

Transbay Program

Train Operations Analysis
of Two versus Three
Mainline Tracks
for the
San Francisco Downtown
Rail Extension

October 31, 2017

Parsons

In association with
JCMS, Inc.
Consultants to the Transbay Joint Powers Authority

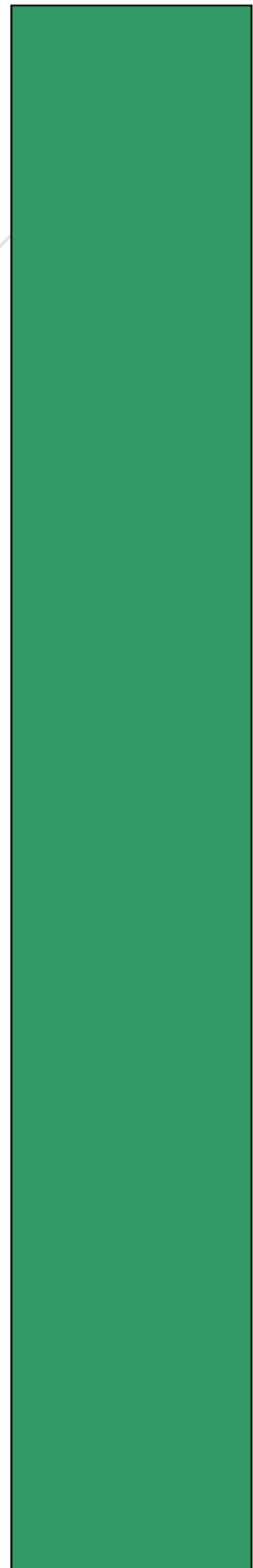


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Acronyms and Abbreviations

CHSRA	California High-Speed Rail Authority
CHSTP	California High-Speed Train Project
CP-	Control Point (interlocking)
DTX	Downtown Rail Extension
EIS/EIR	Environmental Impact Statement/Report
EMU	electric multiple unit
FEIS/FEIR	Final Environmental Impact Statement/Report
FTA	Federal Transit Agency
HSR	high-speed rail
Inbound	Northbound to TC or 4 th & King Street
LPA	Locally Preferred Alternative
NFPA 130	National Fire Prevention Association, <i>Standards for Fixed Guideway Transit and Passenger Rail Systems</i>
Outbound	Southbound from TC or 4 th & King Street
PCJPB	Peninsula Corridor Joint Powers Board
RLPA	Refined Locally Preferred Alternative
TJPA	Transbay Joint Powers Authority
TC	Transit Center
XO	Crossover

1. Project Description and History

The Downtown Rail Extension Project (DTX) will extend the Caltrain commuter rail line 1.3 miles underground from the current Caltrain terminus at 4th and King to the transit center as part of the Transbay Program, and will be designed to accommodate future high-speed rail.

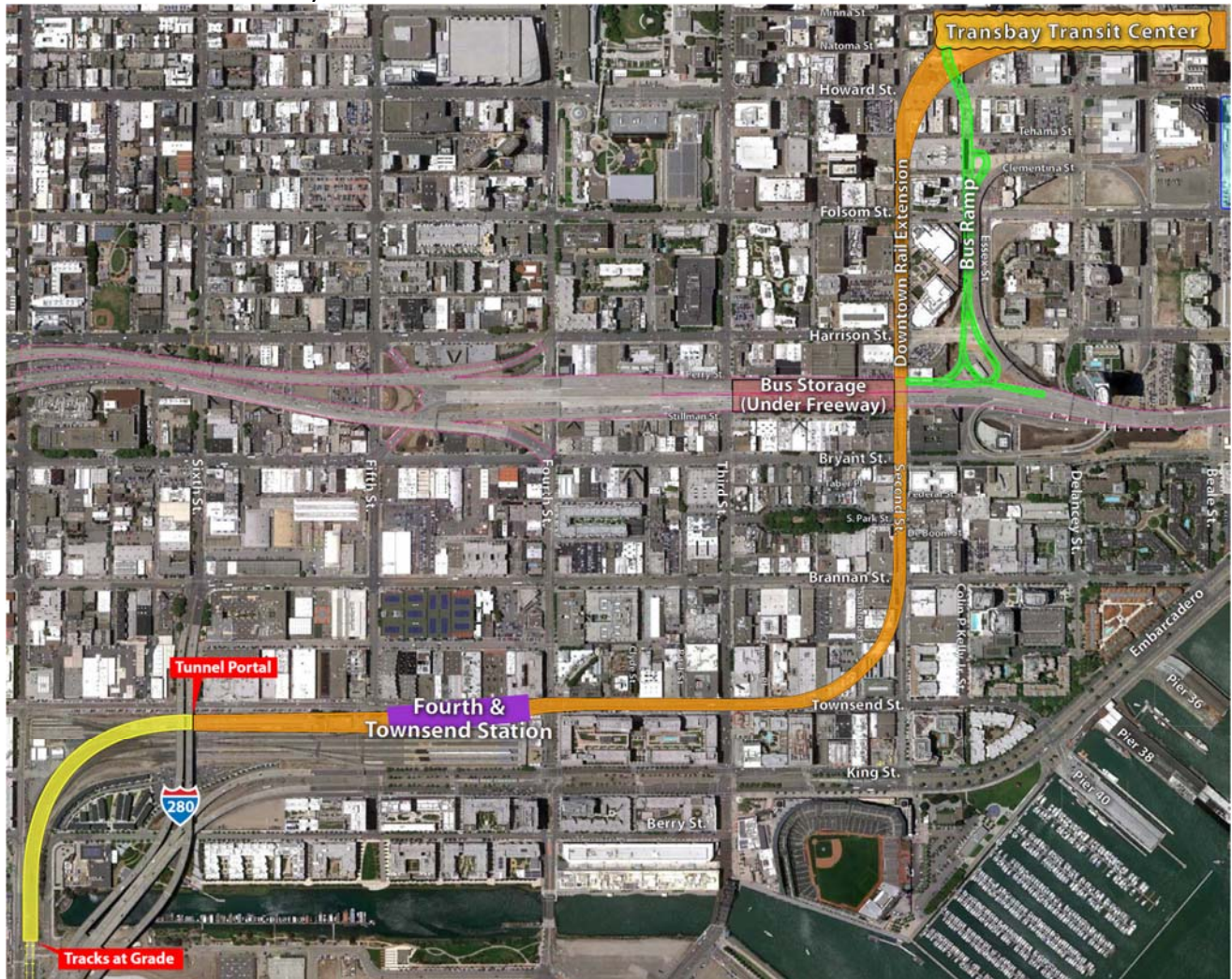
This report evaluates the effectiveness of 2-track and 3-track DTX tunnel alignments to support the planned Caltrain and CHSRA *Blended Service* between San Francisco and San Jose. The impacts of having 2 of 4 CHSRA trains in each direction stop at the 4th & Townsend station is also evaluated. Acceptable schedule performance is defined by the operators as at least 95% on-time performance, which translates into only 1 late train per hour, in either direction. Trains operating northbound into San Francisco are “inbound” to the transit center, and trains southbound from the transit center to San Jose, Gilroy and Los Angeles are considered “outbound”.

The analysis conducted here is the latest in a long series of studies and exercises to define the most operationally successful, safe, and cost-effective DTX alignment to connect Transbay Transit Center to the rail network extending to San Jose and the rest of California. The studies have extended over a period of fifteen years:

- In October 2002, the Peninsula Corridor Joint Powers Board (PCJPB was the original lead agency, with the City, authoring the environmental study for the Caltrain Downtown Extension prior to the TJPA’s formation in 2001), issued the Draft EIS/EIR with Second-to-Main Alternative with two mainline tracks in Second Street, six tracks at the transit center, three mainline tracks through Fourth & Townsend underground station, and provision for underground storage tracks for Caltrain trains at the 4th and King yard. As part of the environmental process, a significant number of alternative alignments and transit center locations were considered including alignments on 3rd Street, Essex Street, Beale Street, Main Street and Mission Street. The number of tracks was also reviewed as part of the environmental process with rail operations analyses determining that three tracks resulted in improved operations.
- In March 2003, the TJPA adopted the Locally Preferred Alternative (LPA) with third mainline track added by PCJPB to improve operational characteristics of the train track/platform layouts, provide for improved train operational efficiency and provide for maximum flexibility for future train design and operations.
- On April 22, 2004, the TJPA Board Certified the FEIS/FEIR with a three-track alignment.
- On February 8, 2005, FTA issued the Record of Decision.
- Beginning in 2005, as part of PE Phase 1 Conceptual Engineering, Parsons carried out extensive train operations simulations, in coordination with the train operators, to test the LPA performance under normal and stressed conditions, including analysis of variations of two to three mainline tracks with two-to-four tracks at 4th and Townsend Street Station.
- Between 2006 and 2007, as part of value management studies, Parsons performed additional train operations simulations to study a proposal for mainline tracks in Second Street combined with a two-track loop track along the Embarcadero and Townsend Street, allowing one-way train operation through the transit center instead of the more complicated bi-directional terminal movements required for the LPA. Also studied were the provision of tail tracks and future extension to the East Bay. These studies, documented in August 8, 2007 “Rail Operations Report

Loop Alternatives Analysis”, demonstrated that operationally a two-track loop configuration provides equivalent performance to the three-track LPA.

- On April 19, 2007, the TJPA Board adopted the Refined Locally Preferred Alternative (RLPA) after completing value management studies, maintaining three mainline tracks in Second Street which could accommodate planned rail service while recommending the Loop for future environmental study as a future phase as future service increased to necessitate the Loop. The RLPA (shown below) included three tracks through Fourth and Townsend Street Station, deferred the tail tracks down Main Street until they were operationally required on the basis that three mainline tracks would be provided through DTX, and eliminated underground storage tracks in the Caltrain Railyard.



- DB International GmbH Consulting International of Frankfurt, Germany, provided a Draft report titled “Professional Opinion on Feasibility and Impact of Extreme Small Radii at the Approach to the Station with International Benchmarking”, dated April 27, 2007. The review also examined two and three mainline tracks in the tunnel, recommended optimizations and concluded that two tracks are considered sufficient subject to verification by dynamic operation simulation.
- In mid-2007 and early 2008, continued Conceptual Engineering was performed subsequent to the DB International GmbH Consulting International report that reviewed the two and three-

track analyses which were documented in the *August 31, 2007 Rail Operations Report* and the May 13, 2008 “Combined Operations Report” which demonstrated that three mainline tracks are necessary. The track alignments reviewed in these analyses are documented in the February 28, 2007, LPA Alternative Alignment and Profile Drawings.

- After 2008, the three-track RLPA was further developed to 30% design as part of Preliminary Engineering Term 2. Modifications to the three-track alignment were incorporated to accommodate the latest CHSRA requirements. The Preliminary Engineering design was completed in April 2011. Limited train operations analyses were performed subsequently by Caltrain as part of the adoption by Caltrain and CHSRA of the corridor-wide plan to share tracks under the Blended System. These limited rail operations analyses used three-tracks in the DTX.
- In 2010 at the request of CHSTA, TJPA assessed DTX alignments on Third Street and Seventh Street/Minna Street. Both alignments were considered to have insurmountable right of way and constructability issues and were dropped from further consideration.
- Preliminary engineering resumed in 2016 to update the RLPA in support of the SEIS/EIR study of the above-mentioned modifications for high speed rail. TJPA requested Parsons to perform the present study to update train operations analyses and confirm the choice of three tracks in Second Street in response to concerns raised by the City and others about cost and property impacts.

2. Modeling Inputs

Simulations are made using the *TrackMaster*© software developed by Parsons. The model loads the Plan and Profile engineering data into a database and creates a graphic display used for the simulation. An internal *Train Performance Calculator* operates trains according to the equipment’s acceleration and braking profile. The simulation model enters trains at Bayshore on-time, per timetable, makes the required station stops and returns the trains back to Bayshore. Simulation outputs include stringlines, full animations of train movements, and reports on delays and schedule performance for each train.

2.1 Track Alignment

For the purposes of the operations modeling, the 3-track layout developed in TASK 5.1 TRACK ALIGNMENT CONCEPT UPDATE, SEPTEMBER 30, 2016, (see [Figure 1](#)) was used with the following modifications:

- XO400 installed at *CP-4th Street North*, #10 diamond crossover with XO401 and XO’s 401-402-403 reduced to #10 crossovers (20 mph) and shifted north to fit within the ventilation zone and interlocking limits;
- Shifts XO601 south 142’, adds XO600, adds #14 diamond crossover (30 mph) at *CP-4th Street South* to facilitate single track operations at 4th and Townsend Street Station.

It was necessary to modify the current track alignment design for the purposes of the 3-track modeling effort (see [Figure 2](#)). The 3-track layout was reconfigured as follows:

- Uses 3-track layout, but removes MT5 in its entirety, removes XO’s 400, 401, and XO’s 301, 302, and 305, eliminates MT2 turnout at STA 212+59, and connects transit center Tracks 21-22 to MT2 with a #10 turnout at STA 160+02.

- Shifts XO601 south 142', adds XO600, adds #14 diamond crossover (30 mph) at CP-4th Street South to facilitate single track operations at 4th & Townsend Street Station.
- The changes at CP-4th Street North were required so that trains that stop at 4th & Townsend would be able to use either MT2 or MT5 to reach TC; otherwise, any train that stops at 4th & Townsend would be limited to a 2-track DTX operation.

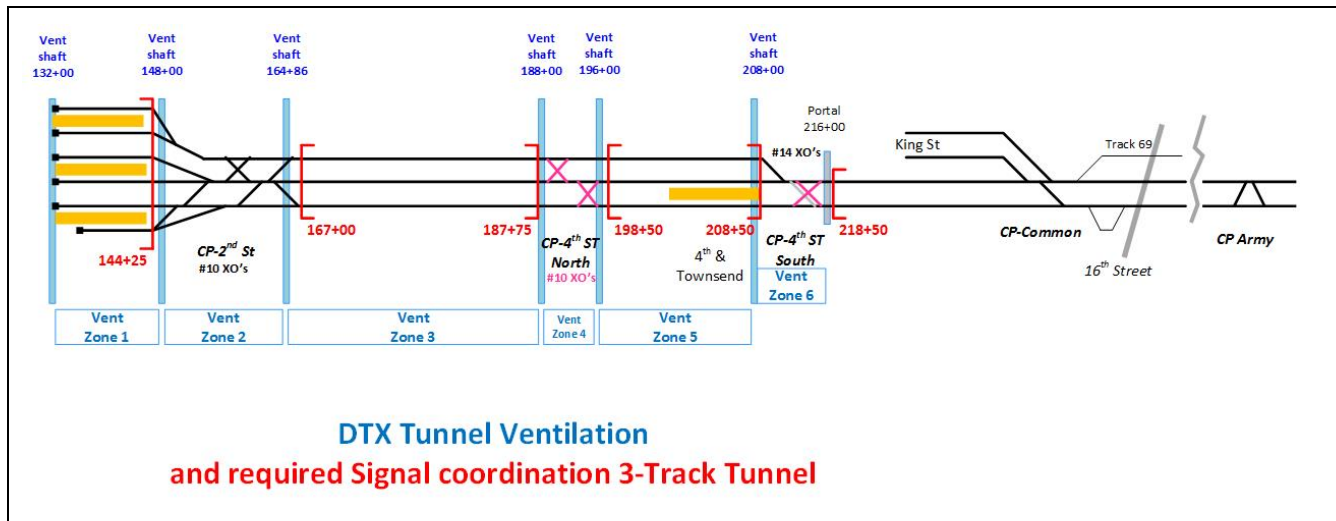


Figure 1, DTX 3-Track Alignment

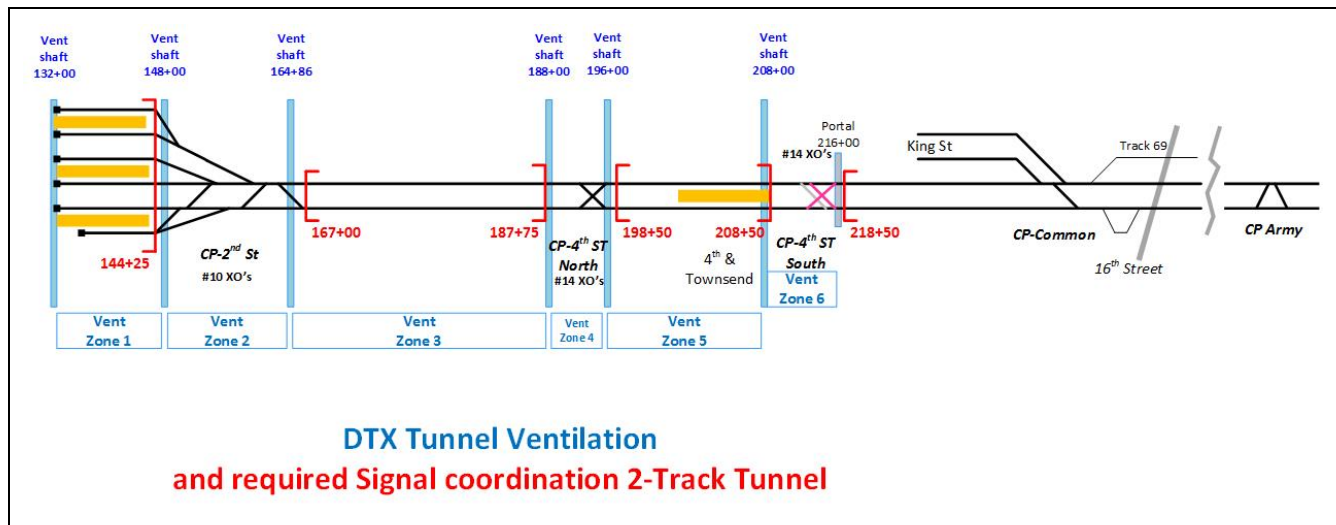


Figure 2, DTX 2-Track Alignment

It is noted that Caltrain and TJPA utilize different naming conventions for the interlockings. [Table 1](#) lists the equivalent interlocking names for Caltrain and TJPA.

The preliminary design control lines and Aspect charts for signaling in the DTX tunnel were reviewed and modified to enforce NFPA 130 "one train per ventilation zone per track" compliance.

Caltrain	TJPA
CP Harrison	CP-2 nd Street
CP Rich	CP-4 th Street North
CP Portal	CP-4 th Street South
CP Common	CP-Common
CP Army	CP-Army
CP Bayshore	CP-Bayshore

Figure 3, Caltrain vs. TJPA Naming Conventions for Interlockings

2.2 Operator Train Sets

The below train specifications for each operator were utilized for the modeling effort:

- CHSRA, 200-meter (656') generic train sets;
 - generic electric multiple unit (EMU) train sets;
 - Tractive effort and acceleration curve, per [Appendix C](#).
- Caltrain, 200-meter (656') Stadler KISS train sets;
 - 4 power cars, 4 idlers, all bi-level;
 - Tractive effort and acceleration curve, per [Appendix C](#).

CHSRA has the option to operate 400-meter “double” train sets in any of its schedule slots on the *Blended Service*. These train sets can be accommodated on TC Tracks 21-25, but not on Track 26 (see [Figure 5](#)). Further, a double CHSRA train set would require selective door opening or other technology and operating practices to stop at the 700' platform at 4th & Townsend station. The operating impact of the longer train sets is an additional 22 seconds of time to clear the TC station throat interlocking at 20 mph.

2.3 Service Plan

The DTX tunnel and its two stations at the transit center and 4th and Townsend Street Station must be operated within the larger context of the *Blended Service Plan* for Caltrain and CHSRA on the Peninsula between San Francisco and San Jose. The *Blended Service Plan* provides schedules and overtakes for each operator that can be maintained on the alignment agreed to by Caltrain and CHSRA. Caltrain and CHSRA trains operate at up to 110 mph on the Peninsula.

The operators (Caltrain and CHSRA) agreed upon a proto-typical timetable that operates the Blended System on the Peninsula to provide a peak 10 trains per hour (TPH) in each direction, split between 6 Caltrain trains and 4 CHSRA trains for use in these analyses:

- C4640_TJPA_4-4-2_BAYSHORE_TC_TIMETABLE_20170720_CLEAN, see Appendix A.

The proto-typical timetable utilizes a “4-4-2” trains per hour pattern (4 CHSRA and 4 Caltrain trains to the transit center, with 2 Caltrain trains to the 4th and King Street surface station). Of the 4 CHSRA TPH, 2 trains stop at the 4th and Townsend Street Station both inbound and outbound with a 2-minute dwell time. (See [Appendix A](#).) The timetable operates a 3-hour morning peak period, as shown in [Table 2](#).

Direction	Time	Trains	To CHSRA-TC	To Caltrain -TC	To Caltrain-King St
North	6AM-7AM	8	4	4	
North	7AM-8AM	10	4	4	2
North	8AM-9AM	10	4	4	2
			From CHSRA-TC	From Caltrain-TC	From Caltrain-King St
South	6AM-7AM	10	4	4	2
South	7AM-8AM	10	4	4	2
South	8AM-9AM	10	4	4	2

Figure 4, C4640 Proto-typical Timetable, AM peak trains

The table shows the derivation of the 4-4-2 designation. It operates a maximum of 8 trains per hour into and out of the transit center.

3. Operations Simulations

The simulation of DTX operations takes place between Bayshore in the south and the transit center and 4th and King Street Station in the north. No capacity analysis or operating simulation is performed at the 4th and King Street Station—it is simply a source and destination for Caltrain, where trains enter or leave the simulation. The simulation assumes that trains enter the simulation from Bayshore “on time” per timetable and the objective of the simulated operation is to deliver each train back to Bayshore “on time” to hit its schedule slot south towards San Jose. Within the Bayshore—Bayshore limits each Caltrain train makes station stops at Bayshore, 22nd Street, and 4th and Townsend Street Station as identified in the proto-typical C4640 timetable. Dwells at 22nd Street and Bayshore are 1-minute each. Two out of four CHSRA trains per hour stop at 4th and Townsend Street Station with 2-minute dwells.

The key design variable to be tested is 2-track vs. 3-track DTX tunnels from the surface to the Transit Center. All operating scenarios are designed to isolate the key 2-track/3-track variable and to hold all other operating assumptions, schedules, and train performances constant for comparison.

Train speeds are governed by the DTX Plan and Profile. Crossover movements on #14 crossovers are limited to 30 mph and 20 mph on the #10 crossovers. A “comfort” brake rate of 1.5 *mph per second* is used for station stops and deceleration into civil speed reductions. Train accelerations are derived from the tractive effort and train weights for the generic CHSRA and Caltrain KISS train sets.

The simulation provides train movement control with movement authorities that will be replicated by the signal system to be installed in DTX, with the requirement to limit operations so that one train per track per ventilation section is maintained at all times. Ventilation sections at *CP-2nd Street* and *CP-4th Street North* will be occupied by a stopped train because the signal control lines will not

permit a train to enter the interlocking limits unless there is an open block beyond the interlocking that can receive the train. This leaves the interlockings clear for other train movements and allows the interlocking ventilation zones to be used as emergency clearance points to remove trains from tracks adjacent to an incident train.

Track 69 is used in the early morning to move non-revenue train sets from the 4th & King Street to put into service at TC. Trains take 2:37 to run onto Track 69 clear of the 16th Street highway crossing, dwell and reverse direction for at least 10 minutes, then take at least 5:18 to run to TC. The four non-revenue movements take place early in the morning peak period and avoid conflicts with revenue train movements at *CP-Common* and in the DTX tunnel. Trains are held on Track 69 rather than interfere with the scheduled revenue train movements. See [Appendix A](#) schedules for the timing of the Track 69 movements.

3.1 Dedicated Platforms

The proto-typical timetable provided by operators assumes that platform tracks at the transit center are dedicated—CHSRA uses tracks 21-22-23-24; Caltrain uses tracks 25-26. Average scheduled transit center dwells are 41.64 minutes for CHSRA and 22.08 minutes for Caltrain. The base timetable (C4640) matches the platform dwell minute assumptions with added schedule times to maintain schedule slots on in and outbound on the Peninsula. These dwell times produce an expected platform utilization rate of 75% or less for both operators. Because Caltrain is limited to 2 platform edges (2*60= 120 platform minutes per hour), all 6 inbound Caltrain trains cannot be accommodated at the transit center with these dwell times, since this would exceed the theoretical capacity (much less the practical capacity, which would include adding provisions for train arrival variability as well as 2-3 minutes for clearing the platform to each train movement). As a result, 2 Caltrain TPH are dispatched to and from the 4th and King Street Station and do not enter the DTX tunnel.

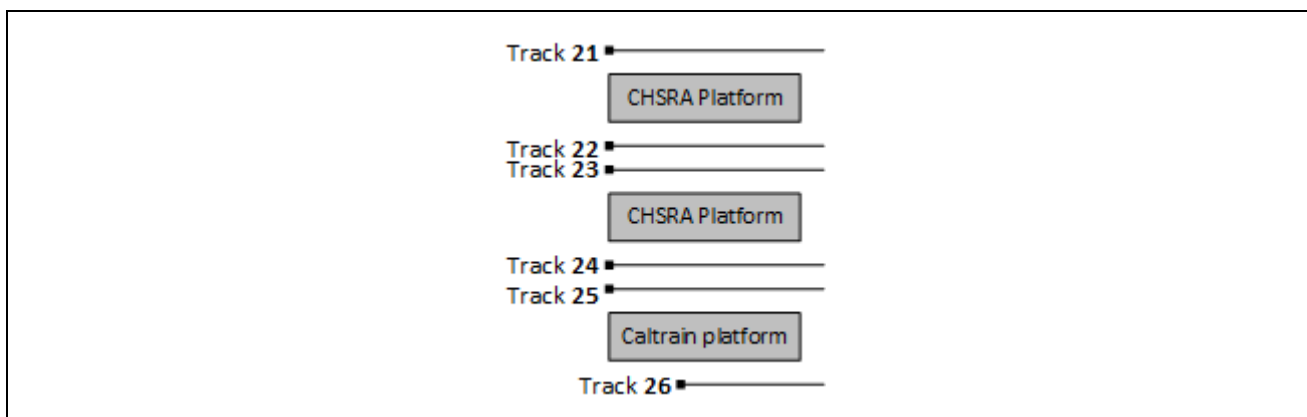


Figure 5, Dedicated Platform Track Assignments at Transit Center

Detailed results of the simulation are presented in Appendices. The comparison of the 2-track and 3-track DTX alignments results in the following conclusions, for the 4-4-2 timetable, with dedicated platform track assignments at the transit center. The base C4640 timetable has trains arriving and departing in close approximation, which results in short delays to trains entering the transit center while waiting for departing trains to clear *CP-2nd Street* at the station throat, but within the recovery time allotted for each service there. Depending on the TC platform track to be used, every train will

cross the *CP-2nd Street* interlocking once, blocking other train movements, on its arrival or on departure. These short delays are easily absorbed into the recovery time built into the proto-typical timetable.

- **3 Track**
 - o All trains on-time at Bayshore southbound
 - o 2 Caltrain trains 14-16 seconds late arriving at the transit center inbound
- **2 Track**
 - o All trains on-time at Bayshore southbound
 - o 2 Caltrain trains 14-16 seconds late arriving at the transit center inbound
 - o 4 CHSRA trains delayed 1:08—1:14 entering the transit center

In all cases, the delays entering the transit center are small enough, less than the “pad” in the station dwell, that the outbound trains are able to meet their schedules and depart on-time. Therefore, under normal operating conditions, DTX can operate with only 2 tunnel tracks between the surface and the transit center and maintain the schedules required by the operators.

3.2 Failure and Recovery Analyses

A key consideration in evaluating the 2-track versus 3-track DTX tunnel configurations is how well each alignment handles unusual conditions. In order to isolate and highlight the performance of 2-track and 3-track tunnels, the base timetable (C4640) and transit center platform assumptions are retained for all the failure and recovery analyses. Four scenarios were analyzed for the alignments:

1. 20-minute incident event on Caltrain Track 25 at the transit center (Section 3.2.1)
2. 20-minute incident event on in the inbound platform track at (MT2) 4th and Townsend Street Station (Section 3.2.2)
3. 20-minute incident event on in the outbound platform track (MT4) at 4th and Townsend Street Station (Section 3.2.2)
4. 20-minute event that closes the DTX tunnel MT4 for train movements between *CP-2nd Street* and *CP-4th Street North* (Section 3.2.3)

The 20-minute incident delay time is a value proposed by the operators as the typical time to evaluate and resolve the incident, and permit the train to continue its operation. For comparison purposes, the same duration delay is used for all failure and recovery scenarios.

3.2.1 Transit Center Incident Event on Caltrain Track 25

The pattern of delays between the 2-track and 3-track tunnels shows that the 3-track tunnel provides reliable access to the transit center for HSR trains; HSR trains are not held behind Caltrain trains in the tunnel while the Caltrain service uses a single dedicated platform track at the transit center while the other platform is occupied by the incident train.

Typically, CHSRA trains have ample recovery time to depart on-time when they arrive late because they are scheduled on 40-43-minute arrival/departure cycles times by the proto-typical service. While Caltrain trains (minimum dwell time 16 minutes) have only 5-7 minutes of schedule recovery time. Given the primary objective is to have southbound trains hit their schedule slots into the rest of the Peninsula, it is required to give the Caltrain train priority to enter the transit center first. An

incident on a Caltrain platform track creates inbound delay for both Caltrain and CHSRA operations when operating a 2-track tunnel, since CHSRA trains become trapped behind a Caltrain train that cannot enter the transit center with only one working platform track. The 3-track alignment allows the CHSRA trains to reach their platforms while Caltrain waits in the tunnel for the one platform track to open. In any delay incident, a substantial delay is incurred to the “incident train”, which the operation must absorb. “Non-incident train” delay captures the effects on other trains and is a better evaluation parameter for the 2- and 3-Track alternatives, since the “incident delay” is present in both operations.

20-minute Emergency at Transit Center	2-Track Dedicated	3-Track Dedicated
Trains per Hour	4-4-2	4-4-2
Inbound Caltrain trains delayed	4	4
Inbound Caltrain delay minutes: seconds	14:47	15:03
Inbound HSR Trains Delayed	5	0
Inbound HSR delay minutes	18:25	0:00
Outbound Caltrain Trains Delayed	2	2
Outbound Caltrain Delay minutes:seconds	24:01	23:57
Outbound Caltrain, non-incident Delay minutes:seconds	5:56	5:55
Outbound HSR Trains Delayed	1	1
Outbound HSR Delay minutes:seconds	4:39	4:36
Outbound HSR, non-incident Delay minutes:seconds	4:39	4:36

Figure 6, 20-minute Incident at the Transit Center

3.2.2 Incident Event at 4th and Townsend Street Station

A 20-minute incident stop at the 4th and Townsend Street Station was also modelled, operating all trains that stop at the station on a single platform track:

- **Outbound** stoppage holds Caltrain 425 for 20-minutes at 7:43-8:03AM.
- **Inbound** stoppage holds Caltrain 410 for 20-minutes at 7:11-7:31AM.

All Caltrain trains must make the station stop (2-minutes) at 4th and Townsend Street Station, and 2 of 4 HSR trains in each direction must also make the station stop—no incident bypassing the station stop was modelled.

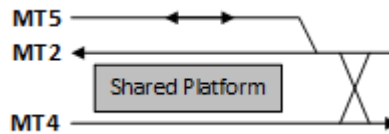


Figure 7, Tracks at 4th & Townsend Station

- 3-Track alignment permits inbound HSR expresses that skip 4th and Townsend Street Station to use MT5 to bypass the station platforms; outbound HSR express trains can also bypass the station using MT5 if that track is not in use by an inbound train.
- 2-Track alignment requires all inbound and outbound trains to use MT2 through 4th and Townsend Street Station, whether an express or a HSR train that stops there.
- An incident on an inbound train can be offset by the schedule recovery time at the transit center; the same incident delay outbound (southbound) has no recovery time at the transit center to offset any delays to southbound trains. Transit center platforms are all operated on a dedicated basis, so the only variables are the incident stop location at 4th and Townsend Street Station and the number of tracks in the DTX tunnel.
- The 3-track tunnel cuts system-wide delays in half for all but the outbound incident train, which has that extra delay time for the incident.
- An incident on the inbound track at 4th and Townsend Street Station can be completely recovered by the 3-track alignment, except for the incident train which can recover only part of the time lost in the incident stop.
- In both inbound and outbound emergencies at 4th and Townsend Street Station, the 2-track tunnel queues all trains through the single available track at the station and increases arrival delays at the transit center and system-wide delays southbound towards San Jose.
- Recognizing that the incident train has incurred a substantial delay, the impact of the incident on other trains' schedule performance at Bayshore is broken out separately ("non-incident trains") so it is not lost in the large delay minutes to the incident train.

20-minute Emergency hold at 4th & Townsend St. Station	MT2 Inbound	MT2 Inbound
Timetable	C4640	C4640
Tunnel tracks	2-Track	3-Track
Transit Center platforms	Dedicated	Dedicated
Trains per Hour	4-4-2	4-4-2
Inbound Caltrain trains delayed	3	3
Inbound Caltrain delay minutes:seconds	26:23	21:58
Inbound HSR Trains Delayed	6	1
Inbound HSR delay minutes:seconds	22:01	2:59
Outbound Caltrain, Trains Delayed	3	1
Outbound Caltrain Delay minutes:seconds	12:49	8:44
Outbound Caltrain Delay, non-incident minutes:seconds	2:34	0:00
Outbound HSR, Trains Delayed	1	0
Outbound HSR Delay minutes:seconds	1:33	0:00
Outbound HSR Delay, non-incident train minutes:seconds	1:33	0:00

Figure 8, 20-minute incident Inbound at 4th and Townsend Street Station

20-minute Emergency hold at 4th & Townsend St. Station	MT4 Outbound	MT4 Outbound
Timetable	C4640	C4640
Tunnel tracks	2-Track	3-Track
Transit Center platforms	Dedicated	Dedicated
Trains per Hour	4-4-2	4-4-2
Inbound Caltrain trains delayed	1	1
Inbound Caltrain delay minutes:seconds	0:16	0:16
Inbound HSR Trains Delayed	4	1
Inbound HSR delay minutes:seconds	5:56	2:09
Outbound, Caltrain Trains Delayed	2	2
Southbound Delay minutes:seconds	20:36	17:37
Southbound Delay, non-incident train minutes:seconds	4:39	1:40
Outbound, HSR Trains Delayed	2	1
Southbound Delay minutes:seconds	2:39	1:39
Southbound Delay, non-incident train minutes:seconds	2:39	1:39

Figure 9, 20-minute incident Outbound at 4th and Townsend Street Station

3.2.3 Incident Closure of DTX Tunnel Track MT4

A 20-minute closure of MT4 is tested, between 7:11AM and 7:31AM, and MT4 cannot be used for train movements between *CP-2nd Street* and *CP-4th Street North*.

For the 2-track alignment, this means single track operation on MT-2 between the transit center and 4th and Townsend Street Station. The 2-track alignment suffers delays as trains are forced to hold at the transit center southbound or 4th and Townsend Street Station northbound until the single tunnel track is cleared by an opposing train.

For the 3-track alignment, this means operating southbound on MT2 and northbound on MT5—essentially operating as if a 2-track tunnel, but with some crossing interference at *CP-2nd Street* and *CP-4th Street North* as a result.

20-minute tunnel track delay	MT4 188+00	MT4 188+00
Timetable	C4640	C4640
Tunnel tracks	2-Track	3-Track
Transit Center platforms	Dedicated	Dedicated
Trains per Hour	4-4-2	4-4-2
Inbound Caltrain trains delayed	2	1
Inbound Caltrain delay minutes:seconds	0:45	0:16
Inbound HSR Trains Delayed	4	0
Inbound HSR delay minutes:seconds	3:45	0:00
Outbound Caltrain Trains Delayed	0	0
Outbound Caltrain Delay minutes:seconds	0:00	0:00
Outbound HSR Trains Delayed	2	1
Outbound HSR Delay minutes:seconds	7:10	1:50

Figure 10, 20-minute tunnel closure on MT4

4. Conclusions

- Modifications to the trackwork, specifically the crossovers, in the TASK 5.1 TRACK ALIGNMENT CONCEPT UPDATE, SEPTEMBER 30, 2016, are required at *CP-4th Street North* (3-track alignment) and *CP-4th Street South* (2-track and 3-track alignments) to accommodate HSR trains stopping at 4th and Townsend Street Station and incident stoppage at that station.
- Operation of the *Blended Service* between San Francisco and San Jose requires precise scheduling and operation of both Caltrain and CHSRA service, with the mix of stopping patterns, overtakes and passing track locations available on the Peninsula Subdivision. **“Acceptable” schedule performance has been defined by the operators as at least “95% on-time” schedule performance.** Given 10 TPH in each direction, that standard requires only 1 of 20 trains be delayed.
- Under an incident scenario (i.e., medical emergency) at the Transit Center, a 2-track alignment and dedicated platforms (2 tracks for Caltrain) causes unacceptable delays that would have systemwide impacts, compared to the 3-track alignment.

- Under an incident scenario (i.e., medical emergency) at 4th and Townsend Street Station, a two-track alignment causes unacceptable delays that would have systemwide impacts, compared to the 3-track alignment.
- An incident scenario that blocks one track reduces the 2-track DTX to single track operation and causes unacceptable delays that would have systemwide impacts if it occurs during the peak.
- An incident scenario that blocks one reduces the 3-track DTX to 2-track operation, which can sustain peak operations without systemwide impacts.
- Based on preliminary train control/tunnel ventilation zone concepts, DTX can operate successfully per NFPA 130, with *“one train per ventilation zone per track”* under both 2-track and 3-track configurations.

APPENDICES

Appendix A **C4640_TJPA_4-4-2_Bayshore_TC_Timetable_20170720_clean**

Appendix B **Train Performance Parameters**

APPENDIX A

C4640_TJPA_4-4-2_Bayshore_TTC_Timetable_20170720_clean

Trip	Previous	CP Brisbane	HSR Brisbane	CP Gevelia	Bayshore	CP Tunnel	CP Army	22nd Street	TRK 69 Yard	CP Common	CP Portal	4th and Townsend	CP Rich	CP Clem	Transbay Transit Center	CP 4th Street	4th & King	TTC Trains	NB Separation at Brisbane	TTC Arrival Headway
B401	X401								4:12:00	4:14:26	4:15:09		4:15:52	4:17:59	4:19:00					
BHSR01			4:05:00	4:05:59	4:06:31	4:07:26	4:12:24	4:13:50		4:16:12	4:16:54		4:17:39	4:19:57	4:22:00					0:03:00
B403	X403								4:42:00	4:44:26	4:45:09		4:45:52	4:47:59	4:49:00					0:27:00
BHSR03			4:35:00	4:35:59	4:36:31	4:37:26	4:42:24	4:43:50		4:46:12	4:46:54		4:47:39	4:50:01	4:52:00			4	0:30:00	0:03:00
BHSR05			5:03:00	5:03:59	5:04:31	5:05:26	5:10:24	5:11:50		5:13:59	5:14:41		5:15:25	5:17:03	5:19:00				0:28:00	0:27:00
HSR00		5:19:24		5:20:21		5:20:47	5:22:33	5:22:51		5:24:24	5:25:09	5:27:00	5:28:28	5:30:46	5:32:00				0:16:24	0:13:00 HSR00 pass BSHR07 at Bayshore
B407	X407								5:13:00	5:16:00	5:16:42		5:17:25	5:33:05	5:34:00					0:02:00
BHSR07			5:18:00	5:18:59	5:19:31	5:22:19	5:27:16	5:28:42		5:30:51	5:31:33		5:32:45	5:35:06	5:37:00				0:01:24	0:03:00
400		5:32:54	5:33:58	5:34:15	5:34:00	5:36:03	5:38:17	5:39:00		5:41:31	5:42:16	5:45:00	5:45:28	5:47:24	5:50:00			5	0:14:54	0:13:00
HSR02		5:49:24		5:50:21		5:50:47	5:52:33	5:52:51		5:54:24	5:55:09	5:57:00	5:58:28	6:00:06	6:02:00				0:16:30	0:12:00
BHSR13			5:56:00	5:56:59	5:57:31	5:58:26	6:03:24	6:04:50		6:08:55	6:09:37		6:10:21	6:11:59	6:14:00				0:06:36	0:12:00
402		6:00:08	6:01:12	6:01:31	6:02:00	6:03:18	6:06:31	6:07:00		6:10:38	6:11:24	6:13:00	6:14:36	6:16:39					0:04:08	0:04:00
B415	X415								6:20:00			reset			6:27:00					0:09:00
HSR04		6:19:24		6:20:21		6:20:47	6:22:33	6:22:51		6:24:24	6:25:09	6:27:00	6:28:28	6:30:06	6:32:00				0:19:16	0:05:00
404		6:34:01		6:35:01		6:35:28	6:37:25	6:37:45		6:39:24	6:40:09	6:42:00	6:43:21	6:45:17	6:47:00				0:14:37	0:15:00
HSR06		6:37:15		6:38:12		6:38:38	6:40:24	6:40:42		6:42:15	6:42:57		6:43:41	6:45:19	6:47:00				0:03:14	0:00:00 needs MT2 and MT5 for TTC entrance
406		6:44:30		6:45:31		6:45:58	6:47:54	6:48:13		6:49:46	6:50:55	6:53:00	6:54:07	6:56:03	6:58:00			8	0:07:16	0:11:00
HSR08		6:49:24		6:50:21		6:50:47	6:52:33	6:52:51		6:54:24	6:55:09	6:57:00	6:58:28	7:00:06	7:02:00				0:04:53	0:04:00
408		6:55:47		6:56:48		6:57:15	6:59:14	7:00:00		7:02:55						7:04:23	7:07:00		0:06:23	
410		7:02:30		7:03:30		7:03:57	7:05:54	7:06:12		7:07:45	7:08:31	7:11:00	7:12:36	7:14:33	7:16:00				0:06:42	0:14:00
HSR10		7:05:39		7:06:36		7:07:02	7:08:48	7:09:06		7:11:54	7:12:36		7:13:19	7:14:58	7:17:00				0:03:09	0:01:00 needs MT2 and MT5 for TTC entrance
412		7:14:33		7:15:34		7:16:01	7:17:57	7:18:16		7:19:49	7:20:41	7:23:00	7:23:53	7:26:05	7:28:00				0:08:55	0:11:00
HSR12		7:19:24		7:20:21		7:20:47	7:22:33	7:22:51		7:24:24	7:25:09	7:27:00	7:28:28	7:30:06	7:32:00				0:04:50	0:04:00
414		7:24:34	7:25:39	7:25:56	7:27:00	7:27:43	7:29:55	7:30:13		7:32:14						7:33:26	7:36:00		0:05:11	
416		7:34:01		7:35:01		7:35:28	7:37:25	7:37:45		7:39:50	7:40:36	7:43:00	7:43:48	7:45:44	7:48:00				0:09:26	0:16:00
HSR14		7:37:15		7:38:12		7:38:38	7:40:24	7:40:42		7:42:15	7:42:57		7:43:41	7:45:19	7:47:00				0:03:14	0:01:00 needs MT2 and MT5 for TTC entrance
418		7:44:30		7:45:31		7:45:58	7:47:54	7:48:13		7:49:46	7:51:17	7:53:00	7:54:29	7:56:25	7:58:00			8	0:07:16	0:11:00
HSR16		7:49:24		7:50:21		7:50:47	7:52:33	7:52:51		7:54:24	7:55:09	7:57:00	7:58:28	8:00:06	8:02:00				0:04:53	0:04:00
420		7:55:47		7:56:48		7:57:15	7:59:14	8:00:00		8:02:55						8:04:23	8:07:00		0:06:23	
422		8:02:30		8:03:30		8:03:57	8:05:54	8:06:12		8:07:45	8:08:31	8:11:00	8:12:36	8:14:33	8:16:00				0:06:42	0:14:00
HSR18		8:05:39		8:06:36		8:07:02	8:08:48	8:09:06		8:11:57	8:12:39		8:13:22	8:15:01	8:17:00				0:03:09	0:01:00 needs MT2 and MT5 for TTC entrance
424		8:14:33		8:15:34		8:16:01	8:17:57	8:18:16		8:19:49	8:20:41	8:23:00	8:23:53	8:26:05	8:28:00				0:08:55	0:11:00
HSR20		8:19:24		8:20:21		8:20:47	8:22:33	8:22:51		8:24:24	8:25:09	8:27:00	8:28:28	8:30:06	8:32:00				0:04:50	0:04:00
426		8:24:34	8:25:39	8:25:56	8:27:00	8:27:43	8:29:55	8:30:13		8:32:14						8:33:26	8:36:00		0:05:11	
428		8:34:01		8:35:01		8:35:28	8:37:25	8:37:45		8:39:50	8:40:36	8:43:00	8:43:48	8:45:44	8:48:00				0:09:26	0:16:00
HSR22		8:37:15		8:38:12		8:38:38	8:40:24	8:40:42		8:42:15	8:42:57		8:43:41	8:45:19	8:47:00				0:12:40	0:01:00 needs MT2 and MT5 for TTC entrance
430		8:44:30		8:45:31		8:45:58	8:47:54	8:48:13		8:49:46	8:51:17	8:53:00	8:54:29	8:56:25	8:58:00			8	0:10:30	0:11:00
HSR24		8:49:24		8:50:21		8:50:47	8:52:33	8:52:51		8:54:24	8:55:09	8:57:00	8:58:28	9:00:06	9:02:00				0:12:09	0:04:00
432		8:55:47		8:56:48		8:57:15	8:59:14	9:00:00		9:02:55						9:04:07	9:07:00		0:11:17	
434		9:02:30		9:03:30		9:03:57	9:05:54	9:06:12		9:07:45	9:08:31	9:11:00	9:11:43	9:14:44	9:16:00				0:13:06	0:14:00
HSR26		9:05:39		9:06:36		9:07:02	9:08:48	9:09:06		9:10:39	9:11:21		9:12:05	9:13:43	9:15:00				0:09:52	0:01:00 needs MT2 and MT5 for TTC entrance
436		9:14:33		9:15:34		9:16:01	9:17:57	9:18:16		9:19:49	9:20:34	9:23:00	9:23:46	9:25:42	9:28:00				0:12:04	0:13:00
HSR28		9:19:24		9:20:21		9:20:47	9:22:33	9:22:51		9:24:24	9:25:09	9:27:00	9:28:28	9:30:55	9:33:00				0:04:50	0:05:00
438		9:24:34	9:25:39	9:25:56	9:27:00	9:27:43	9:29:55	9:30:13		9:32:14						9:33:26	9:36:00		0:05:11	
HSR30		9:49:24		9:50:21		9:50:47	9:52:33	9:52:51		9:54:24	9:55:09	9:57:00	9:58:28		10:06:00			6	0:24:49	0:33:00

Trip	Previous	4th & King	CP 4th Street	Transbay Transit Center	CP Clem	CP Rich	4th and Townsend	CP Portol	CP Common	TRK 69 Yard	22nd Street	CP Army	CP Tunnel	Bayshore	CP Geneva	HSR Brisbane	CP Brisbane	TTC Trains	SB Separation at Brisbane
X401		3:57:00	3:58:46						4:01:17	4:03:00									
X403		4:27:00	4:28:46						4:31:17	4:33:00									
401	B401			4:41:00	4:42:33	4:43:38	4:46:00	4:46:50	4:48:03		4:50:00	4:50:47	4:53:09	4:54:00	4:55:09	4:55:20	4:56:16		0:13:31
X407		4:58:00	4:59:46						5:02:17	5:04:00									
HSR01	BHSR01			4:57:00	4:58:50	5:00:08	5:02:00	5:03:31	5:04:44		5:05:47	5:06:20	5:08:26		5:08:59		5:09:47		0:16:29
X415		6:00:00			Reset					6:10:00									
403	B403			5:11:00	5:12:33	5:13:38	5:16:00	5:16:50	5:18:03		5:20:00	5:20:47	5:23:09	5:24:00	5:25:09	5:25:20	5:26:16		0:13:18
HSR03	BHSR03			5:27:00	5:28:49	5:29:55	5:32:00	5:33:18	5:34:31		5:35:34	5:36:07	5:38:13		5:38:46		5:39:34		0:30:30
HSR05	BHSR05			6:00:00	6:01:50	6:03:08		6:03:48	6:05:01		6:06:05	6:06:37	6:08:43		6:09:16		6:10:04		0:05:34
405	B405	6:06:00	6:06:50		dispatch directly southbound					6:09:17	6:11:00	6:11:59	6:14:11		6:14:47		6:15:38		0:07:38
407	B407			6:08:00	6:09:33	6:10:38	6:13:00	6:13:50	6:15:03		6:17:00	6:17:47	6:20:09	6:21:00	6:22:09	6:22:20	6:23:16		0:01:40
HSR07	BHSR07			6:12:00	6:13:50	6:15:08	6:17:00	6:18:31	6:19:44		6:20:47	6:21:20	6:23:26		6:23:59		6:24:55		0:10:56
409	400			6:22:00	6:23:47	6:25:04	6:27:00	6:28:15	6:29:28		6:31:00	6:32:12	6:34:24		6:35:00		6:35:51		0:04:02
HSR09	HSR00			6:30:00	6:31:51	6:32:57		6:33:37	6:34:50		6:35:53	6:36:26	6:38:32		6:39:05		6:39:53		0:04:08
411	B411	6:34:00	6:34:50		dispatch directly southbound					6:37:40	6:39:00	6:40:22	6:42:34		6:43:10		6:44:01		0:07:25
413	402			6:38:00	6:39:33	6:40:38	6:43:00	6:43:50	6:45:03		6:47:00	6:47:47	6:49:59		6:50:35		6:51:26		0:03:41
HSR11	HSR02			6:42:00	6:43:51	6:45:28	6:48:00	6:48:51	6:50:04		6:51:07	6:51:40	6:53:46		6:54:19		6:55:07		0:09:44
415	B415			6:51:00	6:52:47	6:54:04	6:56:00	6:57:15	6:58:28		7:00:00	7:01:12	7:03:24		7:04:00		7:04:51	8	0:05:13
HSR13	BHSR13			7:00:00	7:01:50	7:03:08		7:03:48	7:05:01		7:06:05	7:06:37	7:08:43		7:09:16		7:10:04		0:06:26
417	B417	7:06:00	7:06:49		dispatch directly southbound					7:10:09	7:12:00	7:12:51	7:15:03		7:15:39		7:16:30		0:06:46
419	404			7:08:00	7:09:33	7:10:38	7:13:00	7:13:50	7:15:03		7:17:00	7:17:47	7:20:09	7:21:00	7:22:09	7:22:20	7:23:16		0:01:40
HSR15	HSR04			7:12:00	7:13:52	7:15:10	7:17:00	7:18:33	7:19:46		7:20:49	7:21:22	7:23:28		7:24:01		7:24:56		0:10:55
421	406			7:22:00	7:23:47	7:25:04	7:27:00	7:28:15	7:29:28		7:31:00	7:32:12	7:34:24		7:35:00		7:35:51		0:04:02
HSR17	HSR06			7:30:00	7:31:51	7:32:57		7:33:37	7:34:50		7:35:53	7:36:26	7:38:32		7:39:05		7:39:53		0:04:40
423	408	7:34:00	7:35:45		dispatch directly southbound					7:38:12	7:40:00	7:40:54	7:43:06		7:43:42		7:44:33		0:06:53
425	410			7:38:00	7:39:33	7:40:38	7:43:00	7:43:50	7:45:03		7:47:00	7:47:47	7:49:59		7:50:35		7:51:26		0:04:08
HSR19	HSR08			7:42:00	7:43:51	7:45:55	7:47:00	7:49:18	7:50:31		7:51:34	7:52:07	7:54:13		7:54:46		7:55:34		0:09:17
427	412			7:51:00	7:52:47	7:54:04	7:56:00	7:57:15	7:58:28		8:00:00	8:01:12	8:03:24		8:04:00		8:04:51	8	0:05:15
HSR21	HSR10			8:00:00	8:01:52	8:03:10		8:03:50	8:05:03		8:06:06	8:06:39	8:08:45		8:09:18		8:10:06		0:06:27
429	414	8:06:00	8:07:34		dispatch directly southbound					8:10:12	8:12:00	8:12:54	8:15:06		8:15:42		8:16:33		0:06:43
431	416			8:08:00	8:09:33	8:10:38	8:13:00	8:13:50	8:15:03		8:17:00	8:17:47	8:20:09	8:21:00	8:22:09	8:22:20	8:23:16		0:01:40
HSR23	HSR12			8:12:00	8:13:52	8:15:10	8:17:00	8:18:33	8:19:46		8:20:49	8:21:22	8:23:28		8:24:01		8:24:56		0:10:55
433	418			8:22:00	8:23:47	8:25:04	8:27:00	8:28:15	8:29:28		8:31:00	8:32:12	8:34:24		8:35:00		8:35:51		0:04:02
HSR25	HSR14			8:30:00	8:31:51	8:32:57		8:33:37	8:34:50		8:35:53	8:36:26	8:38:32		8:39:05		8:39:53		0:04:40
435	420	8:34:00	8:35:45		dispatch directly southbound					8:38:12	8:40:00	8:40:54	8:43:06		8:43:42		8:44:33		0:06:53
437	422			8:38:00	8:39:33	8:40:38	8:43:00	8:43:50	8:45:03		8:47:00	8:47:47	8:49:59		8:50:35		8:51:26		0:04:08
HSR27	HSR16			8:42:00	8:43:51	8:45:55	8:47:00	8:49:18	8:50:31		8:51:34	8:52:07	8:54:13		8:54:46		8:55:34		0:09:17
439	424			8:51:00	8:52:47	8:54:04	8:56:00	8:57:15	8:58:28		9:00:00	9:01:12	9:03:24		9:04:00		9:04:51	8	0:05:15
HSR29	HSR18			9:00:00	9:01:52	9:03:10		9:03:50	9:05:03		9:06:06	9:06:39	9:08:45		9:09:18		9:10:06		0:16:10
441	428			9:11:00	9:12:33	9:13:38	9:16:00	9:16:50	9:18:03		9:20:00	9:20:47	9:23:09	9:24:00	9:25:09	9:25:20	9:26:16		0:13:33
AHSR22				9:15:00	9:16:54	9:18:11	9:18:36	9:18:55	9:21:33		9:23:13	9:24:37	9:29:47						
A430	430			9:17:00	9:19:51	9:21:08		9:27:11	9:28:25	9:30:00	to King Street mid-day storage								
HSR31	HSR22			9:27:00	9:28:52	9:30:10	9:32:00	9:33:33	9:34:46		9:35:49	9:36:22	9:38:28		9:39:01		9:39:49		0:16:27
443	434			9:41:00	9:42:33	9:43:38	9:46:00	9:46:50	9:48:03		9:50:00	9:50:47	9:53:09	9:54:00	9:55:09	9:55:20	9:56:16	6	0:13:50
HSR33	HSR24			10:00:00	10:01:52	10:03:10		10:03:50	10:05:03		10:06:06	10:06:39	10:08:45		10:09:18		10:10:06		

APPENDIX A **C4640_TJPA_4-4-2_Bayshore_TTC_Timetable_20170720_clean : TTC Turns**

Trip	Previous	Arrive	Depart	Turn Time		HSR	Caltrain	Platform Utilization
401	B401	4:19:00	4:41:00	0:22:00	4	35	22	
HSR01	BHSR01	4:22:00	4:57:00	0:35:00				
403	B403	4:49:00	5:11:00	0:22:00			22	
HSR03	BHSR03	4:52:00	5:27:00	0:35:00			35	
HSR05	BHSR05	5:19:00	6:00:00	0:41:00	5	58	41	
407	B407	5:34:00	6:08:00	0:34:00			34	
HSR07	BHSR07	5:37:00	6:12:00	0:35:00			35	
409	400	5:50:00	6:22:00	0:32:00			32	
HSR09	HSR00	5:32:00	6:30:00	0:58:00				
413	402	6:18:00	6:38:00	0:20:00	8	40 46 40 43	20	258 Platform minutes=72% Shared 169 HSR = 70% dedicated 89 CAL = 74% dedicated
HSR11	HSR02	6:02:00	6:42:00	0:40:00				
415	B415	6:27:00	6:51:00	0:24:00			24	
HSR13	BHSR13	6:14:00	7:00:00	0:46:00			21	
419	404	6:47:00	7:08:00	0:21:00				
HSR15	HSR04	6:32:00	7:12:00	0:40:00			24	
421	406	6:58:00	7:22:00	0:24:00				
HSR17	HSR06	6:47:00	7:30:00	0:43:00				
425	410	7:16:00	7:38:00	0:22:00	8	40 43 40 43	22	255 Platform minutes=71% Shared 166 HSR = 70% dedicated 89 CAL = 74% dedicated
HSR19	HSR08	7:02:00	7:42:00	0:40:00				
427	412	7:28:00	7:51:00	0:23:00			23	
HSR21	HSR10	7:17:00	8:00:00	0:43:00			20	
431	416	7:48:00	8:08:00	0:20:00				
HSR23	HSR12	7:32:00	8:12:00	0:40:00			24	
433	418	7:58:00	8:22:00	0:24:00				
HSR25	HSR14	7:47:00	8:30:00	0:43:00				
437	422	8:16:00	8:38:00	0:22:00	7	40 43	22	210 Platform minutes=58% Shared 123 HSR = 51% dedicated 87 CAL = 73% dedicated
HSR27	HSR16	8:02:00	8:42:00	0:40:00				
439	424	8:28:00	8:51:00	0:23:00			23	
HSR29	HSR18	8:17:00	9:00:00	0:43:00				
441	428	8:48:00	9:11:00	0:23:00			23	
A430	430	8:58:00	9:17:00	0:19:00			19	
HSR31	HSR22	8:47:00	9:27:00	0:40:00				
443	434	9:16:00	9:41:00	0:25:00		58	25	6:30AM to 9:3AM Peak
HSR33	HSR24	9:02:00	10:00:00	0:58:00				
							458	
						41.64	22.08	Average scheduled dwell

APPENDIX B

Train Performance Parameters

Engine name: Caltrain 8-car EMU Description:
Based on performance characteristics of Caltrain RFP,
Last change: 30-Jun-17 14:55:54

Engine name: HSR trainset Description:
Standard European HSR trainset for project 2055.1,
Last change: 30-Jun-17 14:56:26

APPENDIX C

HSR Acceleration Table

CHSRA		Davis Resistance formula					1		10		Resistance		Mass		TE		Acceleration		32 axles	
		479.5		14.98438			Air		130		50		479.5		Mass		TE		Acceleration	
		1.3	29	0.03	0.0045	Resistance	0.0015	0.0003	0.050%	4.48221	907.1847	4.48221	2.2369	1.6093	mps ² =Fn/M	Mph/s ²	KpH	TE #	traction coefficient	
Velocity (MPH)	Acceleration Mph/s ²	R=					0.0024	0.00034	R#	F _n	M _g	F _n								
0	1.5069	1551.350	1.300	1.935	0.00000	0.00000	0.00000	0.000	0.000	1551.590	6954.551	434995	300000	0.6737	1.507	0.00	66931	18.61%		
1	1.5066	1568.238	1.300	1.935	0.03000	0.00450	0.34500	0.195	0.150	1568.478	7030.246	434995	300000	0.6735	1.507	1.61	66931	18.61%		
2	1.5061	1585.816	1.300	1.935	0.06000	0.00900	1.38000	0.780	0.600	1586.055	7109.033	434995	300000	0.6733	1.506	3.22	66931	18.61%		
3	1.5057	1604.083	1.300	1.935	0.09000	0.01350	3.10500	1.755	1.350	1604.323	7190.913	434995	300000	0.6731	1.506	4.83	66931	18.61%		
4	1.5053	1623.041	1.300	1.935	0.12000	0.01800	5.52000	3.120	2.400	1623.281	7275.885	434995	300000	0.6729	1.505	6.44	66931	18.61%		
5	1.5048	1642.689	1.300	1.935	0.15000	0.02250	8.62500	4.875	3.750	1642.929	7363.951	434995	300000	0.6727	1.505	8.05	66931	18.61%		
6	1.5044	1663.027	1.300	1.935	0.18000	0.02700	12.42000	7.020	5.400	1663.266	7455.109	434995	300000	0.6725	1.504	9.66	66931	18.61%		
7	1.5039	1684.054	1.300	1.935	0.21000	0.03150	16.90500	9.555	7.350	1684.294	7549.359	434995	300000	0.6723	1.504	11.27	66931	18.61%		
8	1.5034	1705.772	1.300	1.935	0.24000	0.03600	22.08000	12.480	9.600	1706.012	7646.703	434995	300000	0.6721	1.503	12.87	66931	18.61%		
9	1.5029	1728.180	1.300	1.935	0.27000	0.04050	27.94500	15.795	12.150	1728.420	7747.139	434995	300000	0.6719	1.503	14.48	66931	18.61%		
10	1.5023	1751.278	1.300	1.935	0.30000	0.04500	34.50000	19.500	15.000	1751.517	7850.668	434995	300000	0.6716	1.502	16.09	66931	18.61%		
11	1.5018	1775.065	1.300	1.935	0.33000	0.04950	41.74500	23.595	18.150	1775.305	7957.290	434995	300000	0.6714	1.502	17.70	66931	18.61%		
12	1.5012	1799.543	1.300	1.935	0.36000	0.05400	49.68000	28.080	21.600	1799.783	8067.004	434995	300000	0.6711	1.501	19.31	66931	18.61%		
13	1.5006	1824.711	1.300	1.935	0.39000	0.05850	58.30500	32.955	25.350	1824.951	8179.811	434995	300000	0.6709	1.501	20.92	66931	18.61%		
14	1.5000	1850.569	1.300	1.935	0.42000	0.06300	67.62000	38.220	29.400	1850.808	8295.717	434995	300000	0.6706	1.500	22.53	66931	18.61%		
15	1.4994	1877.116	1.300	1.935	0.45000	0.06750	77.62500	43.875	33.750	1877.356	8414.704	434995	300000	0.6703	1.499	24.14	66931	18.61%		
16	1.4988	1904.354	1.300	1.935	0.48000	0.07200	88.32000	49.920	38.400	1904.594	8536.789	434995	300000	0.6700	1.499	25.75	66931	18.61%		
17	1.4982	1932.282	1.300	1.935	0.51000	0.07650	99.70500	56.355	43.350	1932.522	8661.967	434995	300000	0.6698	1.498	27.36	66931	18.61%		
18	1.4975	1960.900	1.300	1.935	0.54000	0.08100	111.78000	63.180	48.600	1961.139	8790.238	434995	300000	0.6695	1.498	28.97	66931	18.61%		
19	1.4968	1990.207	1.300	1.935	0.57000	0.08550	124.54500	70.395	54.150	1990.447	8921.601	434995	300000	0.6692	1.497	30.58	66931	18.61%		
20	1.4961	2020.205	1.300	1.935	0.60000	0.09000	138.00000	78.000	60.000	2020.445	9056.058	434995	300000	0.6688	1.496	32.19	66931	18.61%		
21	1.4954	2050.893	1.300	1.935	0.63000	0.09450	152.14500	85.995	66.150	2051.133	9193.607	434995	300000	0.6685	1.495	33.80	66931	18.61%		
22	1.4947	2082.271	1.300	1.935	0.66000	0.09900	166.98000	94.380	72.600	2082.510	9334.248	434995	300000	0.6682	1.495	35.41	66931	18.61%		
23	1.4940	2114.338	1.300	1.935	0.69000	0.10350	182.50500	103.155	79.350	2114.578	9477.983	434995	300000	0.6679	1.494	37.01	66931	18.61%		
24	1.4932	2147.096	1.300	1.935	0.72000	0.10800	198.72000	112.320	86.400	2147.336	9624.810	434995	300000	0.6675	1.493	38.62	66931	18.61%		
25	1.4924	2180.544	1.300	1.935	0.75000	0.11250	215.62500	121.875	93.750	2180.784	9774.730	434995	300000	0.6672	1.492	40.23	66931	18.61%		
26	1.4917	2214.682	1.300	1.935	0.78000	0.11700	233.22000	131.820	101.400	2214.921	9927.742	434995	300000	0.6668	1.492	41.84	66931	18.61%		
27	1.4909	2249.509	1.300	1.935	0.81000	0.12150	251.50500	142.155	109.350	2249.749	10083.847	434995	300000	0.6665	1.491	43.45	66931	18.61%		
28	1.4900	2285.027	1.300	1.935	0.84000	0.12600	270.48000	152.880	117.600	2285.267	10243.045	434995	300000	0.6661	1.490	45.06	66931	18.61%		
29	1.4892	2321.235	1.300	1.935	0.87000	0.13050	290.14500	163.995	126.150	2321.475	10405.336	434995	300000	0.6657	1.489	46.67	66931	18.61%		
30	1.4883	2358.133	1.300	1.935	0.90000	0.13500	310.50000	175.500	135.000	2358.372	10570.720	434995	300000	0.6654	1.488	48.28	66931	18.61%		
31	1.4875	2395.720	1.300	1.935	0.93000	0.13950	331.54500	187.395	144.150	2395.960	10739.198	434995	300000	0.6650	1.487	49.89	66931	18.61%		
32	1.4866	2433.998	1.300	1.935	0.96000	0.14400	353.28000	199.680	153.600	2434.228	10910.765	434995	300000	0.6646	1.487	51.50	66931	18.61%		
33	1.4857	2472.966	1.300	1.935	0.99000	0.14850	375.70500	212.355	163.350	2473.206	11085.426	434995	300000	0.6642	1.486	53.11	66931	18.61%		
34	1.4848	2512.624	1.300	1.935	1.02000	0.15300	398.82000	225.420	173.400	2512.863	11263.181	434995	300000	0.6638	1.485	54.72	66931	18.61%		
35	1.4839	2552.971	1.300	1.935	1.05000	0.15750	422.62500	238.875	183.750	2553.211	11444.028	434995	300000	0.6634	1.484	56.33	66931	18.61%		
36	1.4829	2594.009	1.300	1.935	1.08000	0.16200	447.12000	252.720	194.400	2594.249	11627.968	434995	300000	0.6629	1.483	57.94	66931	18.61%		
37	1.4820	2635.737	1.300	1.935	1.11000	0.16650	472.30500	266.955	205.350	2635.977	11815.000	434995	300000	0.6625	1.482	59.55	66931	18.61%		
38	1.4810	2678.155	1.300	1.935	1.14000	0.17100	498.18000	281.580	216.600	2678.394	12005.125	434995	300000	0.6621	1.481	61.16	66931	18.61%		
39	1.4800	2721.262	1.300	1.935	1.17000	0.17550	524.74500	296.595	228.150	2721.502	12198.343	434995	300000	0.6616	1.480	62.76	66931	18.61%		
40	1.4790	2765.060	1.300	1.935	1.20000	0.18000	552.00000	312.000	240.000	2765.300	12394.654	434995	300000	0.6612	1.479	64.37	66931	18.61%		
41	1.4779	2809.548	1.300	1.935	1.23000	0.18450	579.94500	327.795	252.150	2809.788	12594.058	434995	300000	0.6607	1.478	65.98	66931	18.61%		
42	1.4769	2854.726	1.300	1.935	1.26000	0.18900	608.58000	343.980	264.600	2854.965	12796.554	434995	300000	0.6602	1.477	67.59	66931	18.61%		
43	1.4758	2900.593	1.300	1.935	1.29000	0.19350	637.90500	360.555	277.350	2900.833	13002.143	434995	300000	0.6598	1.476	69.20	66931	18.61%		
44	1.4748	2947.151	1.300	1.935	1.32000	0.19800	667.92000	377.520	290.400	2947.391	13210.824	434995	300000	0.6593	1.475	70.81	66931	18.61%		
45	1.4737	2994.399	1.300	1.935	1.35000	0.20250	698.62500	394.875	303.750	2994.639	13422.599	434995	300000	0.6588	1.474	72.42	66931	18.61%		
46	1.4726	3042.337	1.300	1.935	1.38000															

APPENDIX C

Caltrain 4x2 Acceleration Table

STADLER 4x2 Velocity (Mph)		Davis Resistance formula										139		710		496		Resistance		Mass		TE		Acceleration		32 axles									
		496		1		15.5		29		0.03		0.0045		Resistance		Air		0.0024		0.00034		0.050%		4.48221		907.1847		4.48221		2.3369		1.6093		16 power axes	
		1.3	29	0.03	0.0045	Resistance	0.0024	0.00034	0.050%	4.48221	907.1847	4.48221	2.3369	1.6093	mps²	mps²	Kph	TE #	traction coefficient																
R=																																			
0	2.3624	1572.800	1.300	1.871	0.00000	0.00000	0.00000	0.00000	0.0000	0.0000	1573.048	7050.731	449964	482251	1.0561	2.362	0.00	107.592	21.69%																
1	2.3618	1590.507	1.300	1.871	0.03000	0.00450	0.59540	0.334	0.262	1590.755	7130.100	449964	482223	1.0558	2.362	1.61	107.586	21.69%																	
2	2.3613	1609.406	1.300	1.871	0.06000	0.00900	2.38160	1.334	1.047	1609.654	7214.805	449964	482195	1.0556	2.361	3.22	107.580	21.69%																	
3	2.3607	1629.495	1.300	1.871	0.09000	0.01350	5.35860	3.002	2.356	1629.743	7304.849	449964	482167	1.0553	2.361	4.83	107.574	21.69%																	
4	2.3601	1650.774	1.300	1.871	0.12000	0.01800	9.52640	5.338	4.189	1651.022	7400.229	449964	482140	1.0551	2.360	6.44	107.567	21.69%																	
5	2.3594	1673.245	1.300	1.871	0.15000	0.02250	14.88500	8.340	6.545	1673.493	7500.947	449964	482112	1.0548	2.359	8.05	107.561	21.69%																	
6	2.3588	1696.906	1.300	1.871	0.18000	0.02700	21.43440	12.010	9.425	1697.154	7607.002	449964	482084	1.0545	2.359	9.66	107.555	21.69%																	
7	2.3581	1721.759	1.300	1.871	0.21000	0.03150	29.17460	18.336	12.828	1722.007	7719.305	449964	482056	1.0542	2.358	11.27	107.549	21.69%																	
8	2.3574	1747.802	1.300	1.871	0.24000	0.03600	38.10560	21.350	16.755	1748.050	7835.125	449964	482028	1.0538	2.357	12.87	107.543	21.68%																	
9	2.3566	1775.035	1.300	1.871	0.27000	0.04050	48.22740	27.022	21.206	1775.283	7957.193	449964	482000	1.0535	2.357	14.48	107.536	21.68%																	
10	2.3558	1803.460	1.300	1.871	0.30000	0.04500	59.54000	33.360	26.180	1803.708	8084.598	449964	481972	1.0532	2.356	16.09	107.530	21.68%																	
11	2.3550	1833.075	1.300	1.871	0.33000	0.04950	72.04340	40.366	31.678	1833.323	8217.340	449964	481945	1.0528	2.355	17.70	107.524	21.68%																	
12	2.3542	1863.862	1.300	1.871	0.36000	0.05400	85.73760	48.038	37.699	1864.130	8355.420	449964	481917	1.0524	2.354	19.31	107.518	21.68%																	
13	2.3534	1895.879	1.300	1.871	0.39000	0.05850	100.62260	56.378	44.244	1896.127	8498.838	449964	481889	1.0521	2.353	20.92	107.511	21.68%																	
14	2.3525	1929.086	1.300	1.871	0.42000	0.06300	116.69840	65.386	51.313	1929.314	8647.592	449964	481861	1.0517	2.352	22.53	107.505	21.67%																	
15	2.3516	1963.445	1.300	1.871	0.45000	0.06750	133.96500	75.080	58.905	1963.693	8801.684	449964	481833	1.0513	2.351	24.14	107.499	21.67%																	
16	2.3506	1999.014	1.300	1.871	0.48000	0.07200	152.42240	85.402	67.021	1999.262	8961.114	449964	481805	1.0508	2.351	25.75	107.493	21.67%																	
17	2.3497	2035.775	1.300	1.871	0.51000	0.07650	172.07060	96.410	75.660	2036.023	9125.881	449964	481777	1.0504	2.350	27.36	107.487	21.67%																	
18	2.3487	2073.726	1.300	1.871	0.54000	0.08100	192.90960	108.086	84.823	2073.974	9295.985	449964	481749	1.0500	2.349	28.97	107.480	21.67%																	
19	2.3477	2112.867	1.300	1.871	0.57000	0.08550	214.93940	120.430	94.510	2113.115	9471.427	449964	481722	1.0495	2.348	30.58	107.474	21.67%																	
20	2.3467	2153.200	1.300	1.871	0.60000	0.09000	238.16000	133.440	104.720	2153.448	9652.206	449964	481694	1.0491	2.347	32.19	107.468	21.67%																	
21	2.3456	2194.723	1.300	1.871	0.63000	0.09450	262.57140	147.118	115.544	2194.971	9838.323	449964	481666	1.0486	2.346	33.80	107.462	21.67%																	
22	2.3445	2237.438	1.300	1.871	0.66000	0.09900	288.17360	161.462	126.714	2237.686	10029.777	449964	481638	1.0481	2.345	35.41	107.455	21.66%																	
23	2.3434	2281.343	1.300	1.871	0.69000	0.10350	314.96660	176.474	138.492	2281.591	10226.586	449964	481610	1.0476	2.344	37.01	107.449	21.66%																	
24	2.3422	2326.431	1.300	1.871	0.72000	0.10800	342.95040	192.154	150.797	2326.696	10438.697	449964	481582	1.0471	2.343	38.62	107.443	21.66%																	
25	2.3411	2372.725	1.300	1.871	0.75000	0.11250	372.12500	208.500	163.625	2372.973	10656.163	449964	481554	1.0466	2.341	40.23	107.437	21.66%																	
26	2.3399	2420.202	1.300	1.871	0.78000	0.11700	402.49040	225.514	176.977	2420.450	10884.967	449964	481527	1.0460	2.340	41.84	107.431	21.66%																	
27	2.3387	2468.871	1.300	1.871	0.81000	0.12150	434.04660	243.194	190.852	2469.119	11067.108	449964	481499	1.0455	2.339	43.45	107.424	21.66%																	
28	2.3374	2518.730	1.300	1.871	0.84000	0.12600	466.79360	261.542	205.251	2518.978	11290.587	449964	481471	1.0449	2.337	45.06	107.418	21.66%																	
29	2.3361	2569.779	1.300	1.871	0.87000	0.13050	500.73140	280.558	220.174	2570.027	11519.403	449964	481443	1.0444	2.336	46.67	107.412	21.66%																	
30	2.3348	2622.020	1.300	1.871	0.90000	0.13500	535.86000	300.240	235.620	2622.268	11753.556	449964	481415	1.0438	2.335	48.28	107.406	21.65%																	
31	2.3335	2676.451	1.300	1.871	0.93000	0.13950	572.17940	320.590	251.590	2675.699	11993.047	449964	481387	1.0432	2.333	49.89	107.400	21.65%																	
32	2.3321	2730.074	1.300	1.871	0.96000	0.14400	609.69860	341.606	268.014	2730.322	12237.875	449964	481359	1.0426	2.332	51.50	107.394	21.65%																	
33	2.3307	2785.887	1.300	1.871	0.99000	0.14850	648.39060	363.290	285.100	2786.135	12488.040	449964	481331	1.0420	2.331	53.11	105.444	21.26%																	
34	2.3292	2842.890	1.300	1.871	1.02000	0.15300	688.28240	385.642	302.641	2843.138	12743.543	449964	481303	1.0414	2.330	54.72	104.231	21.01%																	
35	2.3279	2901.085	1.300	1.871	1.05000	0.15750	729.36500	408.660	320.705	2901.333	13004.384	449964	481275	1.0408	2.329	56.33	102.937	20.75%																	

STADLER 4x2 TE, Resistance, Acceleration

