IEOR 180 Senior Project

Client: Alameda-Contra Costa Transit District

Temporary Transbay Terminal Operation Analysis

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Executive Summary

Background of AC Transit

AC Transit is an innovative modern bus system, owned by the public of the East Bay. It not only serves the residents in that area, but also connects other private transportation systems, such as BART stations, Amtrak stations, as well as ferry terminals. Besides these, it also provides service in downtown San Francisco via the Bay Bridge.

Problem Statement

A new expanded Transbay Terminal will be constructed in the downtown San Francisco area. Since the new Terminal will be built at the same site as the existing Terminal, a Temporary Transbay Terminal for AC Transit will be used to continue its Transbay Service. In the Temporary Terminal, the total number of bus stops and staging spaces will be reduced due to space limitation. Therefore we are assigned to investigate the capacity of the Temporary Terminal based on the current bus schedule. There are two areas we need to analyze and give recommendations:

(1) Bus Stop Placement and Bus Loading – how to place bus stops and to operate the unloading and loading processes to ensure the on-time performance.
(2) Storage Issue – how to handle the midday storage of the bus not needed in the East Bay and staging of “deadheads”

Data was collected on-site and from AC Transit to feed the simulation. A Sigma simulation model of the afternoon (2pm-7pm) terminal operations (bus loading, unloading and bus staging) was developed in which alternative designs and configurations were tested for feasibility and efficiency. Numerous sensitivity analyses were made to insure the recommended design is robust for current bus schedule.

Problem Analysis

A Sigma model was built to simulate the 238 buses running in the terminal during 12pm-7pm in a day. The input data for this model mainly included the number of unloading passengers, interarrival time of buses, scheduled leaving time, assigned bus stop for loading, total loading time, and an indicator specifying that if buses initial coming from terminal storage. Inside the operation system, we consider five real processes, including

1. A bus unloads passengers and then leaves the terminal.
2. A bus unloads passengers, and then goes to storage place if it is more than 10 minutes before the scheduled leaving time after unloading; then it leaves storage before 10 minutes of scheduled departure time to begin its loading process.
3. A bus unloads passengers, and starts the loading process directly if its scheduled leaving time is within 10 minutes after unloading.
4. Empty buses from the East Bay will go to the storage right away if its scheduled leaving time is more than 10 minutes from the time it arrives and wait for its loading process.

5. Empty buses from the East Bay will start the loading process immediately if its scheduled leaving time is within 10 minutes.

By running this simulation, we can easily keep track of the state of a bus, trace the number of a bus in the storage and circulating in the terminal at a specific time, the arriving order of a bus, etc.

Sensitivity analysis was performed to test alternative scenarios by changing the number of bus stops from the default (16 bus stops) to 15, 17, and 18, and by testing two bus stop layout methods (based on destination and bus loading frequency) to determine the optimal ahead-of-schedule leaving storage time of a bus. For the storage problem, we analyzed the required staging in different scenarios. In addition, we also tested the flexibility of circulating process in these scenarios.

Conclusion and Recommendation

The result of the model shows that changing the total number of bus stops in the terminal and layout methods do not affect the number of bus in the storage. However, longer Ahead-of-schedule Leaving Storage Time will decrease the required storage spaces, it will definitely worsen the on-time performance of the bus loading process. Approximate 9-minute ahead-of-scheduled leaving time can result in the minimum 90 percentile lateness for different number of bus stops, According to our result, it is feasible to place 16 bus stop in the terminal. However, the two different bus stop layouts give us very similar results.

However, since the demand for AC Transit Transbay Service will be higher in the future, advantages of quick payment method will be more obvious to ensure on-time performance. Special-Pass-Only payment method was tested in the model, and believed it will sufficiently support the future demand. Other suggestions, such as the use of sensor light, and operation in storage were also discussed to optimize the process flow in the Temporary Terminal.

1.0 Introduction

The Client we worked with is Alameda-Contra Costa Transit District (AC Transit), and the contact persons were Mr. Anthony Bruzzone, who is the Manager of the Department of Special Projects in AC Transit, and Ms. Elizabeth Wiecha, who is the Deputy Director and Chief Engineer of the new Transbay Terminal Project.

AC Transit’s history dates back to 1869, the year when AC Transit's first predecessor began carrying passengers from the Broadway to other places in Oakland in a horse-drawn rail car. In 1956, the Alameda Contra Costa Transit District (AC Transit) was established by voters, and the funding for that District was provided to AC Transit with necessary operating assistance. In 1972, AC Transit began to provide feeder buses linking the BART service system. Starting from 1974, AC Transit gradually extended its services to other outlying communities.

At present, AC Transit serves about 1.5 million people living in its 364 square mile service area. There are two special transit service districts. The first one extends from San Pablo Bay to Hayward, including the cities of Richmond, San Pablo, El Cerrito, Albany, Berkeley, Emeryville, Oakland, Piedmont, Alameda, San Leandro, Hayward, and the unincorporated areas of Ashland, Castro Valley, Cherryland, El Sobrante, Kensington, and San Lorenzo. The second one consists of the cities of Fremont and Newark in southwestern Alameda County. Besides these cities mentioned above, AC Transit also serves downtown San Francisco via the Bay Bridge, and Foster City and San Mateo via the San Mateo Bridge. In addition, AC Transit buses connect with 9 other public and private bus systems, 21 BART stations, 6 Amtrak stations, and 3 ferry terminals. According to service statistics of January 2004, AC Transit has 105 bus lines and 6,500 bus stops. Its annual service miles are up to 22.6 millions and its daily service hours are 6,050 hours. Also, it hires approximately 2,302 employees (See Table 1). The headquarters of AC Transit is on 1600 Franklin Street in Downtown Oakland. Its operating divisions are in Richmond, Emeryville, East Oakland, and Hayward.

The annual operating budget is more than $224 million. Most of the funding of AC Transit comes from local, regional and state sources, and the Bus fares only represent about 20% of its operating revenues.

Ridership (2001 –2002 information)

Daily (weekday)	230,000*
Annual	68.9 million
Paratransit (annual)	575,500**

*Includes 60,000 school children and 14,000 Transbay commuters.
** AC Transit and BART contribute to a consortium created to provide paratransit services mandated by the Americans with Disabilities Act.

Service (January 2004 information)

Bus lines*	105

Bus stops	6,5000
Annual service miles	22.6 million
Daily service hours	6,050

*Includes 78 local lines within the East Bay and 27 Transbay line to San Francisco and the peninsula.

Table 1: AC Transit General Facts & Figures
(Source: www.actransit.org)

A new, expanded Transbay Transit Terminal will be constructed in San Francisco. The new terminal will accommodate trains and buses operating down the San Francisco Peninsula as well as buses to and from the East Bay. Since the new terminal would be located at the same site as the existing terminal at Mission and First Streets, temporary terminals will be used to enable bus operations to proceed unimpeded during construction. Among them, a temporary surface terminal for AC Transit buses would be built on the block bounded by Beale, Howard, Main and Folsom Streets to support AC Transit's daily Transbay service.

2.0 Problem Statement

2.1 ***Background of AC Transit's Transbay Service***

Of AC Transit's 97 routes, 27 offer Transbay service between East Bay and the Transbay Terminal, the operator's only San Francisco stop. Midday storage of AC Transit presently occurs on the Transbay Terminal bus ramps, which can provide storage for up to 120 standard 40-foot buses. Of the 27 Transbay routes, three are 'basic service' that operate seven days a week throughout the day and 24 are 'commuter service' that operate during peak periods only. On weekdays, headways for peak period service vary between seven and 30 minutes. Most commute trips are offered in the peak direction only with westbound service provided in the morning and eastbound service in the evening. Approximately 15,000 daily weekday passengers use AC Transit's Transbay service.

2.2 ***Objective***

For our particular project, AC Transit is concerned about on how to deal with the fact that total available bus spaces have been reduced from the current 24 bus spaces to 16 saw-tooth bus spaces. Therefore, the areas of concern are:

- Bus Stop Placement and Bus Loading – how to place the bus stops for the 24 different bus lines operated by two sizes of the buses to ensure the on-time performance. Advance ticket purchase, in lieu of on-board fare payment, may be required to reduce bus-loading time and accommodate all scheduled bus departures with fewer loading spaces.

- Storage Issue – This involves two related issues. The first issue is the midday storage of buses not needed for midday service in the East Bay – how many can be stored while still allowing circulation in the temporary terminal. A second issue is how to handle the movement and staging of "deadheads" – empty buses in the storage waiting for the scheduled departure.

- Evaluate terminal operations to satisfy the afternoon peak conditions under the current system (pay with cash and bus pass) and the prepaid system. Provide recommendations.

- Design the layout for AC Transit's Temporary Transbay Terminal to support AC Transit's normal operation during the construction period of the New Transbay Terminal. Determine the maximum number of storage space is needed in the terminal.

- Determine if fare collection prior to bus boarding is required.

2.3 ***Available Information***

- Passenger demand -- the detailed information of passenger ridership is available for two days in October 2004 (October is one of the peak months of the year) as well as for one day in January, 2005
- Schedule of buses – arrival and departure time of each bus
- Size and proposed layout of the temporary terminal
- The number of different sizes of buses – there are two types of buses, including: 45 and 60 feet

2.4 ***Collected Information***

- Loading time of cash fares – mean and standard deviation.
- Loading time of pre-paid (monthly pass) – mean and standard deviation.
- Loading time with class/special pass – mean and standard deviation.
- The average of passenger queues size during the peak hour
- The average time for the bus to park, to open the door, to close the door, and to departure
- Average total time spent in the terminal for each bus

(Note: boarding time analysis will produce overall dwell times by vehicle type (45 and 60 feet))

2.5 ***Uncertainties***

All the information we have right now is with a certain degree of uncertainty.

The temporary terminal will open in the next two years and be in use for about five years. The data for the Transbay ridership was collected in Winter 2004, and AC Transit may also increase its service starting in the fall of 2005. It is hard to forecast the future demand and bus information. Therefore the information available at this moment may not accurately reflect the future changes. Since it is more likely that the future demand for Transbay buses will increase, by using simulations, we can change the corresponding variables based on the available data to get reasonable forecast. In that way, we can ensure our terminal capacity can handle a certain degree of increase of bus flow in the future.

2.6 ***Decision variables***

- Number of bus loading spaces.
- On-site bus storage (staging) capacity
- Storage design
- Method of ticket selling
- Layout of bus stops
- Ahead-of-schedule leaving storage time

2.7 ***Effect of decision variables to performance measures***

- Number of bus loading spaces (the loading area for operating buses) & Number of buses in the Staging reservoir (the waiting space for “deadhead”-idle buses)
  Due to space limitations, we should find an optimal number of loading spaces/storage spaces that will meet the demand of passengers / idle buses and best utilize the terminal space.
- Methods of ticket selling: purchase ticket on the bus or off the bus from ticket vendor
  It may be costly to buy an automatic ticket machine, and it also takes space. However, it speeds up the process flow. Conversely, purchasing ticket on bus may slow down the process, but it may save the budget.
  Note: Assume there is no ticketing personnel – only ticket vending machines.
- Layout of bus stops. Since the total available bus spaces have been reduced from current 24 bus spaces to 16. Bus stops placement might affect the operation process in the terminal.
- Storage design – with/without interval drive way, bounded/boundless might affect the flexibility and safety issue inside the terminal.

3.0 Problem Analysis and Solution

3.1 ***Explanation of Data Collection Efforts***

On-site data was collected on March 10th and 17th 2005, which included the loading time for each passenger paying with cash, with bus pass, and with special pass, the positioning time of a bus (the time from a bus enters the space, stops, and opens its door), the time for loading all passengers, and the time for departure of a bus (the time from the bus closes its door and completely leaves the space), as well as the total time for a bus spend in the Terminal. All these data was collected during 2pm to 8pm on one of the busiest days during a week

The following tables are the result of the on-site data collection.

3-Floor Bus (45 feet or 60 feet)

	Pay with Cash (sec.)	Pay with Bus Pass (sec.)	Special Pass (sec.)
Total Number of Observations	11	31	0
Average Loading Time	7.072727	5.986567	0
Variance	2.780165	4.092506	0
Std Dev	1.667383	2.022994	0
95% Confident Interval	(6.0874, 8.058)	(6.73843, 8.39282)	0

Table 2: Observation of Loading Time for 3-Step Bus

3-Floor Bus (45 feet or 60 feet)	Senior (sec.)
Total Number of Observations	6
Average Loading Time	6.416667
Variance	7.194722
Std Dev	2.682298
95% Confident Interval	(4.27038, 8.56296)

Table 3: Observation of Loading Time for senior for 3-step bus

4-Floor Bus (45 feet)	Pay with Cash (sec.)	Pay with Bus Pass (sec.)	Special Pass (sec.)
Total Number of Observations	31	155	3
Average loading Time	7.565625	7.257692	6.133333
Variance	5.521631	8.623466	6.020222
Std Dev	2.349815	2.936574	2.453614
95% Confident Interval	(6.7384, 8.3928)	(6.79538, 7.71999)	(3.35680, 8.90986)

Table 4: Observation of Loading Time for 4-Step Bus

4-Floor Bus (45 feet)	Senior (sec.)
Total Number of Observations	11
Average Loading Time	8.027273
Variance	5.30562
Std Dev	2.303393
95% Confident Interval	(6.66605, 9.388849)

Table 5: Observation of Loading Time for senior for 4-step bus

45 Feet Bus (3-step)

	Positioning Time (sec.)	Loading Time (sec.)	Leaving Time (sec.)
Total Number of Observations	6	6	7
Average Time	20.86833	313.7733	6.0914286
Variance	34.83745	15515.93599	4.404612
Std Dev	5.902326	124.56298	2.098717
95% Confident Interval	(16.145486, 25.591174)	(214.1022, 413.4439)	(4.536677, 7.64618)

45 Feet Bus (4-step)

	Positioning Time (sec.)	Loading Time (sec.)	Leaving Time (sec.)
Total Number of Observations	10	10	10
Average Time	16.285	293.121	8.556
Variance	87.71441	14967.279	13.7937
Std Dev	9.365597	122.34083	3.713988
95% Confident Interval	(10.48014, 22.08986)	(217.29337, 368.9486)	(6.25405, 10.85795)

60 Feet Bus

	Positioning Time (sec.)	Loading Time (sec.)	Leaving Time (sec.)
Total Number of Observations	5	4	4
Average Time	12.324	208.3175	11.885
Variance	11.09542	3842.5207	50.95393
Std Dev	3.330979	61.988069	7.138202
95% Confident Interval	(9.404268, 15.24373)	(147.5692, 269.06581)	(4.88974, 18.8804)

- The positioning time of the bus (the time from the bus enters the space, stops, and opens its door)
- The loading time of all passengers
- The departure time of the bus (the time from the bus closes its door and completely leave the space

Table 6: Observation of Positioning Time, Loading Time, and Leaving Time for Two Sizes of Buses with 4 and 6 wheels

	Pay with Cash (sec.)	Pay with Bus Pass (sec.)	Pay with Special (sec.)
Total Number of Passenger	54	236	4
Percentage (%)	18.37	80.27	1.36

Table 7: Proportion of 3 Different Payment Methods

	Adult	Senior	Children
Total Number of Passenger	213	18	3
Percentage (%)	91.026	7.692	1.282

Table 8: Proportion of Age Category

The main reason for us to collect the loading time for individual passenger with different payment methods was to see if we can improve the efficiency of Transbay Terminal's operation by changing different payment methods. We observed that there are over 80.27% of passengers using bus passes, 18.37% using cash, and 1.36% using class/special pass. It generally takes more time for people paying with cash, but paying by bus pass is not tremendously superior. However, there is an exception. The loading time for passengers paying with coins is even faster than bus passes. Though, it may be impractical to demand all passengers paying coins. In order to improve the Terminal's efficiency, we need to consider changing to other payment method completely—such as paying before boarding. In that case, we should consider the queueing at the ticket machines and the extra space it takes. Yet, it may speed up the turn over rate of the platform.

As we observed, there are two types of bus fleet, the standard 45 feet and the long 60 feet. By comparing the 45 feet bus with 4 steps and the 45 feet and 60 feet bus with 3 steps, 45-feet buses with 4 steps take longer for passenger to load. According to our calculation, the loading time per passenger for 45-feet with 4 steps is about 0.4 seconds longer than the 3 steps. Also, the impact is more obvious for seniors with 6.42s for 45-feet with 3 step and 8.03s for 45-feet with 4 steps.

We calculated the average loading time per passenger through two methods. The first was by direct observing each passenger and computing their average. The second method was by collecting the total loading time of a bus (from the bus starts to load passengers to it leaves the platform according to schedule) and the total passengers. The average loading time is those dividends of the two. However, the result of the second method is much higher than the first, and this may due to the idle time between the last passenger loads and the time the bus actually departs. For this reason, the first method is more precise.

Through the trip by trip analysis given by AC transit, we can see that actual arrival/departure time for buses are usually late. The time between the schedule and actual arrival/departure time is crucial to our project; however, it might be impossible to generalize a statistic pattern for that, since this depends on the traffic condition during each bus ride.

Besides the data mentioned above, we also did a separate data collection of the passengers using class pass around the campus area. The reason is that there are not too many passengers using class pass in the terminal, and we need to get a more precise average loading time for our calculation. After collecting those data, we have the following result for special pass: the average loading time is 1.83846 seconds, and the standard deviation is 0.31929 seconds.

3.2 ***Several Observations in Current AC Transit Transbay Terminal***

Here are several useful observations in the current Transbay Terminal:

1. People in the front of the line usually act faster since they know that there are still people waiting behind them. People at the end, on the other hand, are slower.
2. People tend to arrange the waiting line through the aid of physical objects such as fence. This is very useful when designing the passenger platform.
3. The time for a passenger to load a bike to the bus is not very relevant in our project, because they usually load their bikes during queuing and the loading bike time overlap with the time that people wait to get on the bus. Therefore we do not need to worry about the bike loading time when queue is long. However, we still consider that when there is short queue, which is a rare case.
4. Young children and disable people are infrequent passengers in the Transbay Terminal. The boarding time for young children is similar to adult passengers.

3.3 ***Temporary Transbay Terminal Stop Layout Design***

There are total of 21 bus stops for 24 different bus lines in the current Transbay terminal. (See Figure 2), and this bus arrangement is based on each bus line's destination. For example, Line W, Line OX, and Line O's final destination is Alameda, so these three bus stops are placed nearby each other. This type of arrangement can bring convenience to passengers. If a passenger misses one bus, which goes to Alameda, he/she can quickly catch up the other one and do not need to run a long distance. Here is each bus line's destination (see figure 1).

S/SA: Hayward
SB: Newark
W: Alameda
OX: Alameda
O: Alameda
F: Berkeley
NL: Oakland
NX1: Oakland
NX2: Oakland
NX3: Oakland
NX4: Oakland
B: Oakland
E: Claremont
P: Oakland, Piemont
C/CB: Piemont, Oakland, Emeryville
V: Piemont, Oakland
FS: North Berkeley
H: El Cerrito, Albany
G/Z: Berkeley, Albany, El Cerrito
L: Richmond, El Cerrito
LA: Hilltop

Figure 1: AC Transit Service Area

		Effective		December 21, 2003							
	LA	L	G/Z	H	FS	Muni 108	V	C/CB	P	E	
S/SA	SB	W	OX	O	F	NL	NX1	NX2	NX3	NX4	B
Outside					Inside					Outside	

Figure 2: Transbay Terminal Stop Layout

However, since the number of bus stops will be reduced to 16 in the Temporary Transbay Terminal, we have to make more bus lines share the same bus stops. After investigating the scheduled leaving time of each bus line, we come up with the following stop layouts for the Temporary Transbay Terminal.

3.3.1 *Inter-Departure Method for Combining Different Routes*

In our temporary terminal, there are only 16 bus stops; but we have total of 24 different routes. Therefore, we should combine two compatible routes at one bus stop. The main idea of combining routes is based on the scheduled leaving time of each bus line. For example, Line H and Line FS can share the same bus stop since none of their buses has the same scheduled leaving time. That is, combining these two routes does not affect any passenger loading processes – this helps to most possibly avoid the conflict of using of the same stop simultaneously. However, in our routes combining design, our maximum inter-departure time between 2 buses can only reach 5 minutes. This affects the following combinations: H/FS, P/E, NX2/W, NX4/B, and NX1/NX3. Compared to the original of 15-minute time interval, this five-minute may significantly affect the on-time performance; however, this is the best of the worst. By using this method, the minimum required number of bus stops is 15. In order to do the sensitivity analysis, we also considered the layouts of 16, 17, and 18 bus stops. Based on the 15's one, we went through the inter-departure time of all the combined routes, and broke the routes and place them to two bus stops. The one has the most numbers of 5-minute inter-departure time, which is the most possible one causes delay, was broken first.

After combining the routes using the Inter-Departure method, we considered how those bus stops should be arranged in the terminal. We used two methods for the layout design--arranging the bus stop by destination, and by departure frequency.

3.3.2 Dimension of Proposed Temporary Terminal Layout

The length of the Temporary Terminal is 450 feet. Since each 45-feet size bus is assigned in the 60-feet long bus stop, as a result, the maximum number of bus stops can be placed in the sides nearing the Main Street and Beale Street is 7 60-feet long bus stops. Also, the other side of terminal can fit in three 60-feet bus stops.

3.3.3 Layout Method 1 ---by destination

In order to minimize the impact of changing bus terminal layout on passengers, the new order of the bus stops should be kept as much as possible as the original one. That is, the proposed bus stop arrangement is also based on each bus line's destination. Bus routes with the same destination are placed nearby.

The following figures are the layout based on Method 1:

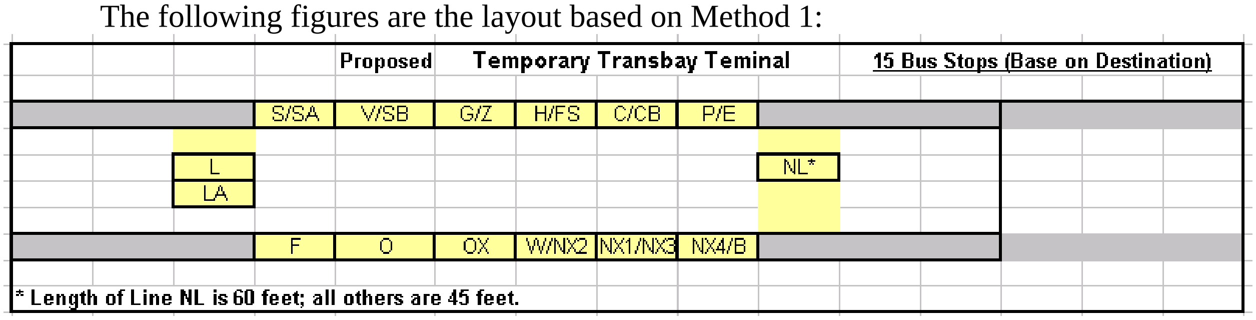

Figure 3: Proposed Temporary Transbay Terminal Stop Layout for 15 Bus Stops (Based on Destination)

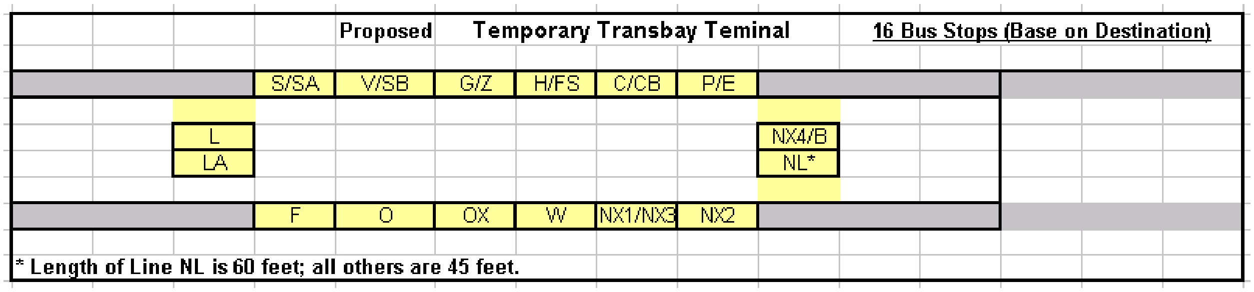

Figure 4: Proposed Temporary Transbay Terminal Stop Layout for 16 Bus Stops (Based on Destination)

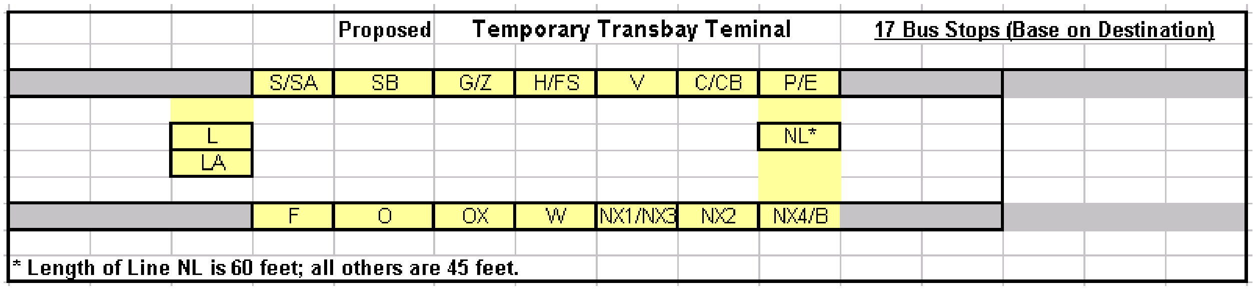

Figure 5: Proposed Temporary Transbay Terminal Stop Layout for 17 Bus Stops (Based on Destination)

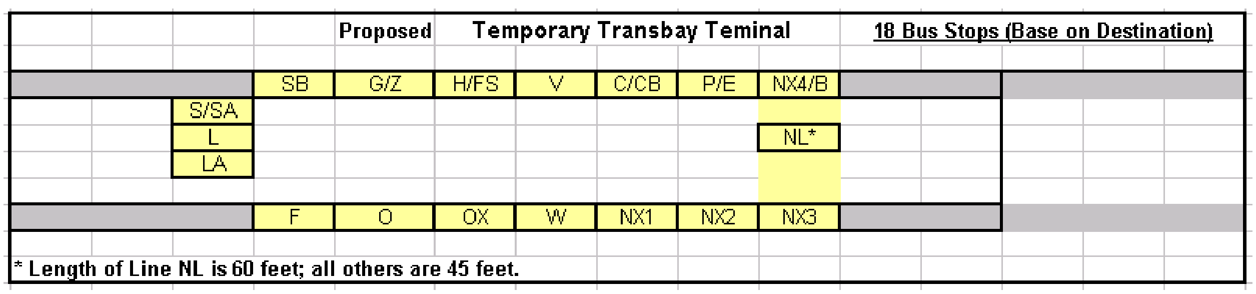

Figure 6: Proposed Temporary Transbay Terminal Stop Layout for 18 Bus Stops (Based on Destination)

3.3.4 Layout Method 2 --- by frequency of departure

Rather than considering each bus line's destination, we use another method - frequency of departure method to arrange the bus stop. We summed up the total number of loading processes during the peak hour (3pm to 6pm) for each bus stop. According to our assumption, bus stops with lower index will experience more unloading processes. Therefore, we placed those routes with less loading frequency close to the terminal entrance.

The following figures are the layout based on Method 2:

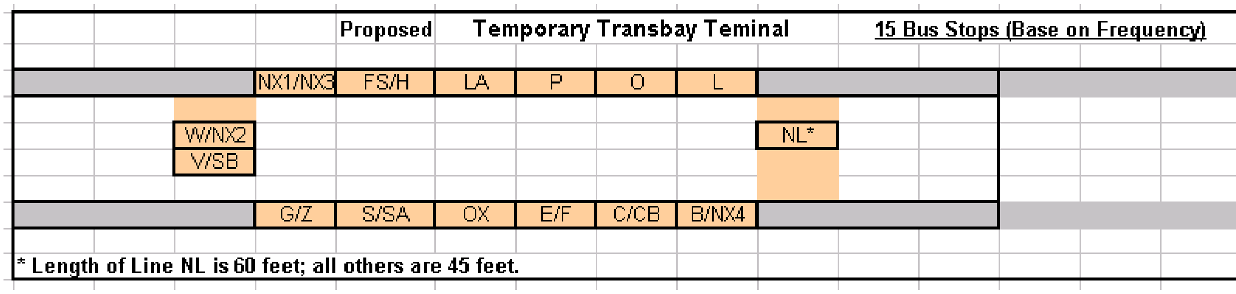

Figure 7: Proposed Temporary Transbay Terminal Stop Layout for 15 Bus Stops (Based on Frequency)

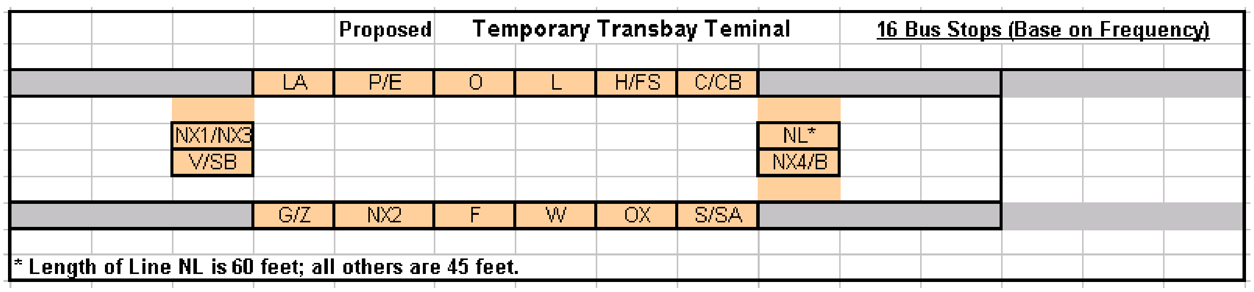

Figure 8: Proposed Temporary Transbay Terminal Stop Layout for 16 Bus Stops (Based on Frequency)

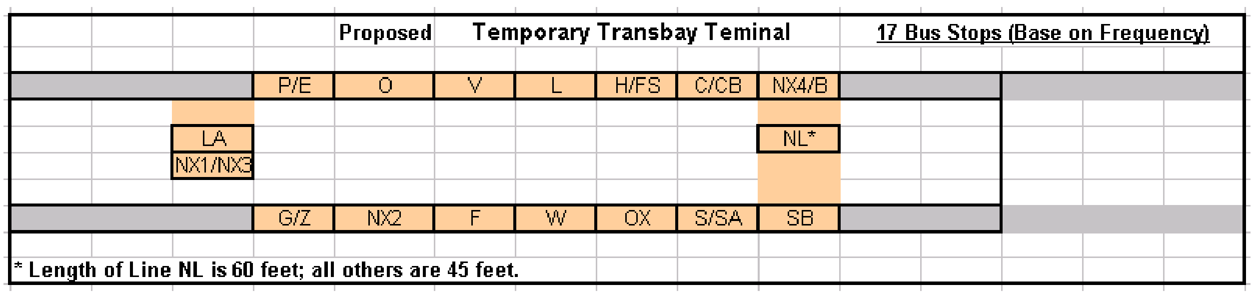

Figure 9: Proposed Temporary Transbay Terminal Stop Layout for 17 Bus Stops (Based on Frequency)

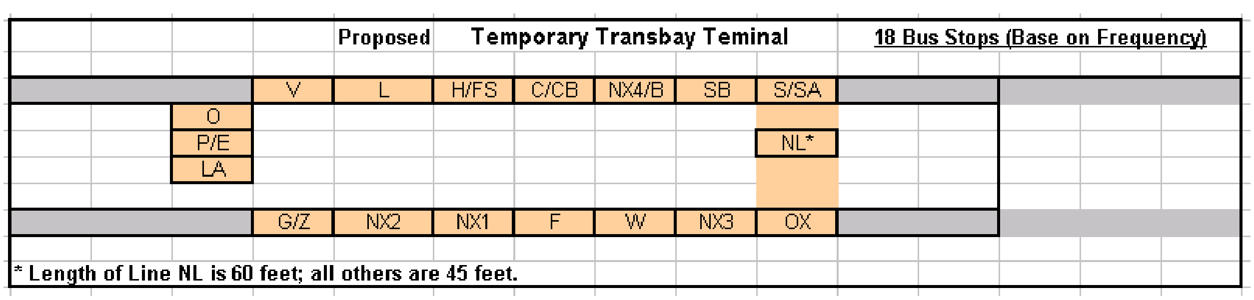

Figure 10: Proposed Temporary Transbay Terminal Stop Layout for 18 Bus Stops (Based on Frequency)