USE OF THE BAY AREA RAPID TRANSIT (BART) EXCESS CAPACITY FOR GOODS MOVEMENT

ANALYSIS OF THE FEASIBILITY OF FREIGHT TRAIN INSERTION INTO THE CURRENT SCHEDULE

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ABSTRACT

The San Francisco Bay Area traffic congestion and trucking activities are increasing due to the rapid population growth and the development of the local, national, and international economy since it is one of the main gates for international freight input/export to many Asia countries. The Bay Area Rapid Transit (BART) system has extra 70% capacity on average unused. If BART’s service is extended to air-freight, extra revenue will be generated. Truck miles travelled will also be reduced leading to a reduced traffic congestion and pollution, as well as improved traffic safety. The objective of this study is to investigate the number of feasible dedicated freight train insertions into BART passenger service lines within the current schedule without negative impact on the service. Headways between consecutive passenger trains in current schedule for trips of selected lines have been considered to evaluate possible freight train insertions. To qualify this, the headway between two passenger trains needs to be greater than twice the minimum headway required based on BART train safety requirement, and acceleration/deceleration capabilities. The findings are as follows: for peak periods, it would be infeasible to add more trains without adjusting the current schedule. For non-peak periods such as early mornings and evenings, slots for dedicated freight train insertion are available. Air-freight trains can and should be scheduled so that the available slots are matched to the appropriate air-freight collection/dispatching schedules in order to maximize air-freight transportation efficiency.

However, the above considerations are based on current BART train control system which is over 40 years old. If a modern train control system is adopted, the safety headway requirement will be significantly lower, which could increase the capacity of BART. Accordingly, more slots would be available for inserting dedicated freight trains for operation.
1.1 INTRODUCTION:

Freight flow volumes within San Francisco Bay Area and the United States in general have increased at almost twice the rate of population growth over the past three decades (TRB 2008). Although there has been a drastic decline in Air-freight within the Bay Area during 2007-2011, it has been picking up since 2012.

Freight movement is a critical factor to the bay area economy. Beside the role of importing/exporting from/to international market through seaport and airports, over 37 percent of Bay Area economic output is manufacturing, freight transportation, and warehouse and distribution businesses. Air freight is an important part of the exported products through the San Francisco Bay Area. Approximately one-third of California’s specialty crops are exported. The growth trend is steady with the demand from the Asian and European markets, particularly in China (O’Connell, 2005, 2007, 2008).

Trucking is the most frequently adopted mode in freight movement for these activities. As a consequence, congestion and pollution seems inevitable. Heavy duty diesel vehicles alone contributed to 30% of nitrogen oxide emissions in 2005 (Metropolitan Transportation Commission, 2004; 2008a, 2008b). More efficient use of the extra capacities of some transportation modes among existing infrastructure, therefore, is of paramount importance. To this end, the focus of this study is to investigate the feasibility of using existing infrastructure such as the BART to accommodate some of the demand for freight transport. Aside from the economic benefits that may accrue to using the BART, it could use greener technology with less pollution. Besides, it may potentially have positive impact on road traffic by freeing more space to accommodate faster and reliable travel on highways.

A new mode in the US – High Speed Rail (HSR), could potentially be added in California. It could be used for combined passenger as well as fast freight services such as long distance haul air freight movement. Considering this factor in HSR design and construction at the beginning has at least the following advantages: (a) including freight movement in HSR can definitely increase the demand and generate more favorable business case and make the costly system more efficient; (b) in corporate freight movement ingredients could avoid future system modification which could be cost prohibitive. Although HSR load is limited to approximately 2 tons, such loads could be satisfactory for air freight movement since it is typically in low weight and high value. Some air freight type containers could be modified to fit into the train car. If direct connection is available, it would be sufficient to design optimal operational logistics to link the HSR with other modes so that seamless intermodal transportation chains can be created and integrated in the overall transportation system for efficient and smooth movement of passengers and freight.
Knowledge of the current patterns of air freight activities and decision-making processes are important aspects in the development of these modern transportation models. The critical issue is to obtain required data. However, it is not easy to obtain comprehensive and reliable data on behaviors of freight carriers/shippers through surveys due to some institutional issues including information privacy and competitions between different carriers of the same mode and those between different modes. In this study, engineers from FedEx Western Regional Hub at OAK and BART Division of Operation have been actively participating, which makes the study more realistic.

This study focuses on the feasibility of utilizing existing infrastructure specifically the BART to transport air freight. The operational logistics consideration is on BART side with the assumption that FedEx can flexibly operate their trucks to establish a seamless hand-shake with BART system operation. If this is going to operate in practice, feasible schedule and routes for hand-shake of both BART freight cars and FedEx ground connection vehicles of the two systems can be negotiated. This can be conducted with an overall system performance well defined, such as minimizing the overall logistics cost for a given transportation task. Once the model is implemented, the excess capacity of the BART will be utilized.

1.2 LITERATURE REVIEW

Previous studies on urban freight have largely ignored the concept of incorporating air freight into a transit system. Instead, they investigated issues such as intermodal transfers, cost and reliability of line-haul, last-mile delivery, and social impacts. These issues are relevant to the current study though, and are outlined below. Additionally, some European cities have undertaken pilot programs using streetcars or trams to deliver small packages to central city businesses. While this type of system poses a slightly different problem than the current study, these pilot programs offer some valuable information on transshipment, which could be borrowed for this project.

Arvidsson (2010) was among those works that sheds light on the “last mile problem.” The author examined the potential for a combination of trams and electric delivery vehicles (EDVs) to lower the social costs of urban freight. The work summarized several case studies from Western Europe and presents logistical, capital, and political barriers to a successful implementation.

Maes and Vanelslander (2009) studied the economic, social, and logistical issues of incorporating rail into the urban supply chain. Their domain focused on the French Monoprix system though the lessons were extendable. Reduction in KMT, congestion, GHG emissions, and an increase in supply chain efficiency were shown to be within reach for an urban freight rail system.
Moving up from the city-level, Nozzolo et al (2007) presented both a methodology and the results of using railways to distribute freight throughout a metropolitan region. The case study used was for the region near Naples, Italy which, like the San Francisco Bay Area, presented problems related to freight interference with passenger rail service. The authors found a feasible solution, albeit one that required public subsidy which was justified by the externalities imposed by the status quo.

Bozicnik (2007) suggested that intermodal freight service through urban regions was most sustainable in certain niche market segments. These segments included valuable goods (a large portion air freight’s raison d’être) and perishable goods (which were vital to producer market in the San Francisco Bay Area and consumer market in Asia). This paper also stressed needs for cooperation among stakeholders for successful intermodal regional freight transport.

More specific to the Bay Area, Wei (2009) discussed the major air freight data resources available for California. The discussion lead to an explanation of air cargo importance to the regional economy, and therefore a justification for increased investment in air freight distribution.

Regarding externalities, ICF International (2009) and Base Energy Inc. (2007) provided important data on the rail versus truck comparison generally, as well as BART-specific energy use profiles. Additionally, Delucchi (2000) offered a more general view of the environmental damage done by automobile use in America. This study could be used to justify more efficient use of rail system such as BART.

Paaswell’s (2009) discussed site selection at Long Island. New York conducted a careful weighing of both the benefits of increased efficiency in intermodal shipping and the costs which accrue from site selection, including construction, traffic, and other effects on the nearby population. The importance of stakeholder buy-in was also given in the study, but was not noted as the single determinant of project success.

Finally, work by Smirti et al (2007) modeled the Logistics of FedEx International Express. Their work examined the zero, one, and two transshipment cases for all air freight moved by FedEx. They presented a method for estimating the effects of network expansion, modification of transshipments, and new technologies, and found that either additional revenues (to offset costs) or simply lowered costs are possible.
2. DEDICATED FREIGHT TRAIN SLOTS IN CURRENT BART SYSTEM

2.1 Data and Analysis
The data was obtained from the BART General Transit Feed Specification (GTFS). It was thereafter sorted to classify the trips using different Origin and Destinations of the BART links. The data includes information about the BART train runs which pass through the respective stations at particular times, from the first to the last run of the day. The study focuses on trips which occur during weekdays for the reason that the air freight carriers, such as FedEx, do not work on weekends.

In BART current schedules, there are southbound and northbound trips and these have been categorized and analyzed separately. Propose schedule timing are based on final destinations of the individual dedicated freight train trips. Two critical sections have been identified for all the dedicated freight trains: (a) Access to Oakland Annex Shop (OAS); and (b) Downtown San Francisco BART corridor. They are typical since the shortest time headways for current passenger services have been observed at those locations. Therefore, once insertions of dedicated freight trains are feasible at those locations, they will be feasible at other locations of the lines and other scenarios.

2.2 Access to Oakland Annex Shop
The reason for the selection of OAS is as follows: FedEx has its Western Regional Hub (sorting site) at OAK (Oakland International Airport). Recently, FedEx finished its sorting system upgrade by replacing previous manually operated system with a fully automatic sorting system based on barcode recognition. Such an upgrade has significantly increased the sorting capacity of this site. Because of this, more states such as Alaska have been included in this hub for sorting and transfer. UPS also has its sorting center at OAK. Although, it has freight flight from/to SFO (San Francisco International Airport), their products have to be moved to OAK for sorting and transfer. Therefore, OAK has large demand for the products from the two integrated air freight carriers. It would be ideal if BART has a direct link with OAK, which could greatly facilitate air freight in the Greater Bay Area movement using BART. At least, there should be a close access point of BART system from OAK. Unfortunately, this is not available yet. The nearest location of BART system with a spur track which could be used for container loading and unloading is the OAS (Oakland Annex Shop). It is also recommended that, if the state government is to invest for building some access points in BART system for freight operation in the future, it is necessary to select a point closest to OAK in BART system. Also, for BART link with OAK, it is recommended to use full size BART train instead of smaller trains since the former could greatly facilitate an integrated passenger and air freight movement.
The San Francisco Downtown BART corridor is the only path between OAK and SFO. This is critical since both FedEx and UPS have their flights in SFO. As we mentioned before, their products in SFO have to be moved to OAK for sorting and transfer. The main sources of the products are related to booming Asian markets. Integrated air freight carriers wish to have some convenient link for their freight operation without being affected by road traffic congestion. However, current Bay Bridge pass are often very congested in peak hours. For those reasons, UPS had a project several years ago which intended to use helicopters to transfer their products between SFO and OAK, which was not successful due to high cost. FedEx has to do such transfers in non-peak hours which might affect the schedules of all the modes in their intermodal transportation chain.

Figure 1: BART Access Points for freight trains
As shown in figure 2 above, Oakland Annex Shop (OAS) is located on the west side of the BART tracks. Freight trains northbound from OAS would have to cross the southbound BART tracks. The tracking change locations are fixed and are known. This creates a temporary bottleneck for incoming northbound freight trains. Schedules should therefore be monitored to identify slots with large enough gap to ensure a safe and smooth track change for the freight trains. Gaps within the BART train schedule for both directions have been identified to allocate the number of possible freight train insertions for the respective directions. For freight trains heading south from OAS or arriving from the northbound direction, only gaps in the respective direction need to be determined to ensure a possible freight train insertion. Due to the above reasoning, the capacity for freight train allocation is higher for the southbound direction. In this paper, it will be assumed that the critical direction of movement is northbound, which will be the focus in the remainder of the paper.

Oakland Annex Shop is located between Fruitvale and Lake Merritt BART stations. In the analysis, BART schedules for these two stations have been used to estimate the minimum headways required for northbound freight train insertion to and from OAS. The times when the trains arrived at particular points between Fruitvale and Lake Merritt have been obtained using interpolation of the BART train stop times at the two stations. Figure 3 below details the distances between the stations.
Fig 3(a): Access Point to Oakland Annex Shop

- Parameters used in the analysis
  - 2 mph/sec acceleration/deceleration
  - 20 mph maximum operating speed while switching tracks
  - Maximum Operating Speed of 80mph, Average 33mph
  - Maximum length of the train is 710ft or 216.408m (assuming 10 cars).
  - Cross-over switch takes only 3 seconds to operate
  - 1.5 mile minimum separation distance between BART trains

2.2.1 Determination of northbound insertion slots at OAS

Description:

1A: Indicates the point at which the freight train crosses over from the NB track to the SB.
1B: Indicates the point at which the entire length of the train joins the NB track equivalent to the maximum length of the train; 760ft from point 1A.
2A: Point at which freight train crosses over to and from the SB track.
2B: Point at which freight train joins or leaves the OAS.

Fig 3(b): Access Point to Oakland Annex Shop
Given the above assumptions, it would require 10 seconds to accelerate from 0 to 20mph and 40 seconds from 0 to 80 mph. For the two cases, the distance travelled would be 0.055 miles and 0.833 miles respectively.

2.2.2 Determination of available capacity for northbound freight trains heading to OAS

To determine the available capacity for northbound freight trains heading into OAS, the following information is required:

- Minimum headway between two consecutive northbound BART trains
- Minimum headway between two consecutive southbound BART trains
- Minimum headway between northbound BART train at cross-over point and the next southbound train at point OAS termed as the NS-lag

Headway between two consecutive NB passenger trains:

Distance between the preceding passenger train and the freight train should be maintained above 1.5 miles, the safe distance between the two trains. Assuming maximum speed of 80mph, the headway between the two trains should be minimum 67.5 seconds.

Interchanges between tracks can be performed at 20mph and time required to decelerate to this speed assuming the trains had previously achieved the maximum speed is 30 seconds. Distance required to decelerate from speed of 80 mph is 0.333 miles.
Distance that would have been travelled in 30 seconds at 80mph is 0.666miles or 1072.9m. When it slows down to 20mph in 30 seconds, it travels for half the distance it would have travelled had it not slowed down. An additional separation distance of 0.333 miles will therefore be considered in the analysis.

Total separation distance at Fruitvale to maintain the minimum 1.5 separation distance will be 1.833 ~2 miles. Taking a maximum speed of 80mph, the time headway required is 90 seconds. Therefore minimum headway between two consecutive northbound passenger trains should not be less than 158 seconds to allow an insertion of a NB freight train within the schedule.

\[ N_{bound} = 90 + 68 = 158 \text{ seconds}. \]

**Headway between two consecutive SB trains:**

After a SB passenger train passes the cross-over point (point 2A), the freight train has to cross over from the NB tracks to the SB track heading north towards OAS. It has to reach its destination (OAS) before the next SB passenger train approaches OAS.

The distance from Lake Merritt to 2A is 6143ft which is equivalent to 1872m (1.163 miles). Assuming an average speed of 40mph, it will take approximately 105 seconds for the passenger train to travel this distance.

Taking the assumption that the freight train will maintain a constant speed of 20mph from the point it changes its tracks till it reaches its destination in OAS. The distance from 2A to OAS, (distance in the NB direction that the freight train has to travel in the SB direction) is 2494 feet ~0.29 miles. With a speed of 20mph, it will take 53 seconds for the freight train to travel this distance.

For the next southbound train, assuming that it travels at an average speed of 40mph, to travel from Lake Merritt to OAS interchange point (distance of 4359ft = 0.8256 mile), it would take 74 seconds.

Total time headway between two SB trains should be \( S_{bound} = 105 + 53 = 158 \text{ seconds} \). Adding a lag time of 60 seconds, the minimum headway between two consecutive trains is 218 seconds.

**NS lag: Time lag between the northbound (NB) train at 1A and the next SB train at OAS.**

The NS lag is the difference between the times at which the NB passenger train approaches the crossover point (1A) and when the SB passenger train reaches OAS station. This should be large enough to
accommodate a freight train crossing over from the NB side to the OAS without collision with the oncoming SB passenger train.

\[ NS_{lag} > NBFT \text{ lag} + T(1A \text{ to OAS}) \]

whereby; NBFT is the NB-freight train lag time

Whereby: NBFT is the NB-Freight Train lag time, and \( T(1A \text{ to OAS}) \) is the time required for the freight train to travel from point 1A to OAS at the average speed of 20mph. Distance from 1A-train to OAS is 2706ft ~ 0.318 mile. It takes 58 seconds for the freight train to travel from point 1A-train to OAS.

\[ NS_{lag} > 68 + 58 = 126 \text{ seconds} \]

Adding extra 90 seconds as safe time lag between the freight train and the SB train:

\[ NS_{lag} \geq 68 + 58 + 90 = 216 \text{ seconds} = 3.6 \text{ minutes} \]

Figure 4 depicts the northbound insertion of a freight train showing gap allowances for the leading and preceding BART trains.

**Description:**

- The blue squares symbolize northbound BART trains from Fruitvale to Lake Merritt
- The red rectangles symbolize a freight train.
- Green rectangles symbolize southbound BART train.

*Blue: NB BART trains, Green: SB BART trains, Red: Freight train.*
2.2.3 Capacity for northbound freight trains originating from OAS

Northbound freight trains have to crossover to the northbound track given the location of OAS. Because the track changes, the capacity in this direction is limited by both the northbound and southbound train movements. In order to determine the available capacity, the following parameters were determined; (1) Minimum headway between two consecutive northbound BART trains, (2) Minimum headway between two consecutive southbound BART trains, (3) Minimum headway between northbound BART train at cross-over point and the next southbound train at point OAS termed as the NS-lag.

Headway between two consecutive NB passenger trains:

As previously stated, the safe distance between two consecutive trains travelling at 80mph is 1.5 miles which is equivalent to a minimum headway of 68 seconds. Since the freight train is going to follow this already fast train, the minimum allowable headway is reduced by the time the freight train takes to accelerate to a speed of 80mph.

As the freight train joins the NB track, its speed reduces to zero due a direction change. The time and distance required to accelerate to maximum speed is 40 seconds and 0.444 miles respectively. The
distance that would have been travelled in 40 seconds at 80mph is 0.889 mile. While accelerating from zero to 80mph, it will travel for approximately half the distance it would have travelled had it been at maximum speed. This creates an extended distance buffer and therefore reduces the safe distance limit for the preceding NB train but increases that for the next NB train.

Following the above trend of thought, the headway between preceding train and the freight train at the point of entrance into the NB track should be 45 seconds considering a safe distance of 1 mile at point 1A while that between the freight train and the next NB train should be 90 seconds considering a safe distance of 2 miles at point 1A assuming a maximum speed of 80mph. Minimum headway in the northbound direction, Nbound H, is given as;

\[ N\text{bound } H \geq 40 + 90 = 130 \text{ seconds}. \]

**Headway between two consecutive SB trains:**

The headway between two consecutive southbound trains shall be constrained to the minimum safe headway between the two trains. Taking for instance a southbound train travelling at maximum speed of 80mph, with a safe distance gap of 1.5 miles, the headway would be 68 seconds.

There has to be a reasonable gap for the freight train to join the tracks and thereafter crossover before the next passenger SB train departs from Lake Merritt. In addition, the headway has to be large enough to allow a freight train to merge onto the tracks before the next southbound passenger train departs from Lake Merritt. With 2mph/sec acceleration, it will take the freight train 10 seconds to achieve a speed of 20mph. As shown on figure 3(a), point 2A is 0.482 miles from OAS entrance location. At a speed of 20mph, it will take 87 seconds to travel this distance hence approximately 100 seconds for the freight train to cross the SB track to the NB track. Minimum headway between two SB trains should be given as;

\[ S\text{bound } H = 68 + 100 = 168 \text{ seconds} \]

Adding a lag time of 60 seconds, the **Sbound H = 225 seconds**

**SN lag:** Time lag between the southbound train (at 2B) and next northbound train (at 1B).
SN lag is critical and ensures that there is adequate time for the freight train to crossover from the SB track to the NB track and then continue in the NB direction. In order to ensure a safe transition, the time at which the freight train approaches point 1B is a critical factor in determining how further apart the trains on the northbound track should be spaced. Adequate gap (which is determined below) is required for the freight train to join the NB track just ahead of the next NB train.

With reference to the above figure, the times at which the trains pass the marked points were determined. Given the time period between the instances at which the freight train departs OAS and when it arrives at point 1A (period A); and the time period between the instances at which the southbound train approaches point 2B and the northbound train arrives point 1B on their respective tracks (period B). It follows that period A should be less than period B.

While travelling at an average speed of 20mph, it will take the freight train 114 seconds to cover 0.635 miles, the distance from OAS to point 1A on the NB track with a 10 second buffer allowing for deceleration. As stated above, the minimum headway between the freight train and the next NB train and between the freight train and next SB train are 87, and 30 seconds respectively. These are all summed up to provide an estimate of the SN-lag.

\[
SN_{lag} = 30 + 128 + 87 = 245 \text{ seconds} \approx 4.0 \text{minutes}.
\]

The SN_{lag} should therefore be greater than 4 minutes to allow freight train movements from OAS heading northbound. Figure 5 illustrates northbound freight train maneuvers. Note that the BART trains are capable of propulsion in both directions.

The blue trains are the NB BART trains, green symbolizes SB BART train while red is for the freight trains.
Illustration of Northbound insertion between Fruitvale and Lake Merritt BART station:

Freight train waiting to join SB track

Freight train joins track and crossing over to NB track

Freight train joins NB track and next NB train approaches crossover point

Freight train joins NB track and starts accelerating to maximum speed.

Figure 5: Northbound freight train maneuver from OAS
2.2.3 Discussion of Results:
The tables below show the findings for the available slots within the current schedule given the constraints explained above.

**Table 1(a): Minimum headways for northbound freight trains heading to OAS**

<table>
<thead>
<tr>
<th>Headway</th>
<th>Time (s)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>158</td>
<td>2.6</td>
</tr>
<tr>
<td>Southbound</td>
<td>218</td>
<td>3.6</td>
</tr>
<tr>
<td>NS lag</td>
<td>216</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**Table 1(b): Minimum headways for freight train insertion northbound from OAS**

<table>
<thead>
<tr>
<th>Headway</th>
<th>Time (s)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>130</td>
<td>2.2</td>
</tr>
<tr>
<td>Southbound</td>
<td>225</td>
<td>3.8</td>
</tr>
<tr>
<td>NS lag</td>
<td>245</td>
<td>4.1</td>
</tr>
</tbody>
</table>

**Table 1(c): Number of insertions for northbound freight trains heading to OAS**

<table>
<thead>
<tr>
<th>Period</th>
<th>Insertions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:00am – 10:00am</td>
<td>22</td>
</tr>
<tr>
<td>10:00am – 4:00pm</td>
<td>23</td>
</tr>
<tr>
<td>4:00pm – 12:00am</td>
<td>37</td>
</tr>
<tr>
<td>Total</td>
<td>82 per day</td>
</tr>
</tbody>
</table>

**Table 1(d): Number of insertions for northbound freight trains from OAS**

<table>
<thead>
<tr>
<th>Period</th>
<th>Insertions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:00am – 10:00am</td>
<td>18</td>
</tr>
<tr>
<td>10:00am – 4:00pm</td>
<td>4</td>
</tr>
<tr>
<td>4:00pm – 12:00am</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>32 per day</td>
</tr>
</tbody>
</table>

In summary, there are 32 northbound freight train insertions possible per weekday from Oakland Annex Shop and 82 insertions per weekday to OAS from the south.
Figure 6: Northbound freight train maneuvers from/to the Oakland Annex Shop

Figure 6 above shows freight train movements and the available capacity for the northbound trains from/to Oakland Annex shop. At minimum, there will be 32 freight trains that will be able to run for a complete loop to and from OAS assuming this is the only constraint to the capacity. Given the case of a monopoly user of the service such as FedEx, there is much room for flexibility to ensure that it utilizes the slots at maximum capacity. In the case of more demand for the service, a scheduling system can be devised by the BART agency to distribute the available slots for maximum utilization efficiency.

For the BART system as a whole, there were two bottlenecks that were identified. The second critical section is discussed below.

2.3 San Francisco BART corridor

All BART lines which run from San Francisco (SF) across the bay pass through a common corridor running from Daly-City to Embarcadero BART stations. This is the corridor with the highest operation frequency of passenger trains in the entire BART system. It is referred to as the critical corridor in the description below.

Stop times within the critical corridor have been sorted chronologically, and thereafter sorted per station within the corridor. The time difference between two consecutive train-runs at a station, also referred to as
‘headway’, has been determined for the entire duration of BART train operations. The headway has been used as basis to check the availability of a slot in the schedule. Headways which are twice as large as the minimum allowable headway were considered possible slots for insertion of freight trains. The time slots which met the above condition were considered to be possible freight insertion points.

![Image](attachment:image.png)

**Figure 7: BART corridor with highest frequency of trains**

For a clearer picture about the insertion slots, Time Space Diagram (TSD) plots have been used to show freight train insertions within the current schedule. Distances between the respective stations in the critical corridor obtained above have been used to locate the respective positions of the nine stations in the corridor.

### 2.3.1 Northbound Direction (NB)

To determine the trips in this category, data was sorted by destination and all those trips which were heading out of San Francisco were identified. The following destinations are northbound.

- Dublin/Pleasanton (Blue line)
- Pittsburg/Bay Point (Yellow line)
- Fremont (Green line)
- Richmond (Red line)

It was observed than the minimum allowable headway for the BART trains is 2 minutes. A detailed analysis of headways at the particular stations was performed and the minimum headway for the corresponding runs identified. Headways greater than twice the minimum headway were noted and analyzed using two possible scenarios described below.
A. Optimal Scheduling.

For this case, the minimum headway between consecutive trains was taken to be 4 minutes to affirm insertion of an extra freight train hence meeting the allowable minimum headway of 2 minutes. This means that the dedicated freight train should always be on schedule when traversing this corridor.

B. Conservative Scheduling.

An extra minute was added to act as slack in case the freight train fluctuated from its current schedule therefore making the headway between a passenger and the dedicated freight train to be minimum 3 minutes. For this case, in-order to count it as an available slot for a freight train, the minimum headway between consecutive passenger trains had to be at-least 6 minutes.

Both cases were analyzed separated and the results are displayed in table 2 below.

<table>
<thead>
<tr>
<th>Possible Insertions</th>
<th>Case A (2 min. gap)</th>
<th>Case B (3 min. gap)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:00 am to 6:00am</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>6:00am to 7:00pm</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td>7:00 pm to 8:00 pm</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>8:00pm to 10:00pm</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>10:00pm to 12:00am</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Total # of Trips</td>
<td>81</td>
<td>35</td>
</tr>
</tbody>
</table>

The Time Space Diagram (TSD) was used to illustrate the insertion of the freight trains within the slots identified above. Figure 8 shows time-space diagrams showing the insertion of dedicated freight trains between BART runs within the critical corridor.
It’s important to note that the passenger trains always stop at stations as depicted by the step-wise motion of the train trajectory. However, the freight trains do not have to stop at any of the stations since dispatch is at the tail track. From the figure above, the freight trains are able to maintain a uniform speed with
slight variations in their speed from the start to the end of their destination. Trackers on the freight trains would be able to detect separation distances and vary speeds accordingly.

Figure 8(a) attests to the fact that some slots can accommodate more than one freight train as indicated by large headways between consecutive trains. However in this paper, one dedicated freight train insertion per slot was considered.

Cumulative plots were made showing possible slots for freight train insertion during the BART operation period for the two cases. Figure 9 shows the plots.

**Observation:**

In the Optimal scheduling scenario, it was observed that except the period between 6:30 am and 8:00 am in the morning and the three hour period (peak period) between 4:00 pm and 7:00 pm, there are always available slots for insertion of an extra train. It can also be observed that there are greater gaps available in the morning before 6:30am and in the evening after 7:00pm. The time gaps can accommodate at least one extra train every 10 minutes and even a higher frequency after 7:00 pm in the evening.

For the Conservative case, one can observe a huge gap between the schedules for availability of slots. In the cumulative plot from figure2 above, it can be observed that there is uniform increment of available slots with time from 4am to around 6:30am. There are no available slots for freight train insertion from
6:30 am to about 7:00 pm. Then onwards, there is a stable increment in the availability of slots for freight trains.

It can be inferred from the above observation that the slots available within the day for the Optimal scheduling case can only accommodate one train insertion, and only for such cases whereby the trains are strictly on schedule to maintain the two minute headway requirement between consecutive trains.

2.3.2 Southbound Direction (SB)
To determine the trips in this category, data was sorted by destination. The following destinations were considered as southbound.

- Millbrae
- San Francisco International Airport
- Daly City
- Montgomery

To determine possible insertion slots for freight trains moving southbound, the analysis was carried out in two cases as described above; that is (1) Optimal Scheduling and (2) Conservative Case. Analysis for both cases was carried out separately and the findings are displayed in table 3.

Table 3: Insertion slots for Freight trains heading SB

<table>
<thead>
<tr>
<th>Possible Insertions</th>
<th>Case A (2 min)</th>
<th>Case B (3 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:30 am - 6:00 am</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>6:00 am to 7:00 pm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7:00 am to 8:00pm</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>8:00pm to 10:00 pm</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>10:00pm to 12:00 am</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total # of trips</strong></td>
<td><strong>32</strong></td>
<td><strong>19</strong></td>
</tr>
</tbody>
</table>
Figure 11 shows the cumulative time slots for insertion of an extra train within the BART schedule.

![Cumulative slots for possible freight train insertions in the SB direction](image)

**Figure 10: Number of slot insertions in the SB direction**

**Observation**

- From figure 10, it can be observed that there is no significant difference in the number of available slots for the two cases. Availability of slots follows exactly the same trend till around 8:00 pm in the evening whereby the curve for optimal scheduling diverges slightly further away from the Conservative case.
- In both cases, it is not feasible to insert freight trains during the day from 6:00 am to about 7:00 pm without any adjustment in the current schedule.

**Table 4: Number of possible insertions for both Optimal and Conservative Case**

<table>
<thead>
<tr>
<th>Period</th>
<th>Optimal (2 min)</th>
<th>Conservative (3 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NB</td>
<td>SB</td>
</tr>
<tr>
<td>Before 6:00 am</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>6:00 am – 7:00 pm</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td>After 7:00 pm</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>81</td>
<td>32</td>
</tr>
</tbody>
</table>
2.4 DISCUSSION OF RESULTS
The feasibility of freight train insertion within the BART schedule has been preliminarily investigated. It can be shown that there are available slots within the current BART schedule although limited to particular time periods as detailed above. The question as to how many of these trains can actually fit into the schedule can now be answered quantitatively in principle, but practically finding the optimal number to fit into the available slots is beyond the scope of this paper. What can be ascertained is that this number will be limited to the southbound schedule of passenger trains. For practical operation, it is necessary to ensure that the dedicated freight trains travel in a complete loop seamlessly for efficient use of the infrastructure.

The above schedules have been obtained based on the assumption that there is just one freight train insertion per time gap although there are some possibilities of multiple freight train insertions for time slots greater than 6 minutes (for Optimal Scheduling) and 9 minutes (for the Conservative case). This finding is important in cases whereby multiple freight trains are necessary due to the demand form the air freight side.

3. CONCLUSION
In summary, two factors are critical for dedicated freight train operation in current BART system: convenient access point of BART line to OAK and the BART line corridor in San Francisco Downtown. The latter runs from Daly City to Embarcadero BART stations. The trends for the NB and SB directions are similar showing many feasible slots in the morning before 6:00am, and later in the evening after 7:00pm. However the SB direction has fewer available slots in both cases analyzed above and therefore becomes the critical direction for further analysis. In the current weekday BART schedule, the total number of possible insertions is four (4) from 4:30 am to 6:00 am and twenty eight (28) after 7:00pm in the evening.
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