69
8	Equiv Annual Capital Costs (Palmdale - Burbank)	$514,226,355	3,276,240	$156.96
	Total Cost per train-mile			$173.43
	Total Cost per train-mile (excl. initial capital costs)			$16.47

Estimated access charges for XpressWest

The access charge is calculated based on the costs per train-mile as summarized in Table 6-26 above. The question is whether or not XpressWest should also be asked to share in the capital recovery costs. If one assumes that the initial construction costs were independent of whether or not XpressWest would operate on the network, then the access charge should be based only on their estimated share, or the incremental costs of the operations, maintenance and rehabilitation. In that case, with the estimated Phase 1 XpressWest service of 1,747,620 train-miles/year, this translates into an access charge of 1,747,620x$16.47 = $28,790,159 per year. On the other hand, if capital recovery costs are included, this would 1,747,620x$173.43 = $303,090,046 per year.

Note that this access charge is only for the Palmdale to Burbank Section, since the Burbank to Los Angeles Section will also include LA's Metrolink operations and is owned and/or will be managed by Metrolink.

12.3.1: Comparison of Access Charge Prices

Table 6-27 shows the compares the access charge estimated in this study for the CHRS system to those for selected European countries' HSR systems presented in Section 2-2.

Table 12-27: Comparing Access Charges

Country	**Access charge ($/train mile)**
Germany	$24.92
France	$24.07 – $48.05
Spain	$15.18 – $27.83
Italy	$10.78 – $14.18
CHSR (this study; O & M and Rehab Costs only)	$16.47

If the capital cost component of access charge is excluded, the access charge calculated in this study is relatively comparable to those in Europe. However, it should be noted that the access charges from the European countries included not only maintenance and operation costs but also some form of lifecycle capital recovery costs. The capital recovery cost for the CHSR System is very high and results in an estimated $156.96 per train-mile (Table 6-26) based on planned CHSR and XpressWest Phase 1 operations. Application of this full amount may not be economically feasible. The reason for the very high capital recovery cost is the very high construction cost for system, currently at system over $200,000,000 per mile.

12.4: Estimation of incident charges

It is typical for train operators to be assessed a fee or charge every time their train is responsible or is the cause of an operational incident. This fee is designed to cover the resulting incremental costs of train operations and other related costs incurred by the infrastructure manager and other train operators affected. One of the primary components of the incident charges is the “train delay” cost, which consists of the following incremental costs (Schafer II and Barkan, 2008):

1. Train operation cost
2. Train depreciation cost

12.4.1: **Cost of Train Operations**

The cost of operating a CHSR trainset for CHSRA is estimated from the 2020 CHSR O&M report. The cost elements that include in the train operations are on-board personnel, energy, and other/supply costs for personnel. The train operations cost estimation is similar to the cost estimation of train operations in Section 6.2.1. The cost elements included in Section 6.2.1 are only those that are affected by an XpressWest train and do not include the cost of CHSR trainset operations. The cost elements in this section only deal with the cost of a trainset operation for CHSRA.

The cost breakdown of the on-board personnel is shown in Table 6-27. For converting wage per year to wage per minute for the personnel, the O&M report assumption for the personnel work hours per year, 1,794 hours was used. The other/supply costs related to the on-board personnel are shown in the Table 6-28.

Table 12-28: CHSR Trainset Personnel Cost

On-board Personnel Per Trainset	Wage Per Year Per Employee	Fringe Benefits	Total Wage Per Year Per Employee	Number of Positions per trainset	Wage Per Year Per Trainset ($/Year)	Wage Per Minute Per Trainset
Train Engineers	99,050	44,834	143,884	3	$431,653	$4.01
Conductor	83,433	40,766	124,199	3	$372,598	$3.46
Assistant Conductors	71,865	37,753	109,618	6	$657,706	$6.11
Total				12	$1,461,957	$13.58
Unallocated Contingency	5%					$1
Allocated Contingency	21.25%					$3
Total On-board Personnel cost per Trainset Per minute						$17.29

Table 12-29: Equipment and Other Cost for CHSR Trainset Personnel

Other Costs	Cost per Year	Number of Positions	Total Cost per Year	Cost per minute
Cell phones	756.00	12	9,072.00	$0.08
Unallocated Contingency	5%			$0.00
Allocated Contingency	18.33%			$0.02
Total Other costs				$0.10

When a train is delayed due to an incident and is stopped, it requires energy to operate various on-board services and equipment such as heating, ventilation, and air conditioning. These are referred to as auxiliary services and the energy required for these services can be referred to as idle trainset energy consumption. Although the O&M report considers the cost of auxiliary energy consumption it does not provide any information on the process of the cost estimation. The literature on the energy consumption of auxiliary systems in a high-speed train is very limited. The work of (Watson, 2012) is the most relevant to the purpose of the study. Watson, 2012 develops a computational model and estimates the energy consumption of a high-speed train through simulations. Simulations were done in Watson, 2012 for a high-speed train with a top speed of 205 mph for an HSR line in the UK that spans 109 miles. Their simulation results showed that the energy consumption by the auxiliary services for the high-speed train considered was 5.4 kWh per train-minute on an average. The train characteristics considered in Watson, 2012 are similar to the trains CHSRA considers in their SPM report. Therefore, the energy consumption for the auxiliary services for this study was assumed to be an average of 5.4 kWh per train minute. The cost per kWh assumed in the CHSR O&M report and in this study was $0.1312. This translates to a cost of $0.71 per train-minute for the auxiliary services and can be considered the cost of idle train operation. The total cost of a trainset operation per train-minute was $18.1.

12.4.2: **Cost of Train Depreciation**

For estimating the train depreciation cost, the required information was taken from the CHSR 2020 50-Year Life-cycle Capital Cost model document. The purchase cost of a single trainset was $54,366,325. The report states that as part of the rehabilitation process, each trainset will be overhauled after 15 years of purchase. The cost of overhauling a train is 75 percent of the purchase cost. Each trainset will be replaced after 30 years. Using this information and assuming a discount rate of 5 percent per year, train depreciation cost, i.e., capital recovery costs, was estimated and reduced to cost per minute based on an estimated 6,480 operating hours per year (18 hours/day x 360 days/year), allowing for maintenance and repair off days (Table 6-29).

Table 12-30: Train Depreciation Cost

Initial purchase cost	$54,366,325
Rehab cost at 15 years (75% of initial)	$40,774,744
Discount rate	5%
Equivalent total present worth	$73,979,674
Service life (years)	30
Capital recovery cost/year	$4,812,484
Revenue hours/year	6,480
Train depreciation cost per train-min	$12.38

12.4.3: Calculation of Incident Cost for XpressWest

By adding both train operation cost and train depreciation cost, the total train delay cost for CHSR trains impacted by XpressWest-caused incidents was calculated. The incident cost per train-minute is $32.24 and the cost breakdown is shown in Table 6-30.

Table 12-31: Incident Cost for XpressWest Trains Per Train-minute Delay of CHSR Train

CHSR Train Operation Cost per train-min	$18.10
CHSR Train Depreciation Cost per train-min	$12.38
Total incident impact cost per train-min	$30.48

Tables 5-6 and 5-9 in Chapter 5 summarized the impact of XpressWest incidents on CHSR trains. Given the incident impact cost rate of $30.48 per train-minute, the CHSR costs per incident caused by an XpressWest is $3,514 per peak period incident and $1,737 per off-peak period incident (Table 6-31). These are the rates which XpressWest could compensate CHSR operations for each incident caused. For an estimated 5 incidents per year (2 peak and 3 off-peak) the total estimated charges per year would be $12,240.

Table 12-32: CHSR train incident impact costs due to XpressWest incidents

	CHSR Train-minutes of delay per incident	Total CHSR Cost per incident	Projected XpWest incidents per year	Projected total cost per year
Peak-period	115.30	**$3,514**	2	$7,028
Off-peak-period	57.0	**$1,737**	3	$5,212
Total estimated cost per year				**$12,240**

Note that these charges do not include passenger delay costs as well as any direct impacts to the infrastructure. So, the actual charge per incident would be significantly higher than the estimated provided here.

Chapter 13: Conclusions and Recommendations

13.1: Summary and Conclusions

The study developed a VISSIM simulation model for a Palmdale - Los Angeles shared HSR rail system corridor that operates CHSR and XpressWest. Train operations in the shared HSR corridor were analyzed using the simulation model. The simulation model considered the characteristics of the infrastructure of the shared system, planned operations of the CHSR and XpressWest, HSR rolling stock, and signaling system characteristics. The developed model was calibrated to replicate the expected travel times of the trains between the stations by the operators.

The Palmdale - Los Angeles shared corridor consists of three stations Palmdale, Burbank, and Los Angeles. CHSR train and XpressWest trains have different maximum attainable speeds. The maximum operational speed for the Palmdale - Burbank section for CHSR trains is 220 mph and for XpressWest is 180 mph while for the Burbank - Los Angeles section, the maximum operational speed for both trains is 95 mph. The corridor consisted of a single track between the stations in each direction. HSR rolling stock characteristics such as speed, acceleration, and deceleration profiles were obtained from the operators when available and from the literature. The signaling system used in the model was a fixed block signaling system.

Allowable minimum headway between successive trains were determined using the simulation model. Utilizing the CHSR draft timetable for the CHSR network, headways between successive CHSR trains were estimated and used to develop timetables for the simulation model. Information related to the expected XpressWest headways in the shared system were obtained from the literature. Based on the allowable minimum headway, the estimated headways of the CHSR train from the draft timetable, and the expected XpressWest headways, the study developed timetables and analyzed train operations for peak hour and off-peak hour services.

A framework to simulate incidents in the simulation model was developed. VISSIM does not have an in-built function to simulate incidents. Using the Component Object Module of VISSIM and Python programming language, a program to simulate incidents during a VISSIM simulation was developed. Train operations when an incident was simulated in the model such as the train priorities at stations and overtaking of the trains were programmed using VisVAP, a signal programming software provided by VISSIM.

Incident data of an HSR system was obtained and the frequency of incidents depending on the amount of train traffic and the incident durations were analyzed. Based on the analysis, several incidents were simulated for the peak hour and off-peak hour service. The impact of incidents on the network model was estimated by analyzing the incident simulations in terms of schedule delays, station delays, and running time delays of the trains. Utilizing the estimated delays, the impact of incidents caused by XpressWest trains to the CHSR train was determined.

A framework for calculating access charges for the CHSR shared corridor was developed. Various cost elements involved in the operation and maintenance of the CHSR corridor were analyzed. Cost elements that will be affected by the addition of XpressWest trains were considered. Train operations costs, dispatch and control operations costs, Track and Systems, and station operations and maintenance costs were studied in detail, and cost per train-mile was determined for all the cost elements. Incident costs due to the incidents caused by the XpressWest trains to the CHSR train was calculated.

This study determined that for the Palmdale - Burbank shared CHSR corridor, the access charge of operation and maintenance costs is 14.61 $/train-mile. The amount of access charge that XpressWest has to pay for the Palmdale - Burbank section is $19,709,474 per year. The total cost XpressWest has to pay for Palmdale - Los Angeles shared corridor is $23,468,083 per year.

13.2: Contributions

The key contributions of this research include the development of frameworks for:

1. Analysis of HSR operations using VISSIM

   Rail operations are usually simulated and analyzed by the rail operators using simulation software that are specifically made for modeling rail infrastructure and operations. These software provide great in-depth details of the rail operations and can be expensive and hard to obtain for academic purposes. VISSIM is a microscopic traffic simulation software developed mainly to analyze road traffic and light rail operations. VISSIM is used extensively in the academic community and can be obtained fairly easier and cheaper. By using VISSIM’s inbuilt features, this study provides a framework to model HSR infrastructure, HSR rolling stock characteristics, and signaling system in VISSIM. The model can be used to analyze the HSR operations which can provide principal details of the HSR operations such as timetables containing arrival and departure of the trains and space-time plots of all the trains.

   While VISSIM provides the feature to create a fixed block signaling system, the system cannot differentiate between different types of trains and can only be used for low-speed train operations and simpler operations not involving incidents. Using the system caused the erratic acceleration and deceleration of the high-speed trains. For smooth and efficient operations of high-speed trains and complex operations involving trains with different speeds and different train priorities the study developed a signaling program for HSR operations using vehicle actuated signal programming software, VisVAP provided as an add-on to VISSIM.

   VISSIM does not have the in-built feature to create incidents during the simulation. Using Component Object Module (COM) and Python programming language a program to create incidents during a VISSIM simulation.

   The programs developed in this study can be used for future research purposes involving HSR operations in VISSIM.

2. Analyzing incidents and impact of incidents

To estimate the impact of incidents on an HSR network, several incidents need to be simulated and analyzed. Several incident durations are needed for this purpose. Available incident data on HSR sections are limited and not sufficient for creating several incidents. By analyzing available incident data of an HSR section, this study develops a framework for creating numerous incident durations that resemble the original data.

The study developed a framework to estimate the effect of an incident on a network in terms of schedule delays, station delays, and running time delays. These delays provide different details and can be used by the operators to plan operations when an incident occurs.

3. Calculation of Access charge for CHSR system

   The literature review performed in the study showed that various HSR systems have different access charge systems specifically tailored based on the system's operation structure and to recover the operations and maintenance cost of additional traffic by operator accessing the HSR systems. CHSR is an HSR system that is under construction. By utilizing the technical reports of the CHSRA that estimates the CHSR's operation and maintenance costs, the study developed a framework to calculate access charge for the CHSR network. The cost elements that could be affected by the addition of traffic in the network were identified in the research. These can provide insights into the cost elements involved in access charges for CHSR and operators accessing the network. When CHSR starts operating and actual operation and maintenance cost data is available, CHSR can adopt the framework to calculate access charges for its network

13.3: Recommendation for Future Research

The research presented in the study can be further improved by:

1. Model grades and curves in the simulation

   The simulation model developed in the study does not model the impact of grades and curves on train performance. Although curves in the HSR network are designed for high-speed train operations the train will be required to travel at lower speeds at some curves for safer operations. These cause the trains to travel at different speeds in different parts of the tracks. By modeling these details in the simulation model, more in-depth information on train behavior between stations can be obtained.

2. Running the simulations with various headways between trains and analyzing the impact of incidents and delay propagation in the network

   This study estimates the impact of incidents for the fixed timetable developed for peak and off-peak hours. Several simulations can be run with trains at variable headways and analyzing the impact of a set of incidents on the network. This can provide a realistic view of the relationship between headways and incidents on the network and can be used to develop a timetable that has a minimum impact of an incident.

3. Effect of train operational speed on maintenance costs

   The study does not consider the effect of train speed on the maintenance costs. Different train speeds cause different static and dynamic loading of the tracks and can impact the deterioration of the track differently. The literature on the effect of speed on the deterioration of the track was very limited. Further research can be done to find the effect of speed on track deterioration and can be included in the maintenance cost calculation of tracks in shared HSR systems with trains operating at different speeds.

4. Calculation of passenger delay costs

   When passengers are delayed due to an incident, the rail operator may be required to compensate the passengers for the loss of their time. These costs can be included in the incident cost calculation.

5. Brightline West Routes

   This study considers the HSR operations of XpressWest before it was acquired by Brightline West. The first route of Brightline West is similar to the initially planned operations of the XpressWest which connects to Los Angeles from Victorville via Palmdale. This study addresses the analysis of HSR operations and determination of access charges for the first route. Brightline West may change the initially planned operations of XpressWest. By following the methodology developed in this study, access charges for the new operations can be determined.

   The second route of Brightline West is to travel to Los Angeles from Victorville via Rancho Cucamonga. It'll build a new HSR line from Victorville station to Metrolink station in Rancho Cucamonga. When this line is built, Brightline West traffic could be split between the first route (via Palmdale) and the second route. This could cause a decrease in the traffic of XpressWest in the Palmdale to Los Angeles shared CHSR corridor. The access charge that XpressWest has to pay for CHSRA could be decreased.

   When the new HSR line in the second route is built, Brightline West could be sharing tracks with Metrolink and other rail operators (Scauzillo, 2020, SBCTA, 2020). The section from Victorville to Los Angeles could become a shared HSR system where Metrolink and other rail operators will be accessing Brightline West's infrastructure system. Metrolink and other rail operators will have to pay an access charge to Brightline West. Brightline West trains reach a maximum speed of 200 mph while Metrolink trains are not high-speed trains and reach only a maximum speed of 110 mph. As in the case of the Burbank to Los Angeles shared CHSR section, Brightline West will have to travel at reduced speeds. For this Brightline West shared corridor from Victorville to Los Angeles, the access charge can be determined using the framework developed in this study. Brightline West can develop a simulation model of this shared corridor and use the methodology developed in this study to analyze the HSR operations. For the determination of access charges, Brightline West can analyze its operations and maintenance costs in terms of train operations costs, dispatch and control costs, maintenance of infrastructure and, stations' costs as proposed in this study.

References

1. Abril, M. et al. (2008). “An assessment of railway capacity”. In: *Transportation Research Part E: Logistics and Transportation Review* 44.5, pp. 774–806. DOI: https://doi.org/10.1016/j.tre.2007.04.001 (Cited on Page: 3).
2. ADIF – Spain Rail Infrastructure Manager (2020) Network Statement 2020. URL: http://adif.es/en_US/conoceradif/doc/book_ADIF_NS_V0_2020_20200604.pdf; accessed November 20th, 2020 (pages 23, 24).
3. Akers, Mick (Apr. 2020). *Nevada bond approval last roadblock in high-speed rail project. Las Vegas* Review-Journal. URL: https://www.reviewjournal.com/news/news-columns/road-warrior/nevada-bond-approval-last-roadblock-in-high-speed-rail-project-2010209/ (Cited on Page: 31).
4. Brightline (2020). XpressWest, Las Vegas / Southern California Expansion. © Brightline 2020. URL: https://www.gobrightline.com/xpresswest; accessed November 20th, 2020 (Cited on Page: 7).
5. Brightline West Construction (2020) Learn More About Brightline West: A High-Speed Passenger Rail Service Connecting Southern California and Las Vegas (2020). © Brightline. URL: https://brightlinewestconstruction.com/; accessed November 20th, 2020 (pages 7, 8).
6. California High Speed Rail Authority (CHSRA 2010). *Automatic Train Control: Concept of System*. Technical Memorandum, Retrieved from: https://hsr.ca.gov/docs/programs/eir_memos/Proj_Guidelines_TM3_3_1R00.pdf; accessed November 20th, 2020 (Cited on Page: 31).
7. California High Speed Rail Authority (CHSRA 2012). Caltrain/California HSR Blended Operations Analysis. Peninsula Corridor Joint Powers Board (JPB). Retrieved from: https://www.caltrain.com/Assets/Caltrain+Modernization+Program/Documents/Final-Caltrain-California+HSR+Blended+Operations+Analysis.pdf; accessed November 20th, 2020 (Cited on Page: 28).
8. California High Speed Rail Authority (CHSRA 2016). Service Planning Methodology. Retrieved from: https://hsr.ca.gov/docs/about/business_plans/2016_Business_Plan_Service_Plan_Methodology.pdf; accessed November 20th, 2020 (pages 30, 34).
9. California High Speed Rail Authority (CHSRA 2017). Fresno to Bakersfield Project Section Draft Supplemental EIR/EIS Report: Project Costs and Operations, November 2017. https://hsr.ca.gov/wp-content/uploads/docs/programs/fresno-baker-eir/FBLGA_Draft_EIRS_Vol_1_CH_6_Project_Costs_Operations.pdf; accessed November 2021
10. California High Speed Rail Authority (CHSRA 2018). 2018 Business Plan. Retrieved from: https://hsr.ca.gov/docs/about/business.plans/2018_BusinessPlan.pdf; accessed November 20th, 2020 (pages 5, 6, 30).
11. California High Speed Rail Authority (CHSRA 2020a). Draft 2020 Business Plan. Retrieved from: https://hsr.ca.gov/docs/about/business_plans/2020_Business_Plan.pdf; accessed November 20th, 2020 (pages 4, 30).
12. California High Speed Rail Authority (CHSRA 2020b). Operations and Maintenance Cost Model Documentation. Retrieved from: https://hsr.ca.gov/docs/about/business_plans/2020_Business_Plan_Operations_and_Maintenance_Cost_Model.pdf; accessed November 20th, 2020 (pages 5, 37, 86).

13. California High Speed Rail Authority (CHSRA 2020c). Service Planning Methodology. Retrieved from: ttps://hsr.ca.gov/docs/about/business_plans/2020_Business_Plan_Service_Planning_Methodology.pdf; accessed November 20th, 2020 (pages 28, 30, 31, 39, 42, 48, 86).
14. California High Speed Rail Authority (CHSRA 2020d). 2020 Business Plan - 50-year Lifecycle Capital Cost Model Documentation. Retrieved from: https://hsr.ca.gov/wp-content/uploads/2021/04/2020_Business_Plan_50-Year_Lifecycle_Capital_Cost_Model.pdf; accessed November 20th, 2020
15. California High Speed Rail Authority (CHSRA 2020e). San Jose to Merced Project Section Draft Project EIR/EIS: Appendix 6-A: PEPD Record Set Capital Cost Estimate Report. https://hsr.ca.gov/wp-content/uploads/docs/programs/san_jose_merced/Draft_EIRS_JM_V2-52_APP_6.0-A_PEPD_Record_Set_Capital_Cost_Estimate_Report.pdf; accessed November, 2021
16. California High Speed Rail Authority (CHSRA 2020f). Bakersfield to Palmdale Project Section Draft EIR/EIS: Appendix 6-B: PEPD Draft Capital Cost Estimate Report. https://hsr.ca.gov/wp-content/uploads/2020/06/BP_Draft_EIRS_Vol_2_App_6-B_PEPD_Final_Capital_Cost_Estimate_Report.pdf; accessed November, 2021
17. Connor, P. (2014). “High Speed Railway Capacity Understanding the factors affecting capacity limits for a high speed railway.” In: 1964-2014 High Speed: Celebrating Ambition. University of Birmingham, 8-10 December 2014. Retrieved from: http://www.railway-technical.com/books-papers--articles/high-speed-railway-capacity.pdf; accessed November 20th, 2020 (Cited on Page: 32).
18. Cox, Wendell and Adrian T Moore (2012). The XpressWest High-Speed Rail Line from Victorville to Las Vegas: A Taxpayer Risk Analysis. *Reason Foundation*. URL: https://development.reason.org/wp-content/uploads/2012/08/xpresswest_victorville_las_vegas_train.pdf (Cited on Page: 7).
19. Deutsche Bahn AG (2020a) Annex 6.1 to the Network Statement of DB Netz AG 2020 URL: https://fahrweg.dbnetze.com/resource/blob/3589412/c092f135a177d211b8545ca74f8df0b5/snb_2020_annex_6-1-data.pdf; accessed November 20th, 2020 (Cited on Page: 18).
20. Deutsche Bahn AG (2020b) Annex 6.2 to the Network Statement of DB Netz AG 2020. URL: https://fahrweg.dbnetze.com/resource/blob/3589410/882a2594f10e3c4f6e846d7863e33723/snb_2020_annex_6-2-data.pdf; accessed November 20th, 2020 (Cited on Page: 21).
21. ECA - European Court of Auditors (2018). “A European high-speed rail network: not a reality but an ineffective patchwork.” In: Special report 19, 2018. ISSN: 1977-5679 (pages 1, 10, 12).
22. ECMT - European Conference of Ministers of Transport (2005). Railway Reform and Charges for the Use of Infrastructure. URL: https://www.oecd-ilibrary.org/content/publication/9789282103524-en (pages 16, 18).
23. Feng, Ziyan, Chengxuan Cao, and Yutong Liu (Jan. 2019). “Train delay propagation under random interference on high-speed rail network”. In: *International Journal of Modern Physics* C 30.8, 1950059, p. 1950059. DOI: 10 .1142 /S0129183119500591 (Cited on Page: 4).
24. FRA - Federal Railroad Administration (2020). DesertXpress “XpressWest” - Las Vegas to Victorville. U.*S. Department Of Transportation,*. URL: https://railroads.dot.gov/environment/environmental-reviews/desertxpress-xpresswest-las-vegas-victorville (Cited on Page: 7).
25. Gattuso, Domenico and Antonio Restuccia (2014). “A Tool for Railway Transport Cost Evaluation”. In: *Procedia, social and behavioral sciences* 111, pp. 549–558 (Cited on Page: 15).

26. Hornyak, Tim (n.d.). Shinkansen high-speed train network in Japan. Retrieved from: https://www.japanstation.com/shinkansen-high-speed-train-network-in-japan/; accessed November 20th, 2020 (Cited on Page: 1).
27. Huang, Ping et al. (2019). “Modeling the Influence of Disturbances in High-Speed Railway Systems”. In: *Journal of Advanced Transportation* 2019, pp. 1–13. DOI: https://doi.org/10.1155/2019/8639589 (Cited on Page: 4).
28. IRG - Independent Regulators’ Group – Rail (2018). Updated Review of Charging Practices for Minimum Access Package in Europe, IRG-Rail (18) 10. URL: https://www.irg-https://www.irg-rail.eu/download/5/529/IRG-Rail1810OverviewchargingpracticesforminimumaccesspackageinEurope.pdf (Cited on Page: 15).
29. Janic´, M. (2016). “A multidimensional examination of performances of HSR (High-Speed Rail) systems”. In: *Journal of Modern Transport*. 24, 1–21. DOI: https://doi.org/10.1007/s40534- 015-0094-y (Cited on Page: 32).
30. Lam, C. Y. and K. Tai (2020). “Network topological approach to modeling accident causations and characteristics: Analysis of railway incidents in Japan”. In: *Reliability Engineering & System Safety* 193, p. 106626. URL: http://www.sciencedirect.com/science/article/pii/S0951832019304247 (Cited on Page: 4).
31. Lawrence, Martha, Richard Bullock, and Ziming Liu (2019). “China’s High-Speed Rail Development”. In: *Chinese Physics B. International Development in Focus*;. Washington, DC: World Bank. © World Bank. URL: https://openknowledge.worldbank.org/handle/10986/31801 (Cited on Page: 1).
32. Levy, Samuel, A. A. Faulkner, and Joseph M. Sussman (2016). “Challenges and Opportunities in Implementation of Future California Rail Network”. In: *Transportation Research Record* 2546.1, pp. 69–77 (Cited on Page: 27).
33. Levy, Samuel J. (2015). Capacity Challenges on the California High-Speed Rail Shared Corridors: How Local Decisions Have Statewide Impacts. Thesis submitted for the Master of Science in Transportation, Massachusetts Institute of Technology. URL: http://web.mit.edu/hsr-group/documents/Sam%5C%20Levy_MST%5C%20Thesis.pdf (Cited on Page: 26).
34. Li, Dewei, Shishun Ding, and Yizhen Wang (2018). “Combinatorial Optimization of Service Order and Overtaking for Demand-Oriented Timetabling in a Single Railway Line”. In: *Journal of Advanced Transportation* 2018, pp. 1–21. DOI: https://doi.org/10.1155/2018/4613468 (Cited on Page: 3).
35. Lin, Chen-Yu, Mohd Rapik Saat, and Christopher P. L. Barkan (2020). “Quantitative causal analysis of mainline passenger train accidents in the United States”. In: *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* 234.8, pp. 869–884. DOI: https://doi.org/10.1177/0954409719876128 (Cited on Page: 4).
36. Maca´rio, Rosa´rio et al. (2007). Rail Infrastructure Pricing for Intercity Passenger Services in Europe: Possible Impacts on the Railways Competitive Framework. International Conference on Competition and Ownership in Land Passenger Transport, 10TH (pages 17, 18).
37. Nash, Andrew (2003). Best Practices in Shared-Use High-Speed Rail Systems, *MTI Report* 02-02. Mineta Transportation Institute Publications (pages 11, 13).
38. Ollivier, Gerald et al. (2014). High-Speed Railways in China: A Look at Traffic. Vol. 11. East Asia and Pacific; China; China Transport Topics; No. 11. World Bank, Beijing (Cited on Page: 1).

39. Peterman, David R., John Frittelli, and William J. Mallett (2013). The Development of High Speed Rail in the United States: Issues and Recent Events. *Congressional Research Service*. URL: https://crsreports.congress.gov/product/pdf/R/R42584 (Cited on Page: 2).
40. Prodan, Aleksandr (2011). "Infrastructure Pricing Models for New High-Speed Railway Corridors in Europe". In: Thesis submitted for the MIT Portugal Program, University of Lisbon. [Retrieved from: https://fenix.tecnico.ulisboa.pt/downloadFile/395142788459/dissertacao.pdf; accessed November 20th, 2020] (Cited on Page: 15).
41. RFI – Italian Railway Network (2020) Network Statement 2021. URL: https://www.rfi.it/content/dam/rfi/offerta/offertaaccessorete/Network%20Statement%202021-july20.pdf; accessed November 20th, 2020 (pages 24, 26).
42. Rothengatter, Werner (2003). "How good is first best? Marginal cost and other pricing principles for user charging in transport". In: *Transport Policy* 10.2, pp. 121–130 (Cited on Page: 15).
43. Rus, Gine´s de, ed. (2012). Economic Analysis of High Speed Rail in Europe. Fundacion BBVA / BBVA Foundation. URL: https://EconPapers.repec.org/RePEc:fbb:report:2012126 (pages 10, 11, 13).
44. Sa´nchez-Borra`s, Marta and Andre´s Lo´pez-Pita (2011). Rail Infrastructure Charging Systems for High-Speed Lines in Europe. *Transport Reviews*, 31:1, 49-68. DOI: 10.1080/01441647. 2010.489340 (Cited on Page: 18).
45. San Bernardino County Transportation Authority (SBCTA, 2020). SBCTA Board approves MOU with Xpress West to explore high-speed rail service into Rancho Cucamonga (July 2020). © 2020 SBCTA. URL: https://www.gosbcta.com/sbcta-board-approves-mou-with-xpress- west-to-explore-high-speed-rail-service-into-rancho-cucamonga/ (Cited on Page: 111).
46. Sapkota, Sameeksha (2018). Calculation of Access Charge for High Speed Rail Xpresswest of Nevada. Thesis submitted for the Master of Science – Civil Engineering, University of Nevada, Las Vegas. URL: https://www.proquest.com/docview/2210173203?accountid=3611 (pages 27, 101, 102).
47. Scauzillo, Steve (July 2020). Rancho Cucamonga route could be added to $5 billion train to Las Vegas. San Gabriel Valley Tribune. URL: https://www.pe.com/2020/07/01/rancho-cucamonga-route-could-be-added-to-5-billion-train-to-las-vegas/ (pages 7, 111).
48. Schafer II, D.H. and C.P.L. Barkan. (2008). "A Prediction Model for Broken Rails and an Analysis of Their Economic Impact". In: *Proceedings of the American Railway Engineering and Maintenance-of-Way Association Annual Conference*. Salt Lake City, UT. (Cited on Page: 40).
49. Scordamaglia, Damiano (2015). High-speed rail in the EU, PE 568.350. *European Parliamentary Research Service* (pages 1, 13).
50. Silavong, Catherine, Laure Guiraud, and Julien Brunel (2014). "Estimating the marginal cost of operation and maintenance for French railway network". In: *International Transportation Economics Association Conference* – June 2014. URL: https://editorialexpress. com/cgi-bin/conference/download.cgi?db_name=ITEA2014&paper_id=137 (Cited on Page: 22).
51. SNCF Re´seau. (2019a). Appendix 6.1.1, Network Statement 2020 Timetable. URL: https://www.sncf-reseau.com/sites/default/files/drr_horaires/drr_2020/en/DRR2020M-appendix-6-1-1.pdf; accessed November 20th, 2020 (Cited on Page: 21).

52. SNCF Re´seau. (2019b) Appendix 6.2, Network Statement 2020 Timetable. URL: https://www.sncf- reseau.com/sites/default/files/drr_horaires/drr_2020/en/DRR2020M-appendix-6-2_2.pdf; accessed November 20th, 2020 (Cited on Page: 23).
53. Steer Davies Gleave (2004). High-speed Rails: International Comparisons. *Commission for Integrated Transport*, London (Cited on Page: 12).
54. Teixeira, Paulo and Aleksandr Prodan (2014). "Railway Infrastructure Pricing in Europe for High-Speed and Intercity Services: State of the Practice and Recent Evolution". In: *Transportation Research Record* 2448.1, pp. 1–10. DOI: https://doi.org/10.3141/2448-01 (pages 17, 18).
55. UIC – International Union of Railways (2015). High Speed Lines in the World. Retrieved from: https:/ / uic.org / passenger / highspeed/article/high- speed- rail- history; accessed November 20th, 2020 (Cited on Page: 1).
56. UIC – International Union of Railways (2020). High Speed Lines in the World. Retrieved from URL: https://uic.org/IMG/pdf/20200227_high_speed_lines_in_the_world.pdf; accessed November 20th, 2020 (Cited on Page: 2).
57. Vranich, Joseph, Wendell Cox, and Adrian T Moore (2013). California High Speed Rail: An Updated Due Diligence Report. *Reason Foundation*. URL: http://reason.org/files/california_high_speed_rail_report.pdf (Page: 26).
58. Watson, Robert (2012). "Factors Influencing the Energy Consumption of High Speed Rail and Comparisons with other Modes". In: Thesis submitted for the Diploma of Imperial College (DIC), PhD degree of Imperial College London. [Retrieved from: https://spiral.imperial.ac.uk/bitstream/10044/1/11653/1/Watson-R-2012-PhD-Thesis.pdf; accessed November 20th, 2020] (Cited on Page: 103).
59. Yaghini, Masoud, Nariman Nikoo, and Hamid R. Ahadi (2014). "An integer programming model for analyzing impacts of different train types on railway line capacity". In: *Transport*; Vilnius, Lithuania 29.1, pp. 28–35. DOI: https://doi.org/10.3846/16484142.2014.894938 (Cited on Page: 3).
60. Ye, Yuling and Jun Zhang (2020). "Accident-Oriented Delay Propagation in High-Speed Railway Network". In: *Journal of Transportation Engineering, Part A: Systems* 146.4. 2473-2893, p. 04020011. ISSN: 2473-2907 (pages 4, 32).

ACKNOWLEDGEMENTS

This study was conducted with the support from the USDOT Tier 1 University Transportation Center on Railroad Sustainability and Durability.

ABOUT THE AUTHORS

Sameeksha Sapkot

Ms. Sameeksha Sapkota was a graduate student working on this research project. She received her Bachelor's degree from the Institute of Engineering, Tribhuvan University, Nepal.

Komal Sree Teja Boyapati

Mr. was a Graduate Student for his master's degree in civil engineering at UNLV. He obtained his bachelor's degree in civil engineering from Birla Institute of Technology & Science Pilani, India.

Jin Ouk Choi, Ph.D.

Dr. Jin Ouk Choi was an assistant professor when he worked on this project. His research interests are construction engineering and project management; modular construction (building, industrial, and civil); scheduling; sustainability; project information management system; pre-project planning; commissioning and startup, and complex projects. He has his MS and Ph.D. degrees from the University of Texas at Austin.

Mohamed Kaseko, Ph.D.

Dr. Mohamed Kaseko was an Associate Professor when he worked on this project. His expert areas include transportation systems analysis, artificial intelligence applications, traffic operations analysis and design, and transportation planning. He has his MS and Ph.D. degrees from Connel University and the University of California at Irvine.