

## 10.0 Appendices

### 10.1 Detailed Technical Description of Sigma Model

#### 10.1.1 Assumptions

1. The rush hour is from 2pm to 7pm, but our model runs from noon to 7pm. the reason we start earlier is because we should include a buffer period. That is, when the rush hour starts, there should already be some buses occupying some bus stops and storage.
2. There are 15 bus stops, which is denoted with BS[B], B=0,1,2,3,...,14.
3. All buses arrive according to the schedule, that is, no bus is late.
4. For the loading process, buses can only load at their assigned bus stop. The index of the bus stop is denoted in the "arrival.dat" file.
5. The interarrival time of buses is based on the current bus schedule, stored in the disk file arrival.dat. For example, if a line F bus arrives at the terminal at 3:20pm, and the next line NL bus arrives at 3:20, then the interarrival time for bus F is 10 minutes.
6. For unloading, the bus will check from BS[0] for availability, then BS[1], and so on, the checking time is 0.2 minutes, for example, if the bus find BS[0] available, then checking time is 0; while if it finds both BS[0] and BS[1] busy, then the checking time is 0.4.
7. Based on our collected data for unloading, we observe that the age of passengers does not affect their unloading time much. However, disabled passengers do take lots of time. Therefore, according to our data, we assume 99% of passengers are normal and 1% is disabled. It has this homogeneous distribution in all buses.
8. According to our data, we have four categories of passengers who may have different average loading time. They are 18.37% paying with cash, 80.27% paying with bus pass, 0.68% class pass and 0.68% disabled. We assume it has homogeneous distribution among all buses. There is another case: passengers with bikes, which we have omitted. The reason is that they load bikes during other people's queueing. Therefore, it does not affect the total loading time.

10.1.2 Verbal Event Graph

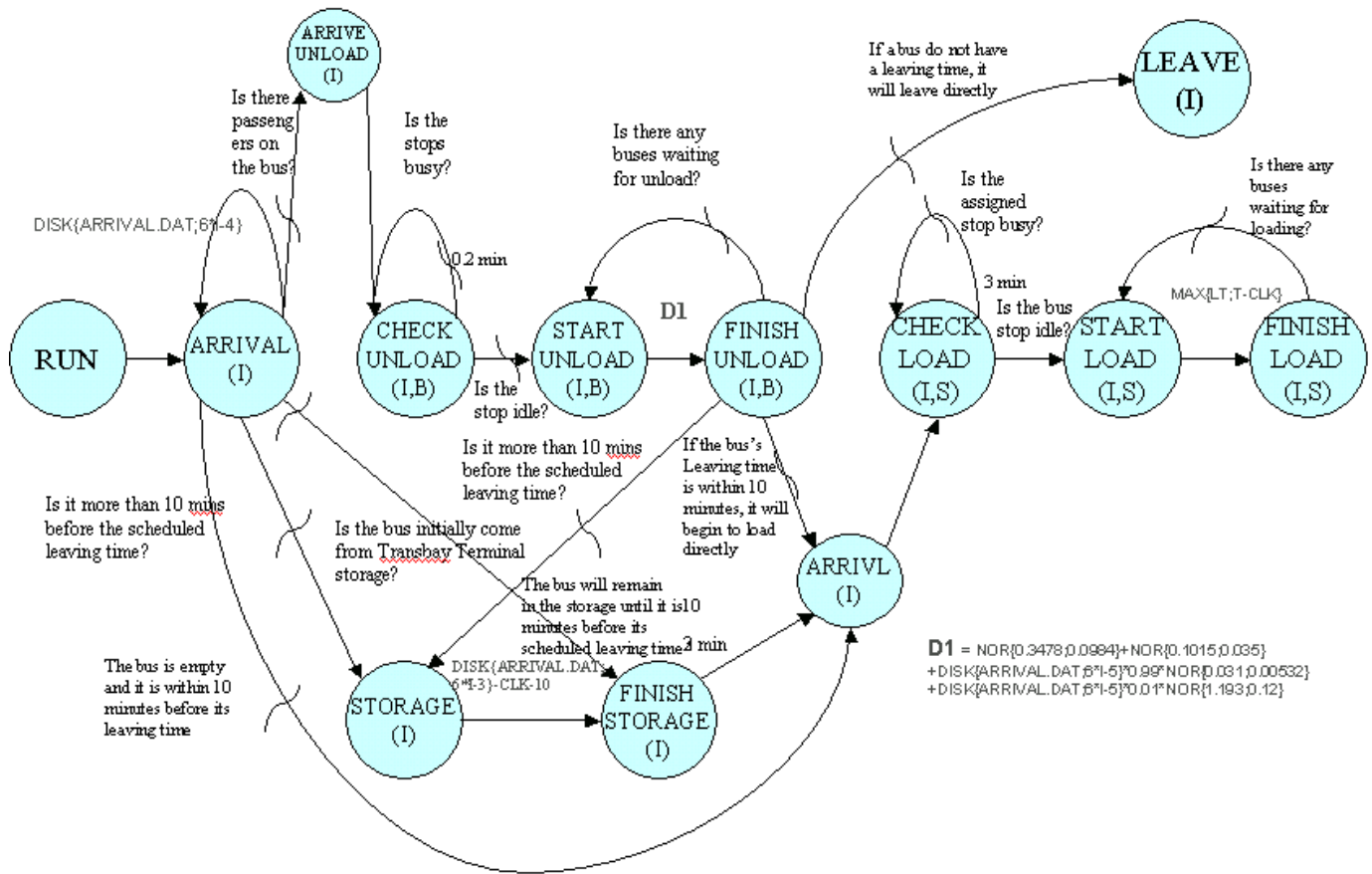


Figure 12: Verbal Event Graphs

Event Graph

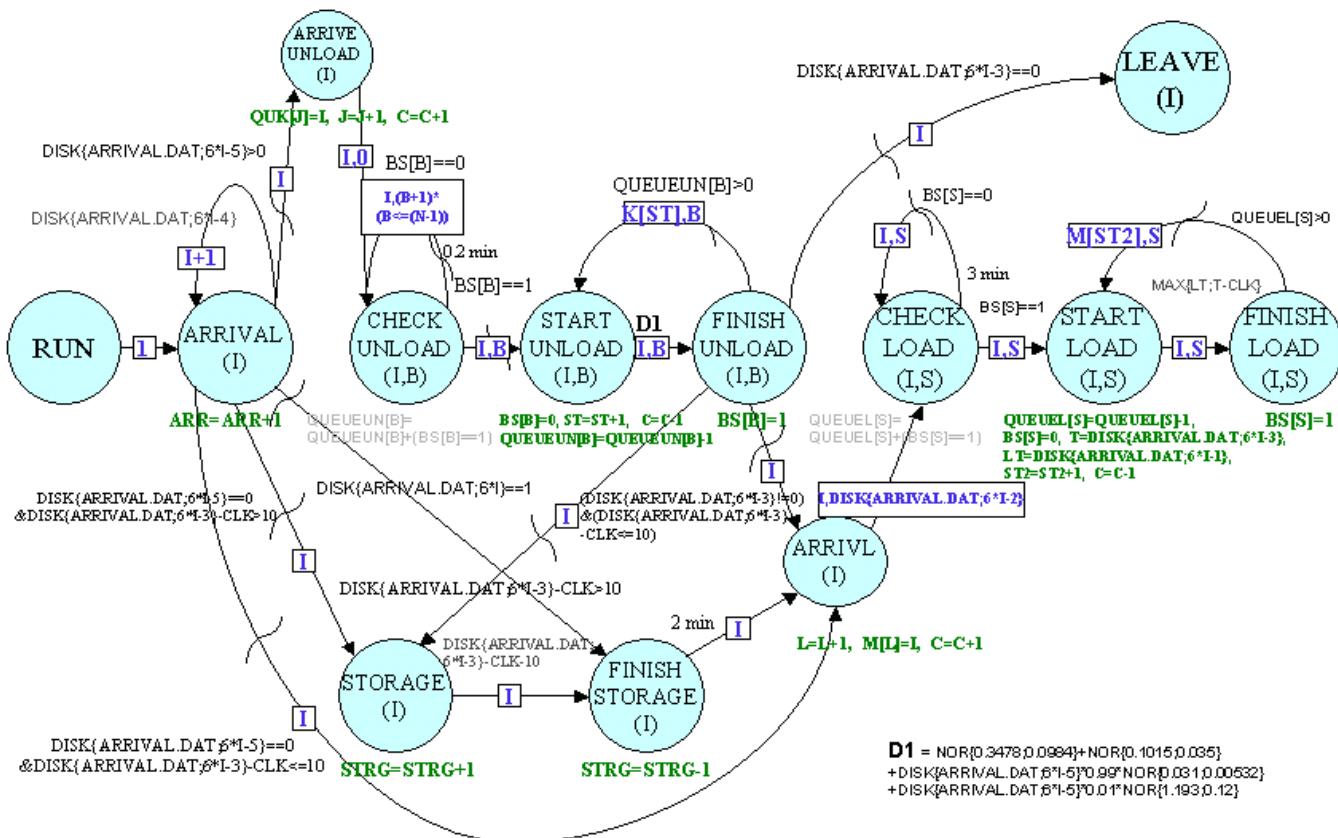
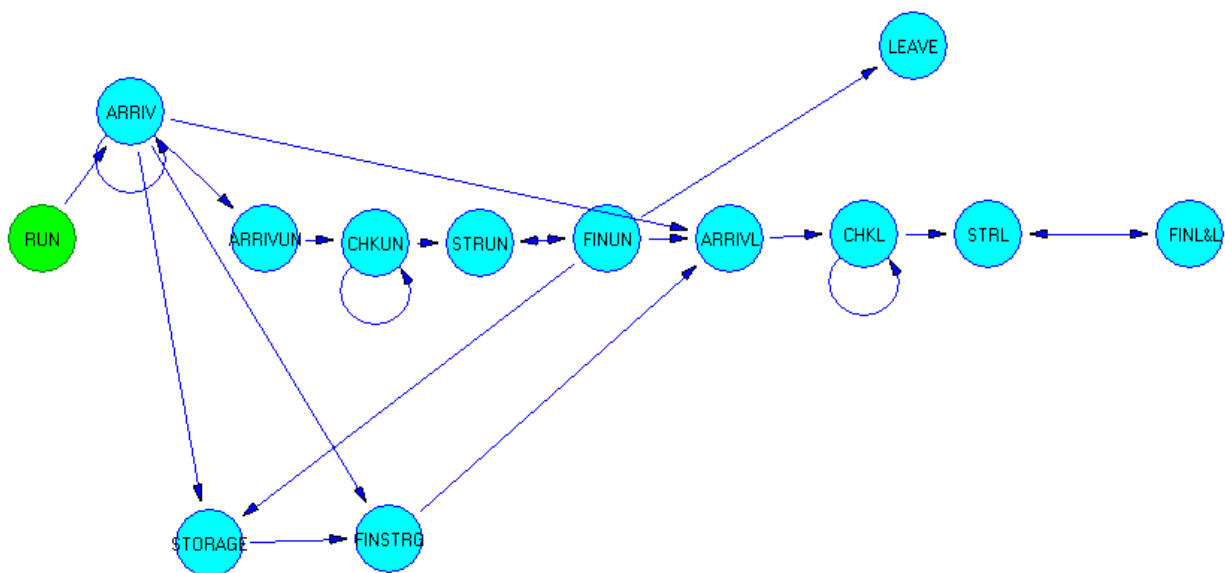


Figure 13: State Change Graph

Event Graph in Sigma



**Figure 14: Event graph for sigma**

*10.1.3 Calculation for delay time*

1. The speed limit in the terminal is 10miles/hour. The perimeter of the temporary terminal is 0.5mile.
2.  $t_{cu}$ : checking time for unloading for each stop. Since we assume buses check for unloading from the first bus stop that is available. Therefore, its checking time for stop J, is the traveling time from stop J-1 to J. hence,  $t_{cu} = (0.5\text{mile}) / (10\text{mile/hour}) / (15\text{bus stops}) = 0.003333\text{hr/stop} = 0.2\text{min/stop}$
3.  $t_{cl}$ : checking time for loading. Since a bus can only load at its assigned bus stop, if the stop is occupied when it arrives, then it will circulate in the terminal once and come back to see if the stop is now empty. Therefore,  
 $t_{cl} = (0.5\text{mile}) / (10\text{mile/hour}) = 0.05\text{hr/loop} = 3\text{min/loop}$ .
4.  $t_{sl}$ : the time takes for buses to travel from the storage to loading. The  $t_{sl}$  for current terminal is about 3 minutes, but the current storage is located outside the terminal. On the other hand, since our temporary storage is located inside the terminal, we assume  $t_{sl}$  to be 2 minutes in our model.
5.  $t_s$ : the time a bus spent in the terminal. There are two situations.
  - a. For empty buses, if its scheduled leaving time is more than 10 minutes, it will go to the storage. Therefore,  $t_s = \text{scheduled leaving time} - \text{arrival time} - 10\text{min}$
  - b. For buses come with passengers,  $t_s = \text{scheduled leaving time} - \text{finished unloading time} - 10\text{min}$ .
6.  $t_u$ : the time a bus occupies a bus stop for unloading. It should include three components, positioning time, unloading time, and leaving time. For the positioning time and the leaving time, we treat them as random variables with mean 20.87 seconds and standard deviation 5.90 seconds, and mean 6.09s and std dev 2.10s, respectively. This is the time for 40-foot buses, which is the worst case among the three types of buses. For the unloading time, we assume two categories of passengers, 99% normal passengers and 1% disabled. Normal passengers have unloading time with mean 1.86s and std dev 0.319s individually. People with disability have mean 71.6s and std dev 7.2 s. therefore, in sigma,  $t_u = \text{NOR}\{0.3478;0.0984\} + \text{NOR}\{0.1015;0.035\} + \text{DISK}\{\text{ARRIVAL.DAT};5*\text{I-4}\} * 0.99 * \text{NOR}\{0.031;0.00532\} + \text{DISK}\{\text{ARRIVAL.DAT};5*\text{I-4}\} * 0.01 * \text{NOR}\{1.193;0.12\}$
7.  $t_l$ : the time a bus occupies a bus stop for loading. We assume buses will never leave the bus stop before its scheduled leaving time even if it loads all the passengers very early. Therefore,  
 $\text{actual leaving time} = \max\{\text{scheduled leaving time}, t_l\}$

$t_l'$  = positioning time + leaving time + passenger loading time

the first two components are the same as we described in  $t_u$ . For the passenger loading time, we assume 18.37% of passengers pay with cash with mean 7.57s and std dev 2.35s, 80.27% pay with bus pass with mean 7.26s and std dev 2.94s, 0.68% class pass with mean 1.86s and std dev 0.319s, and 0.68% disabled pass with mean 71.6s and std dev 7.2 s. the percentages are based on the real data we collected in the terminal and the loading time is based on the 4-step bus, which is the worse case. Therefore,

$$t_l' = \text{MAX}(0, \text{NORMINV}(\text{RAND}(), 0.3478, 0.0983)) + \text{MAX}(0, \text{NORMINV}(\text{RAND}(), 0.1015, 0.035)) + 15 * (0.1837 * \text{MAX}(0, \text{NORMINV}(\text{RAND}(), 0.126, 0.0392)) + 0.8027 * \text{MAX}(0, \text{NORMINV}(\text{RAND}(), 0.121, 0.049)) + 0.0068 * \text{MAX}(0, \text{NORMINV}(\text{RAND}(), 1.193, 1.202)) + 0.0068 * \text{MAX}(0, \text{NORMINV}(\text{RAND}(), 0.031, 0.0053)))$$

#### 10.1.4 Variables

1. I: index of each arrival bus, starting from 1. this parameter will follow each bus along the model.
2. ARR: the cumulative number of buses that have arrived
3. B: the unloading bus stop index
4. QUEUEUN[B]: the unloading queue for bus stop B
5. N: the total number of bus stop minus one
6. S: the assigned bus stop index for each bus
7. QUEUEL[S]: the loading queue for bus stop S
8. STRG: keeps track of how many buses are in the storage currently.
9. BS[B]: it is a Boolean variable to indicate busy/idle of a bus stop. '1' indicates idle while "0" indicates busy.
10. LT: it reads the loading time for each bus from the "arrival.dat".
11. T: it reads the scheduled leaving time for each bus from the "arrival.dat"
12. J, K, L, M, ST, ST2: they are dummy variables for model construction uses.
13. C: number of buses circulating in the terminal.

#### 10.1.5 Node-to-Node Model Description

1. from RUN to ARRIV: it initiates the run, and it passes a parameter 1 to ARRIV, which is denoted as I in the ARRIVA vertex
2. from ARRIV to ARRIV: the bus will arrive according to the interarrival time stored in "arrival.dat". When it arrives, the variable "ARR" will increase by one.
3. From ARRIV to ARRIVUN: if a bus arrives with passengers, it will need to unload first before it goes to storage or loading.
4. From ARRIV to STORAGE: when empty buses arrive and their scheduled leaving time are more than 10 minutes from now, then those buses will go to the storage.
5. From ARRIV to ARRIVL: when empty buses arrive and their scheduled leaving time is within 10 minutes, then those buses will start to load directly.

6. From ARRIVUN to CHKUN: it passes parameter I and 0 to CHKUN. It indicates the bus is the I-th arrival and the bus will check from bus stop 0.
7. From CHKUN to CHKUN: if bus stop BS[B] is occupied, it will continue to check the next one until finding one stop is not occupied. When it reaches the last bus stop, it will start from the first stop again. The checking delay is  $t_{cu}$  0.2 minutes. When it finds a stop that is idle, the queue for unloading for that stop will be increased by one.
8. from CHKUN to STRUN: it will start unloading immediately when bus stop BS[B] is idle. Then BS[B]=0, which means the state of the bus stop will change to “occupied”. And QUEUEUN[B]=QUEUEUN[B]-1
9. From STRUN to FINUN: the delay time is  $t_u$ . When it finishes unloading, the state of the bus stop will be back to idle, that is BS[B]=1.
10. From FINUN to STRUN: if there are buses waiting for unloading, it will start unloading for the next bus again.
11. From FINUN to LEAVE: after unloading, if a bus does not have a scheduled leaving time, it will leave the terminal immediately.
12. From FINUN to STORAGE: after unloading, if the bus’s scheduled leaving time is more than 10 minutes from now, it will go to the storage.
13. From STORAGE to FINSTRG: a bus will stay in the storage until 10 minutes before its scheduled leaving time.
14. From FINSTRG to ARRIVL: 10 minutes before a bus’s scheduled leaving time, the bus will leave the storage and we assume it takes  $t_{sl}=2\text{min}$  from the storage to the bus’s assigned bus stop.
15. From FINUN to ARRIVL: when a bus finishes unloading, if its scheduled leaving time is within 10 minutes, it will start to load directly.
16. From ARRIVL to CHKL: in “arrival.dat”, we will assign each arrival bus with a fixed bus stop to load passengers. Therefore, a bus should check for availability first for its assigned stop. If it finds the stop idle, the loading queue for that stop will increase by one, that is, QUEUEL[S]=QUEUEL[S]+1
17. From CHKL to CHKL: if it finds its bus stop occupied, it will circulate the terminal once with delay  $t_{cl}=3\text{min}$ .
18. From CHKL to STRL: if a bus finds its assigned stop idle, it will start to load immediately. Therefore, the state of the stop will be busy again and the queue for loading for that stop will decrease by one.
19. From STRL to FINL&L: buses will leave on schedule. However, if there are too many passengers, buses will wait until all passengers are on board. After unloading, the state of the stop will be back idle again.
20. From FINL&L to STRL: if there are buses waiting for the bus stop, it will start loading for the next bus again.
21. From ARRIV to FINSTRG: for those 14 initial staging buses at noon when they leave storage, they will directly go to the node FINSTRG. As a result, the number of staging buses in the terminal will be decreased by 1.

## **10. 2 Detail Explanation on Determining Schedule Arrival and Leaving Time for Each Bus**

A bus' arrival time, scheduled leaving time and its total time spent in Transbay Terminal are essential to our model. However, the PDF format Schedule Report provided by our Client—AC Transit only indicates either the scheduled arrival time or scheduled leaving time for each bus, and therefore we must find out all the other related information through analyzing the Schedule Report. Below is the detail explanation on how to figure out a bus' scheduled arrival time, scheduled leaving time as well as its total spent time in Terminal.

Each bus line in Transbay Terminal includes Westbound—coming to terminal, and Eastbound—leaving terminal. For westbound buses, Schedule Report only provides arrival Terminal time; but for eastbound buses, it only provides leaving Terminal time (see Attached Schedule Report Example).

It is important to understand the process for each bus inside the terminal. Three different situations can happen when a bus arrives in the terminal:

1. A bus comes empty, which means it does not require unloading process; and it leaves after picking up passengers.
2. A bus comes with passengers, but it will leave empty after unloading passengers.
3. A bus comes with passengers, and it will wait for its loading process after unloading process.

The Schedule Report also does not directly show whether a bus requires unloading or loading process, so we need to determine this by doing an analysis on the report. In our model, if a bus comes with zero passengers then it does not require the unloading process. On the other hand, if a bus leaves empty, we will set its schedule time to leave as zero for indicating it does not need the loading process.

At the beginning of a day, each bus comes out from one of the following five AC Transit bus storages:

D2 – 65<sup>th</sup> and San Pablo Avenue, Emeryville

D3 – 22<sup>nd</sup> and MacDonald, Richmond

D4 – Seminary and San Leandro, Oakland

D6 – Corsair and W. Winton, Hayward

ET – Transbay Terminal Storage

When a bus arrives in a stop directly from the bus storage, it does not require unloading process because it would not pick up passengers until it reaches the stop. For example, a bus comes out from storage and then goes to Transbay Terminal immediately. The bus does not need to unload when it reaches the Terminal since it comes without passengers.

Since the driving distance between Terminal and storage is not available, we estimate the driving time from each of the bus storage to Transbay Terminal by using Yahoo Maps:

From D2 to Terminal is 15 minutes

From D3 to Terminal is 24 minutes

From D4 to Terminal is 23 minutes

From D6 to Terminal is 39 minutes

There are two different cases in finding the arrival time of those buses leaving from the five storages. There are two different cases. The first case is those buses coming from the four Eastbay storages. The time they arrive at the terminal will be equal to the departure time from the Eastbay coach yard plus the traveling time from the coach yard to the terminal. As denoted above,

we have found out the traveling time for the four coach yards from Yahoo map. The second case is for those buses directly coming from the on-site storage. The arrival time depends on each bus's schedule departure time and  $t_{ahl}$  (ahead-of-schedule leaving storage time). For instance, if its scheduled departure time is 4:10pm and  $t_{ahl}$  is 10 minutes, the bus will leave the storage at 4:00pm. It will arrive at its assigned bus stop at 4:02pm under the assumption that the travel time from the storage to the stop is 2 minutes.

Schedules Report offers us the bus schedule for both school day (SD) and school holiday (SH). In terms of the storage performance, there are more staging buses during SD than SH due to the deadheads school buses from the Eastbay. They will arrive at the terminal long before their schedule departure time. Thus during the long idle time, they will stay in the storage. Hence, we only need to analyze the worse case, which is the SD.

If a bus does not come out from storages, then it must be in service before arriving in the Terminal. There are three situations under this case:

1. It's a 100-series route bus (the "letter-route" serving the transbay) when it arrives. And it doesn't change route number in the next departure.
2. Empty buses from other series and switch to 100-series for the terminal departure
3. It arrives as a 100-series bus, and switches to other 100-series when departs.

Because each vehicle has been assigned a fixed schedule, therefore we must carefully follow the Block ID, which is a run ID for each bus.

By going through our data, we have the following conclusion on how to determine the schedule arrival and leaving time for each bus.

For Eastbound (leaving terminal) buses: all of them have loading process, and it is leaving time is the schedule departure time given in the report. However, there are a few methods to figure out its arrival time:

1. If the buses are coming from storage, it has no unloading process. The arrival time can be determined from method we mentioned above, which is equal to the storage departure time + the time drive from storage to terminal; for coming from ET, the arrival time is just 10 minutes before the schedule time to leave.
2. For type 2 buses, it arrives at the terminal empty and without unloading process. The arrival time is the departure time from its last stop + the time it drives from last stop to terminal.
3. For type1 and type 3 buses, it arrives with passengers from the Eastbay. Its schedule leaving time can be directly inspected from the schedule report.

Similar analysis can apply to the Westbound (arriving terminal) process. All the westbound service has unloading process and the arrival time is just the given arrival time in terminal. However, there are also a few situations when looking for its loading process:

1. If the bus heads for storage after its unloading process, then it has no loading process. Then its leaving time is just the time when it finishes unloading all the passengers. In this model, we assume that all the buses would leave the terminal as soon as they finish unloading in the case that they do not require loading process.

2. If the bus changes to the bus lines rather than the ones in terminal, the bus leaves without passengers and its leaving time is also the time when it finishing its unloading process.
3. If the bus changes to the westbound bus line, the bus also leaves empty and its leaving time is determined same as above.
4. If the bus changes from westbound service to eastbound services, the bus would leave with passengers. The leaving time is just the schedule leaving time for the eastbound service.

After the scheduled arrival and leaving time for each bus are determined, we check another Excel file, which includes an approximate ridership of each shift of buses taken over a two-day period. For example, it includes the data of scheduled time, route, block ID, boarding alights for inbound and outbound collected on October 20<sup>th</sup> in 2004 and January 27<sup>th</sup> in 2005. From the file, we can match the unloading and loading passengers for each shift of buses.

Most of the data for each route can be filled into the corresponding schedule, but still we cannot find some the passenger number for some specific schedules, then we just filled with the passenger number within the same route around that time.

### **10.3 Finding of Enter or Leave Storage**

Finding of all buses associated with terminal storage in Schedule report.

RTE NUM	Block ID	FR	SF Term	SF Term	TO	FILE	Page
SA	131012	ET-416p	430p			D6	49
S	131014	ET-531p	545p			D6	49
SA	131005			715a	ET-720a	D6	50
SA	131007			745a	ET-750a	D6	50
SB	132006	ET-426p	440p			D6	51
SB	132008	ET-446p	500p			D6	51
SB	132009	ET-536p	550p			D6	51
SB	132002			715a	ET-720a	D6	52
SB	132003			745a	ET-750a	D6	52
SB	132004			815a	ET-820a	D6	52
CB	104004	ET-416p	430p			D2	60----1
CB	104002			745A	ET-750A	D2	61
CB	104003			815A	ET-820A	D2	61
P	104005	ET-351P	405P			D2	68
V	130010	ET-356P	410P			D4	70
V	130003				ET-745A	D4	71
G	120006	ET-426P	440P			D3	18
L	123006			754A	ET-759A	D3	23
W	119006	ET-346p	400p			D4	59
W	119005			ET-900a	855a	D4	60
OX	125006	ET-356p	410p			D4	67
OX	125020	ET-416p	430p			D4	67
OX	125009			ET-829a	824a	D4	69
NX2	129014	ET-351p	405p			D4	71
NX2	129006			ET-808A	803A	D4	73

NX	129005		ET-848A	D4	73
V	130010	ET-356P 410P		D4	74
V	130003		ET-745A 740A	D4	75