# PART 2

# Transit Operations and Operations Planning

# Transit Vehicle Meets System: A Method for Measuring Transfer Times Between Transit Routes

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One barrier to increased use of public transit is poorly scheduled transfer timing, especially between various types of transit or between various transit providers. It has been difficult to identify transfers that need improvement in a way that is convincing to transit providers. A computer system that calculates transfer utility and presents a detailed graphic display of arrivals and departures of the selected routes is described. This system can be used by metropolitan planning organizations and transit planners to show where transfers need to be improved between local bus routes and long-haul routes that are operated by a different provider. Data from San Francisco's Bay Area Rapid Transit and Alameda-Contra Costa Transit, the bus agency serving two of the region's counties, are used to illustrate the system's capability.

In a perfect world, all public transit would take us directly from our homes to where we wish to go, with no waiting. All people would use this remarkable service, and there would be no traffic congestion and much better air quality.

Instead, most transit service currently requires that we transfer, either from our car to a transit vehicle, or from one transit vehicle to another, to get to where we are going. Most plans for greater transit ridership and better transit service depend on users transferring from bus to bus, bus to rail, rail to rail, or rail to bus in greater numbers than ever before.

In the case of rapid rail and commuter rail, parking lots and structures are expensive to build and maintain. Most are full before the rush hour is half over. For these providers, new riders who come by bus and transfer can increase ridership with no additional parking facilities. In some areas, this may be the only way to obtain new riders.

In most urban areas, air quality is a growing concern. Because short auto trips (such as a daily drive to and from a train station) contribute disproportionate amounts of pollutants, one goal is to get people to leave their cars at home and take a bus to the station.

Bus systems are responding to the flight of jobs to the suburbs by changing from a pattern in which all transit lines converge on a central business district to a more gridlike structure of routes. Although it provides more service to more destinations, this system also requires more transfers.

If transferring can be made more pleasant, faster, and less problematic, more people will be willing to do it. Signage, public information, shelters, and schedule adherence all contribute to a better transfer experience. The most important factor, however, is the length of the scheduled wait. If the schedule is ill-planned, no amount of good operation will fix it. Therefore, the schedules are the basic foundation for good multioperator service.

Within a single transit provider's system, transfer times between routes are handled by the run cutting and scheduling (RUCUS) system. Standards for transfer times can be specified, and the resulting schedule reflects them. Where several transit operators' routes meet, schedule coordination becomes more difficult.

In the San Francisco Bay Area, for example, there are two long-haul rail systems: Bay Area Rapid Transit (BART) and Caltrain, and six large and many small bus-light-rail-ferry systems. Although most of the large operators have RUCUS systems, some do not, and there is no overall scheduling system. As the regional planning agency, the Metropolitan Transportation Commission (MTC) is charged with coordinating the schedules of these separate systems.

In practice, this involves mostly working toward better bus connections to and from the train stations. History and habit insist that the train schedules are not changed to meet buses, so all accommodation must be done by the bus systems. In this way, the situation is similar to many commuter rail-local bus combinations around the country.

Traditionally, MTC has looked at the train schedules and feeder bus schedules and noted where improvements needed to be made. This method is tedious and vulnerable to error, and there is no way to quantify improvement. Calculations have been done, but without visual illustration they were too abstract to prove a point to the bus operators who needed to improve their schedules at the rail stations.

This paper describes a computer system for measuring scheduled transfers between transit routes over several hours. To facilitate describing the way the system works, the term "meet" is used. In this context, a possible meet is any appearance of the feeder vehicle at the transfer point; a good meet is one that fits the wait criteria defined by the planner. The system can chart two or more schedules graphically and show whether each measured vehicle's appearance is in the user-defined "window of opportunity" for transfer or not. It can also calculate the number of possible meets, good meets, and the percentage of good meets. Such a calculation is based on assumptions that the planner using the system has already made: for each feeder line at a given transfer point, what is the least amount of time needed for transferring?, at which times is the feeder line feeding to the main line?, when is it receiving riders from the main line?

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## WHAT'S SO BAD ABOUT TRANSFERRING?

A new rider on any transit trip requiring a transfer has to find out how to do it: where to transfer, on which corner or bus stop or platform to wait, and so forth. When riders have to wait a long time, doubts and fears that the transfer won't work will arise. Transferring riders may have to stand on a windy platform or a rainy street corner or be exposed to what may be perceived as unpleasant street people, homeless people, panhandlers, and so forth. But any transit patron will agree that the most frustrating situation is watching the vehicle to which one wishes to transfer depart just as one arrives at the transfer point. This experience, and long waits in general, undoubtedly drive transit users back to automobiles. Seeing the train leave or the bus drive away every day—a common occurrence when meets are bad—could well give rise to disgruntlement with, lack of confidence in, and lessening taxpayer support of transit.

## WHAT IS AN IDEAL TRANSFER SITUATION?

Anyone fortunate enough to have used the bus-ferry-bus combination from Victoria, British Columbia, to Vancouver probably remembers it as one seamless trip. The vehicles are dedicated to feeding passengers from one to the other, so there is a natural flow, with no waiting and no anxiety. In other cities, dedicated shuttles that meet commuter trains also provide this type of service.

Somewhat more hectic, but with almost as good a level of service, are timed transfer points at which all bus routes come to a location at the same time and dwell long enough for patrons to transfer between them. Unlike the one-to-one situation mentioned, the timed transfer point has a many-to-many transferring pattern. The large number of buses and the large size of bus bays means that some patrons must walk a distance to transfer, and the inevitable crossing of paths by hurrying riders contributes mild confusion to the scene. But the bottom line is that the transfers all occur within a short period, and riders get to where they are going. Figure 1 is a diagram of the bus boarding area at a BART station, where Alameda–Contra Costa (AC) Transit initiated a timed transfer point in 1988.

Another method of improving transfers is to hold up one vehicle until its "feeder" vehicle has arrived. This method is being used by means of a real-time computer system in Hamburg, Germany (*1*), and by means of a beacon in Contra Costa County, California, at BART stations on the Concord line, as well as at selected IND "A" subway stations in Queens, N.Y., and in other places. Such holds are normally used when the feeder vehicle is late or when schedules are especially tight.

## OTHER TRANSFERS

When there are no dedicated transfers, timed transfers, or holds, the patron is less fortunate. Bus operators try to provide good transfers between their own feeders and long-haul lines; rail operators optimize transfers in the prevailing directions. But when a bus operator is required to have good meets with a train operation, such meets may be in direct competition with internal system transfers.

To make matters worse, the design of the rail system can introduce a note of schizophrenia to any attempt to provide bus meets. The BART system (Figure 2) has two inbound directions at all stations on the Richmond and Fremont lines during weekdays and one outbound direction (with twice as many trains) at the same stations. (On the Fremont line, alternating trains go to San Francisco and to Oakland/Berkeley/Richmond. On the Richmond line, trains go either to San Francisco or to Oakland/Hayward/Fremont.) These stations are served by AC Transit. Which trains should the buses meet?

In contrast, BART's Concord line, served by Central Contra Costa County Transit, has only one inbound direction, and the MARTA system in Atlanta (Figure 3) has two lines at right angles to each other, meaning only one inbound and one outbound direction at all stations except the transfer station, at which there are four outbound directions and no inbound ones.

## MEASURING THE MEETS

On the surface, it would appear to be straightforward for planners to assess the transfer times between two routes. The

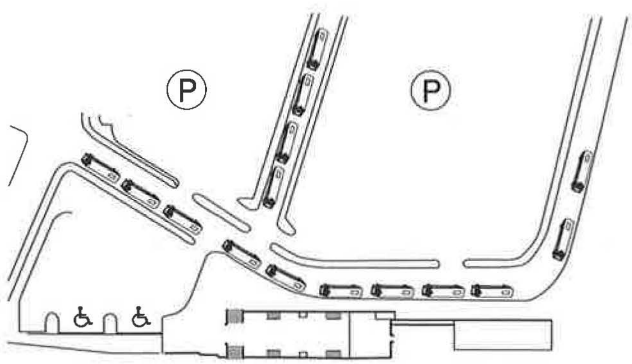


**FIGURE 1 Hayward BART station bus boarding area.**

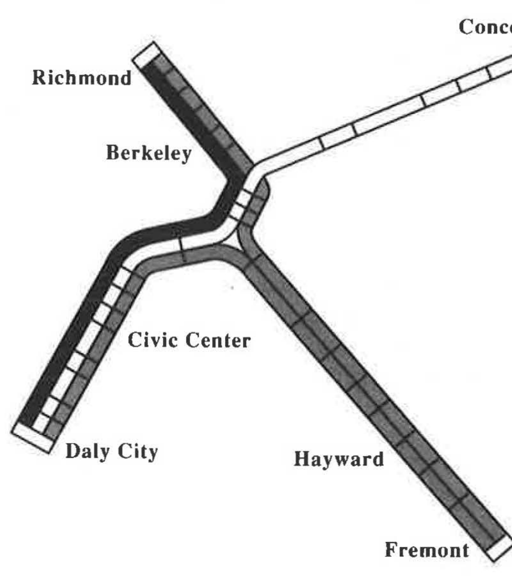


**FIGURE 2 BART system.**

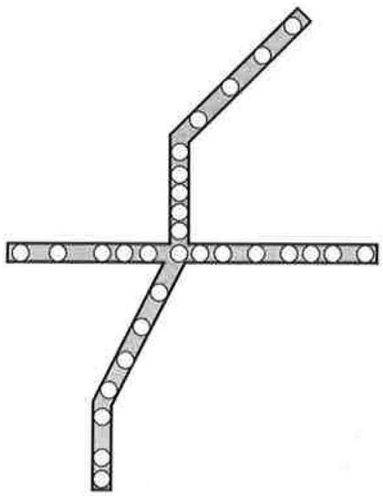

**FIGURE 3 MARTA system.**

only data needed are the schedules and the physical walking distances between the place where patrons get off the first vehicle and board the second. Table 1 shows a listing of two BART schedules at the Berkeley BART station and 2 bus schedules (out of 16). Although an analysis can be done with these data, such schedules are difficult to organize visually to promote an understanding of the analytical results.

Several studies have been done of bus-train meets in the Bay Area, including a 1988 study of interoperator schedule coordination that analyzed meets at 10 transfer point locations (*2*). Although much of this analysis was done by computer, a system to do this on a regular basis was not implemented.

One of the greatest barriers to setting up an automated system for display and analysis of transfer meets has been the difficulty of obtaining up-to-date transit schedules from more than one transit operator at a given transfer point on a routine basis. This barrier was removed at a few transfer points in the Bay Area by the implementation of an electronic schedule display system (ESDS), which shows departures of transit vehicles on video monitors (*3*). Figure 4 shows two screenfuls of data at the Berkeley BART station.

Keeping such systems running continuously required that software be developed to download data from AC Transit's RUCUS system and from BART's computer files of sched-

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Scheduled Departures, 06–28–1991, at 4:10 PM

| DESTINATION | | 1ST | NEXT | BOARD |
|---|---|---|---|---|
| **BART** | | | | |
| | SAN FRANCISCO | 4:23 | 4:38 | Track Level |
| | FREMONT | 4:17 | 4:33 | Track Level |
| | RICHMOND | 4:12 | 4:21 | Track Level |
| **AC TRANSIT** | | | | |
| 7 | ARLINGTON | 4:19 | 4:34 | Home Savings |
| 7 | CLAREMONT | 4:19 | 4:34 | J.C. Penney |
| 8 | GRIZZLY PEAK | 4:30, LHS | 4:50, LHS | Wells Fargo |
| 9 | WEST BERKELEY | 4:15, ( V) | 4:30, ( V) | Wells Fargo |
| 15 | OAKLAND | 4:12 | 4:27 | Wells Fargo |
| 15 | EL CERRITO | 4:23 | 4:38 | Great Western |
| 40 | EAST OAKLAND | 4:17 | 4:29 | Bank of America |
| 43 | EL CERRITO | 4:13, SP | 4:28 | Home Savings |

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Scheduled Departures, 06–28–1991, at 4:11 PM

| DESTINATION | | 1ST | NEXT | BOARD |
|---|---|---|---|---|
| 43 | OAKLAND | 4:12 | 4:27 | J.C. Penney |
| 51 | MARINA | 4:18, 3U | 4:26, (M) | Home Savings |
| 51 | OAKLAND, ALAMEDA | 4:16 | 4:24, (A) | J.C. Penney |
| 64 | OAKLAND | 4:36 | 5:09 | J.C. Penney |
| 65 | WEST BERKELEY | 4:16 | 4:31 | Home Savings |
| 65 | EL CERRITO | 4:13 | 4:28 | J.C. Penney |
| 67 | KENSINGTON | 4:14 | 4:34 | Great Western |
| F | SAN FRANCISCO | 4:13 | 4:43 | J.C. Penney |
| **SHUTTLES** | | | | |
| | U.C. CAMPUS | 4:20 | 4:30 | Bank of America |
| | LBL (Restricted*) | 4:20 | 4:30 | Wells Fargo |

**FIGURE 4 Electronic schedule display system at Berkeley BART station.**

ules. These ESDS data bases and their precursor data from the transit operators are therefore available for the sites at which systems are installed: currently at Berkeley BART, 12th Street BART, Hayward BART, and the Palo Alto Caltrain Station, and more will be installed in the next year.

## TRANSIT MEETS SYSTEM

The Transit Meets System is very different than the ESDS: it is intended to be used by planners in their offices to give them the information necessary to improve schedules at trans-

TABLE 1 SELECTED SCHEDULES AT BERKELEY BART STATION, WEEKDAYS BETWEEN 6 a.m. AND 10 a.m.

| BART SAN FRAN. (from Richmond) | BART FREMONT (from Richmond) | AC 7 ARLINGTON (NB, from Claremont) | AC 7 CLAREMONT (SB, from Arlington) |
|---|---|---|---|
| 6:11 | 6:07 | 6:30 | 6:32 |
| 6:26 | 6:22 | 6:45 | 7:02 |
| 6:41 | 6:37 | 7:00 | 7:17 |
| 6:56 | 6:52 | 7:15 | 7:32 |
| 7:12 | 7:04 | 7:30 | 7:47 |
| 7:26 | 7:19 | 7:45 | 8:02 |
| 7:41 | 7:34 | 8:00 | 8:17 |
| 7:56 | 7:49 | 8:15 | 8:32 |
| 8:09 | 8:05 | 8:30 | 8:47 |
| 8:24 | 8:20 | 8:45 | 9:02 |
| 8:39 | 8:33 | 9:00 | 9:17 |
| 8:54 | 8:50 | 9:15 | 9:32 |
| 9:10 | 9:05 | 9:45 | |
| 9:25 | 9:20 | | |
| 9:40 | 9:35 | | |
| 9:55 | 9:50 | | |

fer points, whereas the ESDS is used at a transfer point by the public to find when the next vehicle will depart. In addition, more schedule data are needed for the meets system. Both arrival and departure schedules are needed, because the meets must be measured in the direction of commute (inbound in the morning, and outbound in the evening).

Once a current data set of bus and train schedules at a given transfer point has been prepared and made available to the system, the transit meets may be examined. The system requests that the user make a number of choices and set several parameters. It operates on a Macintosh computer connected to a laser printer. This hardware was chosen because of the need for an understandable printed graphic display of the detailed information. The system is currently written as a custom program using Fourth Dimension, a proprietary data base package. A more portable version, written in C, is planned.

### How It Works

1. A transfer point is chosen for analysis. This must be a place for which schedule data are available and of course where more than one route connects. In the first examples, the Berkeley BART station is selected as the transfer point.
2. One principle transit route must be selected, against which others are measured. All references to "route" mean both route and direction. In the first example, the BART train to San Francisco is chosen as the principal route. Because this example will look at buses feeding to BART, the "to BART" direction was chosen. Should it be BART feeding to buses, the "from BART" direction would be selected. This principal route need not be a train; a long-haul bus route may be used if bus-to-bus transfers are being studied.
3. One or more subordinate routes are selected, as well as the direction of feed. In the example, the AC Transit routes were chosen to be ones that feed riders to BART in the morning.
4. The time of day for analysis should be selected, as well as the type of service (weekday, Saturday, Sunday/holiday). Approximately 1 hr of detailed graphic display fits on a page. Even though this detail is voluminous, several hours should be chosen to have enough scheduled appearances of each route to be useful. The example looks at 7:00 a.m. to 9:30 a.m. on a weekday.
5. Finally, the transfer parameters are selected. What is the shortest reasonable time for this transfer (called "needed delay" by the system)? What is the longest time (called "allowable wait" by the system)? The minutes between needed delay and allowable wait make up the window of opportunity for a good transfer. For the example, needed delay is set at 2 min, allowable wait at 7 min. These times, of necessity, apply to all of the subordinate routes in the run; if some routes require a different transfer window, they should be removed from this run and set up in a separate run. The distance between the bus and rail stops will determine these parameters. Figure 5 is a diagram of bus boarding locations near Berkeley BART station.

### Results of the Sample Run

Figure 6 is a full-sized page from the beginning of the detailed display. The page is divided into minutes, with the time printed at 5-min intervals. The second column shows the principal transit route, in this case the BART train to San Francisco. Its arrival/departure every 15 min causes a dark band to be printed across the page. For 2 min earlier, a slightly lighter band indicates the "not-enough-time" zone; in this run, 2 min was chosen by the user. Above that is the clear white window

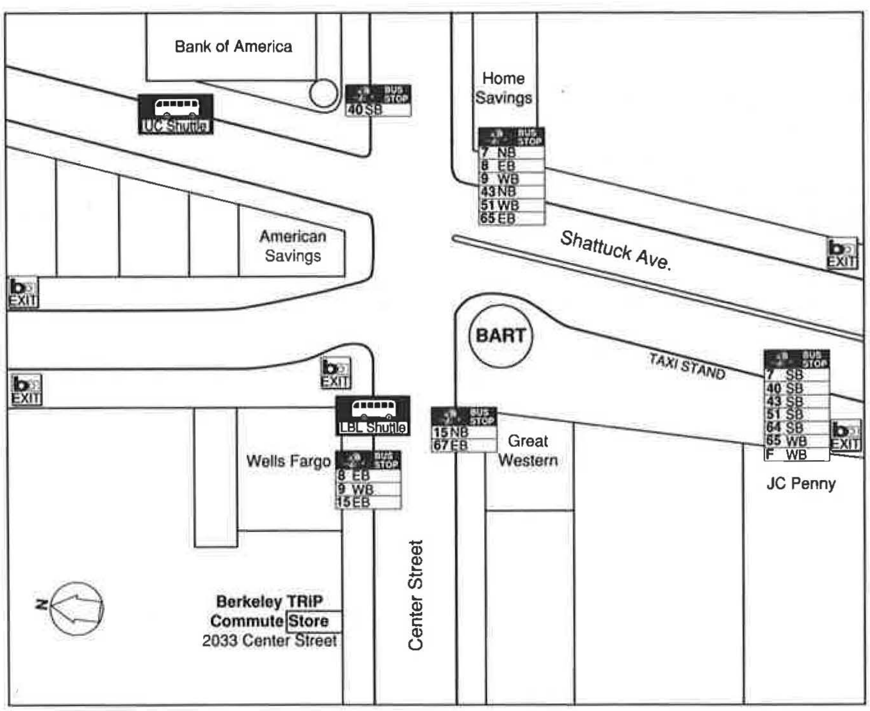


FIGURE 5 Bus boarding map, Berkeley BART station vicinity.

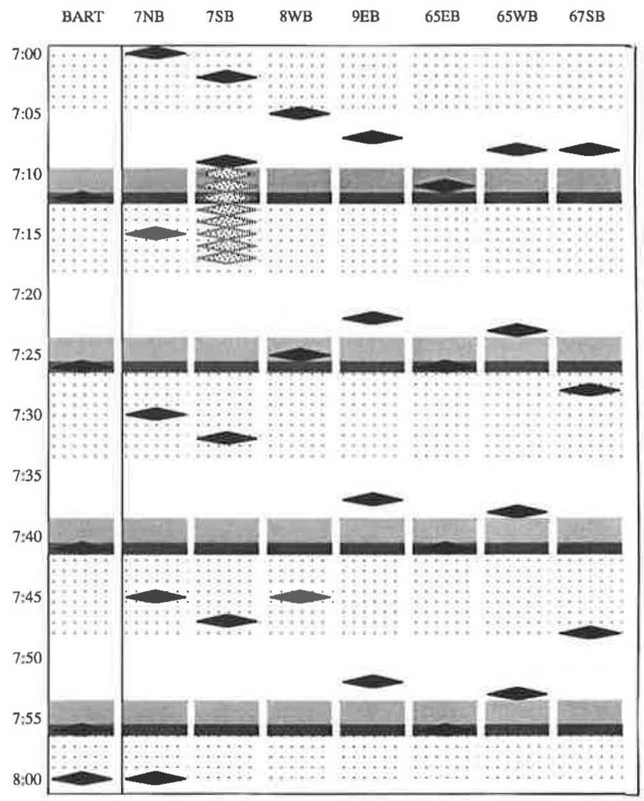


**FIGURE 6 Example of detailed output: buses to BART.**

of opportunity for a good transfer; and above that is the dotted area of "too long to wait," again, chosen by the user.

On this landscape, painted by the arrivals of the train, are printed the arrivals of each bus, one per column. It is visually apparent which one falls into each of the categories. Note that the arrival of the No. 75B is followed by a lighter version of the symbol for several minutes. This indicates a dwell time at the transfer point, which is not significant here because the transfer is from the bus to BART.

Figure 7 shows statistics of "goodness" of meets for the dependent routes during the entire run. Run counts include all appearances of the subordinate vehicle (totals) as well as those with too little time, too long a wait, and those that make a good meet. Percentages are calculated directly from these counts. "Average wait" is a measure of the average length of time a traveler would have to wait for the given transfer during the period. This value is calculated by using the actual number of minutes for all waits longer than the minimum; and for those under the minimum, using the time to the next vehicle, which is what happens in real life when a transferring patron just misses a bus or train.

| BART | 7NB | 7SB | 8WB | 9EB | 65EB | 65WB | 67SB |
|---|---|---|---|---|---|---|---|
| Not Enough Time | | | 1<br>14.3% | 4<br>40% | 6<br>60% | 4<br>44.4% | 2<br>28.6% |
| Good Transit Meets | | 5<br>50% | 3<br>42.9% | 6<br>60% | | 5<br>55.6% | 2<br>28.6% |
| Too long a Wait | 10<br>100% | 5<br>50% | 3<br>42.9% | | 4<br>40% | | 3<br>42.9% |
| Total Runs | 10 | 10 | 7 | 10 | 10 | 9 | 7 |
| Minutes to Wait (mean) | 10.1 | 7.5 | 9.2 | 8.8 | 13.7 | 8.5 | 10.4 |

**FIGURE 7 Statistics: buses to BART (San Francisco).**

### Which Train Does the Bus Meet Well?

Arguments have arisen as to whether certain AC Transit bus routes have good meets with BART. One transit rider says the bus does not meet well; the other insists that the same bus line has good meets with BART. Could this discrepancy be because these buses meet one BART direction well and the other one poorly? To test this theory, a run identical to the first example was made, except that the principal route chosen was the Fremont BART train, which goes through Oakland. Figure 8 shows the statistics for this run. A person living on the No. 7NB line would find the bus-train connections to Fremont to be excellent; a neighbor who travels to San Francisco would not.

### What Is the Evening Transfer Situation?

When commuters who use a bus-train combination have to work late or decide to stay in the city for dinner, how do they get home? Can commuters rely on a good transfer, or will they have a 40-min wait? The situation for these occasional late returns can determine whether a commuter will choose to drive to work on those days (or drive every day if the late returns are spontaneous). Figure 9 shows the same bus lines examined earlier, at the same station, for the period from 8 p.m. to 11:30 p.m. The BART schedule used is the combined runs to Richmond from San Francisco and Fremont; after 8:40 p.m. there are trains from Fremont only. Even though

| BART | 7NB | 7SB | 8WB | 9EB | 65EB | 65WB | 67SB |
|---|---|---|---|---|---|---|---|
| Not Enough Time | | 4<br>40% | 2<br>28.6% | | | | 2<br>28.6% |
| Good Transit Meets | 10<br>100% | 5<br>50% | 2<br>28.6% | | 1<br>10% | | 2<br>28.6% |
| Too long a Wait | | 1<br>10% | 3<br>42.9% | 10<br>100% | 9<br>90% | 9<br>100% | 3<br>42.9% |
| Total Runs | 10 | 10 | 7 | 10 | 10 | 9 | 7 |
| Minutes to Wait (mean) | 4.4 | 9.1 | 9.7 | 12.5 | 8.9 | 11.5 | 11.1 |

**FIGURE 8 Statistics: buses to BART (Fremont).**

| BART | 7NB | 7SB | 8WB | 9EB | 65EB | 65WB | 67SB |
|---|---|---|---|---|---|---|---|
| Not Enough Time | | 2<br>28.6% | | | | | |
| Good Transit Meets | 5<br>71.4% | 3<br>42.9% | | 4<br>66.7% | 4<br>100% | 4<br>100% | 1<br>33.3% |
| Too long a Wait | 2<br>28.6% | 2<br>28.6% | | 2<br>33.3% | | | 2<br>66.7% |
| Total Runs | 7 | 7 | | 6 | 4 | 4 | 3 |
| Minutes to Wait (mean) | 8.2 | 8.5 | | 7.6 | 4.5 | 4.5 | 11.0 |

**FIGURE 9 Statistics: buses from BART (evening).**

the downtown Berkeley area is not a timed transfer location, certain buses have dwell times there during the evening. Such dwell times greatly increase the perception (and possibly the actuality) of security for patrons: to get out of a BART station and right onto the bus is far preferable to waiting 5 min on the street corner, even if the bus does not leave for 5 min.

Transfer possibilities range from excellent (the No. 65 in both directions) to poor (the No. 67). and nonexistent (the No. 8 does not run at all by then).

Although all runs of a given bus route (such as the No. 65) have good meets with the train, not all BART trains are met by the bus because of sparser schedules on the bus line. Patrons still must plan to take the trains that give them good meets with their buses. This program calculates the number of good meets from the number of possible meets (appearances of a vehicle on the subordinate route).

### Are Bus-Train Transfers Better at Timed Transfer Points?

Does a transfer point with buses on a timed transfer schedule (including dwell time of 5 min) have better meets with BART? To examine this question, the Hayward BART station in Hayward, California, was chosen as the transfer point. In addition to timed transfers, this staion differs from the Berkeley station because many people transfer from BART to buses in the morning, with destinations in the industrial areas, as well as California State University, Hayward, and Chabot College. (In contrast, the University of California, Berkeley, is within walking distance of the BART station, and there is also a shuttle bus with 10-min headways.) Because of this situation in Hayward, three separate runs were made with each direction of BART train: residential area buses to BART, 7:00 a.m. to 9:30 a.m.; BART to industrial area buses, 6:00 a.m. to 8:00 a.m.; and BART to colleges, 7:30 a.m. to 9:30 a.m. Table 2 shows the percentages of good meets for these runs.

Hayward residents wishing to take a bus to San Francisco BART had better live on the No. 21 or on Kelly Hill (No. 95); otherwise, they are out of luck. If they wish to go to points in Oakland or north on BART, results are mixed and not particularly good from any line.

Perhaps workers arriving on BART fare better. In fact, those arriving from San Francisco who wish to take the No. 77 to points in South Hayward or to take the BART Express Bus U to Dublin are fortunate in their transfer, but no other bus patrons are. Travelers from Richmond, on the other hand, have a good transfer to the Samtrans 90E to San Mateo and a moderately good transfer to the industrial areas on the No. 86, or to San Leandro on the No. 81; the rest, not at all.

Finally, students on their way to Cal State or Chabot College have a 50 percent chance of having a good meet if they are coming from San Francisco, and no chance if they are coming on the train from Richmond. Overall, morning commute meets at Hayward BART seem to be somewhat worse than those at Berkeley BART.

It appears that, although timed-transfer schedules (of buses) work well for bus-to-bus transfers, they do not improve bus-to-train or train-to-bus transfers and may even make them worse.

## CAUTION

Extreme care must be used in running the Transit Meets System, because the computer only performs the calculations and generates the graphic displays; choices and assumptions have been left to the user. The user must not only be sure that the schedules are correct and are named correctly so that they may be chosen properly, but also be knowledgeable about the physical layout of the transfer location and of the area served by the transit lines. For instance, to know the predominant direction of travel at various times of day requires knowledge of the location of residential and employment areas.

## CONCLUSION

The Transit Meets System can be a useful tool for planners in measuring transfer utility for patrons. It can provide bench-

TABLE 2 PERCENTAGE OF GOOD MEETS AT HAYWARD BART

| | BUS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | AC21 | AC80 | AC90 | AC91W | AC91E | AC94 | AC95 | BEXPU |
| RES AREAS TO SF BART | 90% | 0% | 0% | 0% | 11% | 0% | 100% | 0% |
| RES AREAS TO RICH BART | 100% | 17% | 38% | 20% | 22% | 40% | 0% | 33% |
| | AC77 | AC81 | AC85 | AC86 | SAMT90E | BEXPU | | |
| BART FR SF TO IND AREAS | 100% | 0% | 0% | 0% | 0% | 100% | | |
| BART FR RICH TO IND AREAS | 0% | 50% | 0% | 67% | 100% | 0% | | |
| | AC92E | AC92W | | | | | | |
| BART FR SF TO COLLEGES | 50% | 50% | | | | | | |
| BART FR RICH TO COLLEGES | 0% | 0% | | | | | | |

marks in schedule coordination between two operators and a way to chart progress. The evening postcommute hours, in which long-haul vehicles feed riders to infrequent local bus routes, are rich areas for analysis because better evening transfer service will encourage more daily riders.

Before-and-after data from when a bus and rail transfer point are converted to timed bus transfers would be useful in planning future timed transfers, and individual operators could use the system to measure planned future schedules against existing ones.

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