

**The Design and Operation of a Ubiquitous-Level
SF Bay Area Transport System for Moving People and Goods
in the Aftermath of a Disaster**

Alfred D. Round

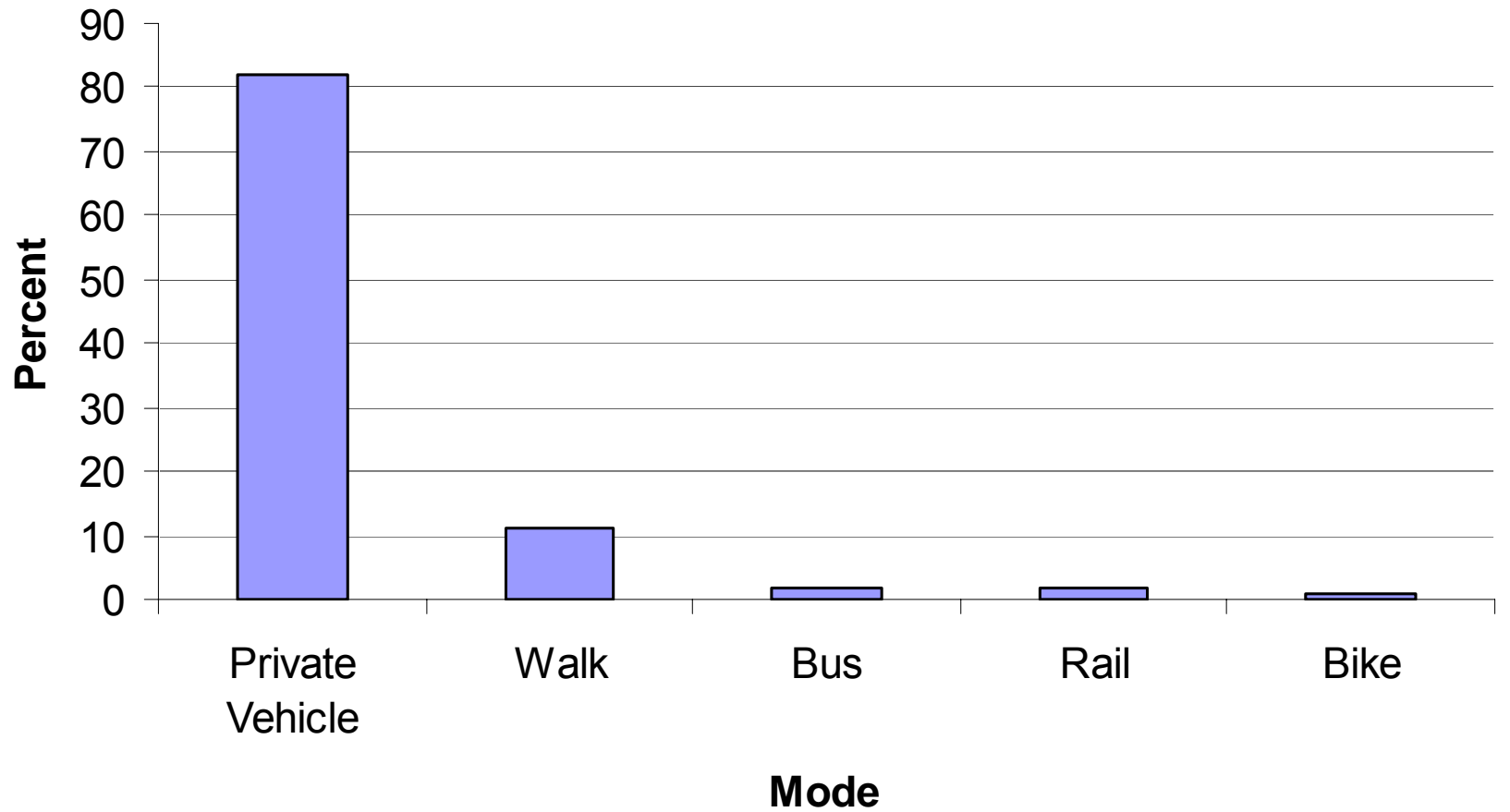
Smart Interfaces LLC

March 4, 2008

alfred_round@yahoo.com

Tel: 510-332-6584

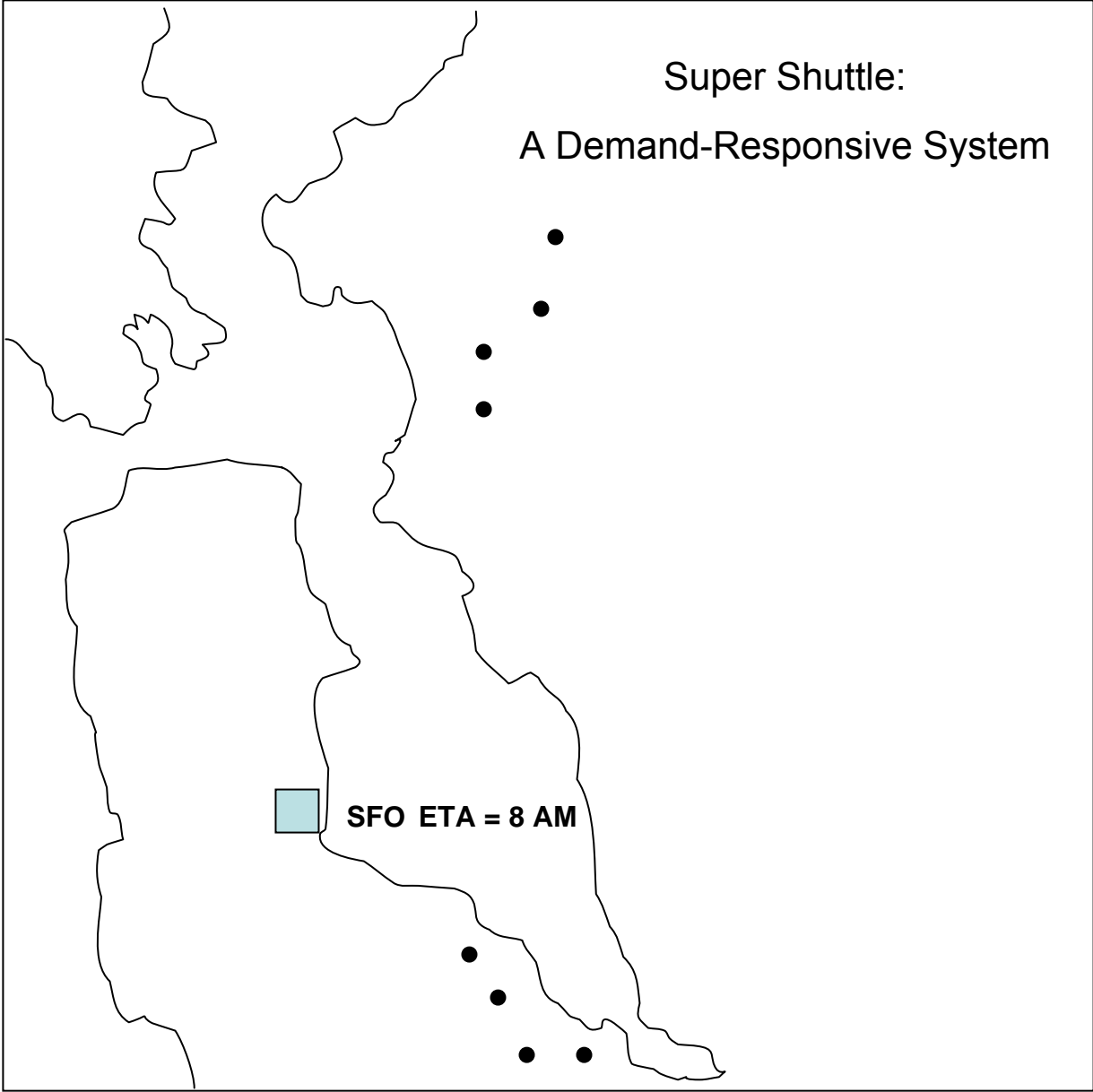
San Francisco Bay Area Mode Split for 2000

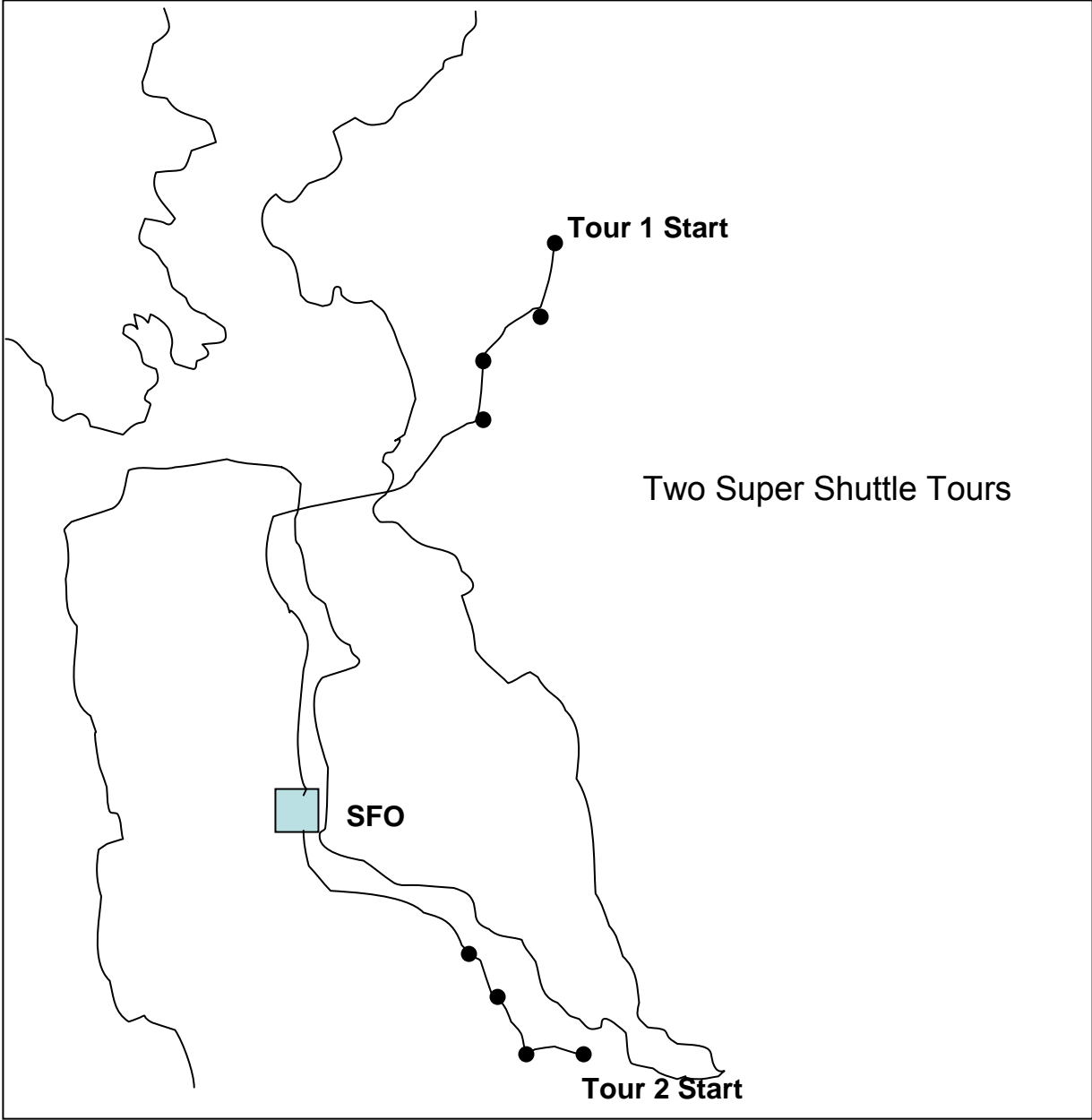


Source: Bay Area Travel Survey, Final Report, Volume 1, Metropolitan Transportation Commission, March 2002

Super Shuttle:

A Demand-Responsive System





Tour 1 Start

Two Super Shuttle Tours

SFO

Tour 2 Start

Two Principles of Demand-Responsive Transit

- A tour carries passengers who are traveling between the same two areas at about the same desired travel time.
- A tour picks up and drops off passengers in the order that minimizes the average on-board passenger time

Is this a good model for public transit?

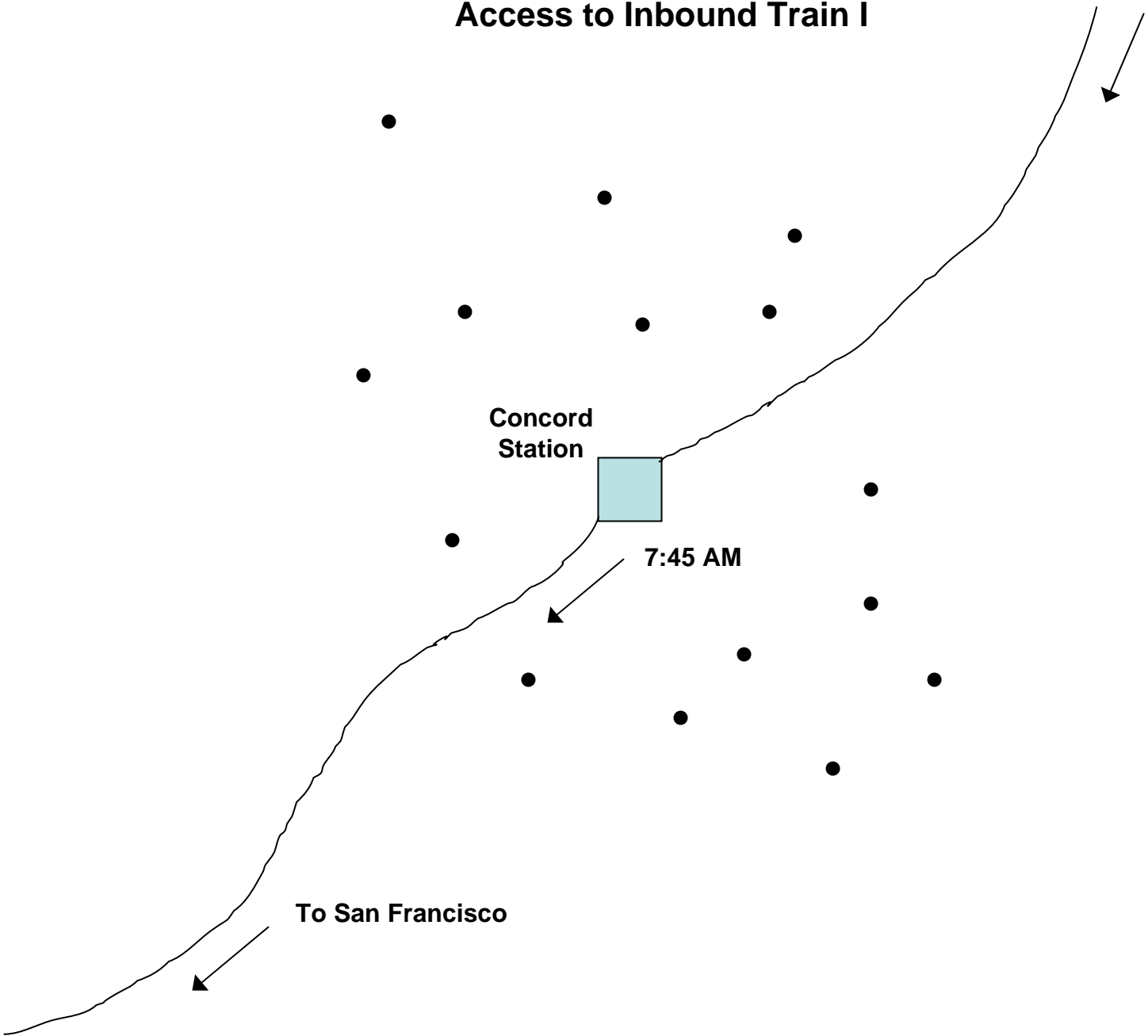
BART vs. Demand-Responsive Shuttle

	BART	Shuttle	Advantage
Coverage	Fixed-Route, Fixed Schedule	Anywhere, Anytime	Shuttle
Connectivity	Limited Access/Egress	Door-to-Door	Shuttle
Operating Cost	High	Low	Shuttle
Right-of-Way	Yes	No	BART
Demand Density	High	Low	BART
Privacy	Anonymous	Reservations	BART

Can we combine the best features of both systems?

Access to Inbound Train I

From Pittsburg/Bay Point



Concord
Station

7:45 AM

To San Francisco

Access to Inbound Train II

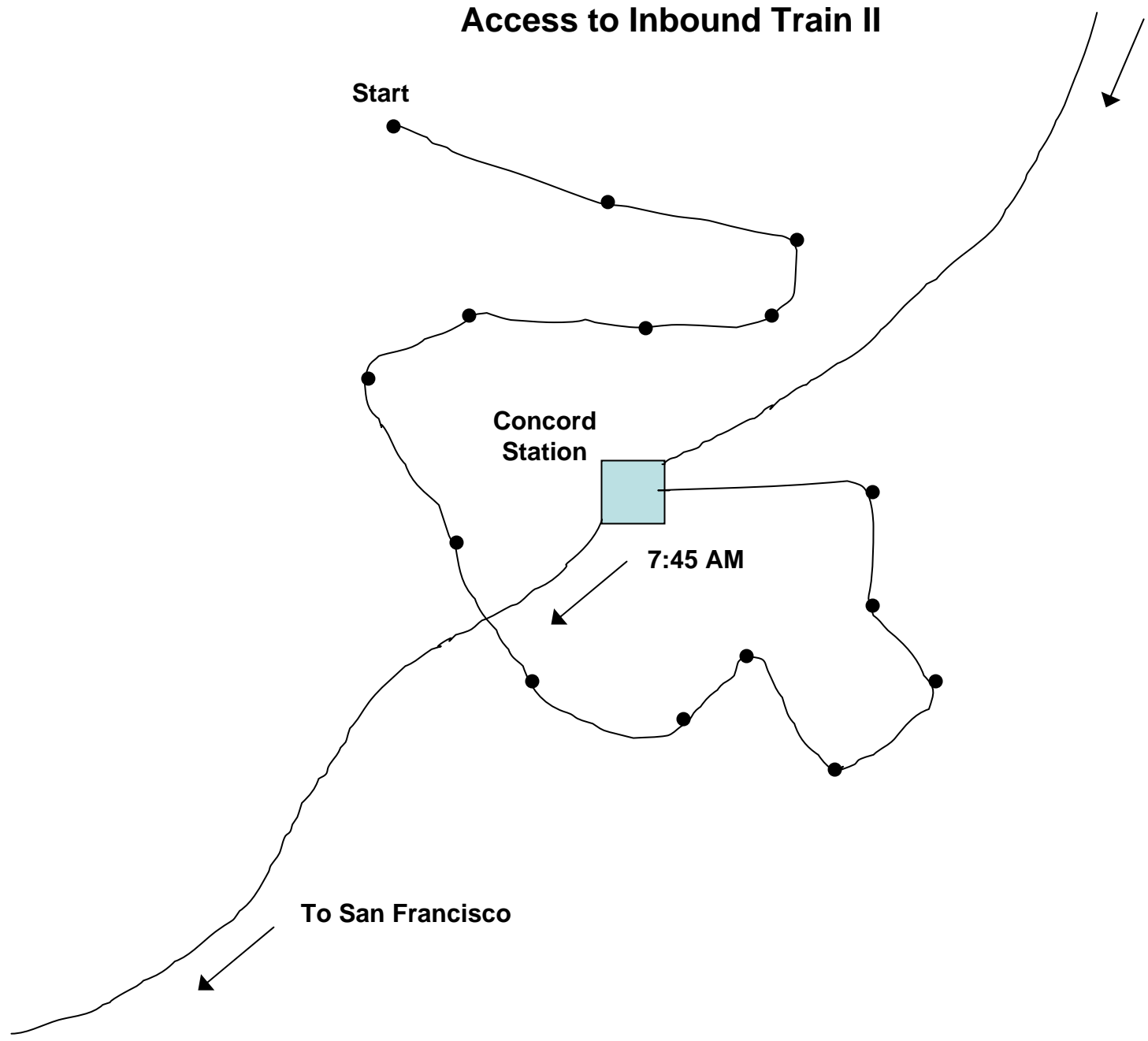
From Pittsburg/Bay Point

Start

Concord
Station

7:45 AM

To San Francisco



Tour Constraints

Capacity

- Number of seats per vehicle

Time

- Maximum Deviation = $(\text{Tour Time} - \text{Car Time}) / \text{Tour Time}$
- Average Deviation = $\sum (\text{TourTime}(i) - \text{CarTime}(i)) / \text{Total Time}$

Typical Values Used in Simulations

- Capacity = 6
- Maximum Deviation = 0.5
- Average Deviation = 0.25

Access to Inbound Train III

From Pittsburg/Bay Point

Start Tour 1

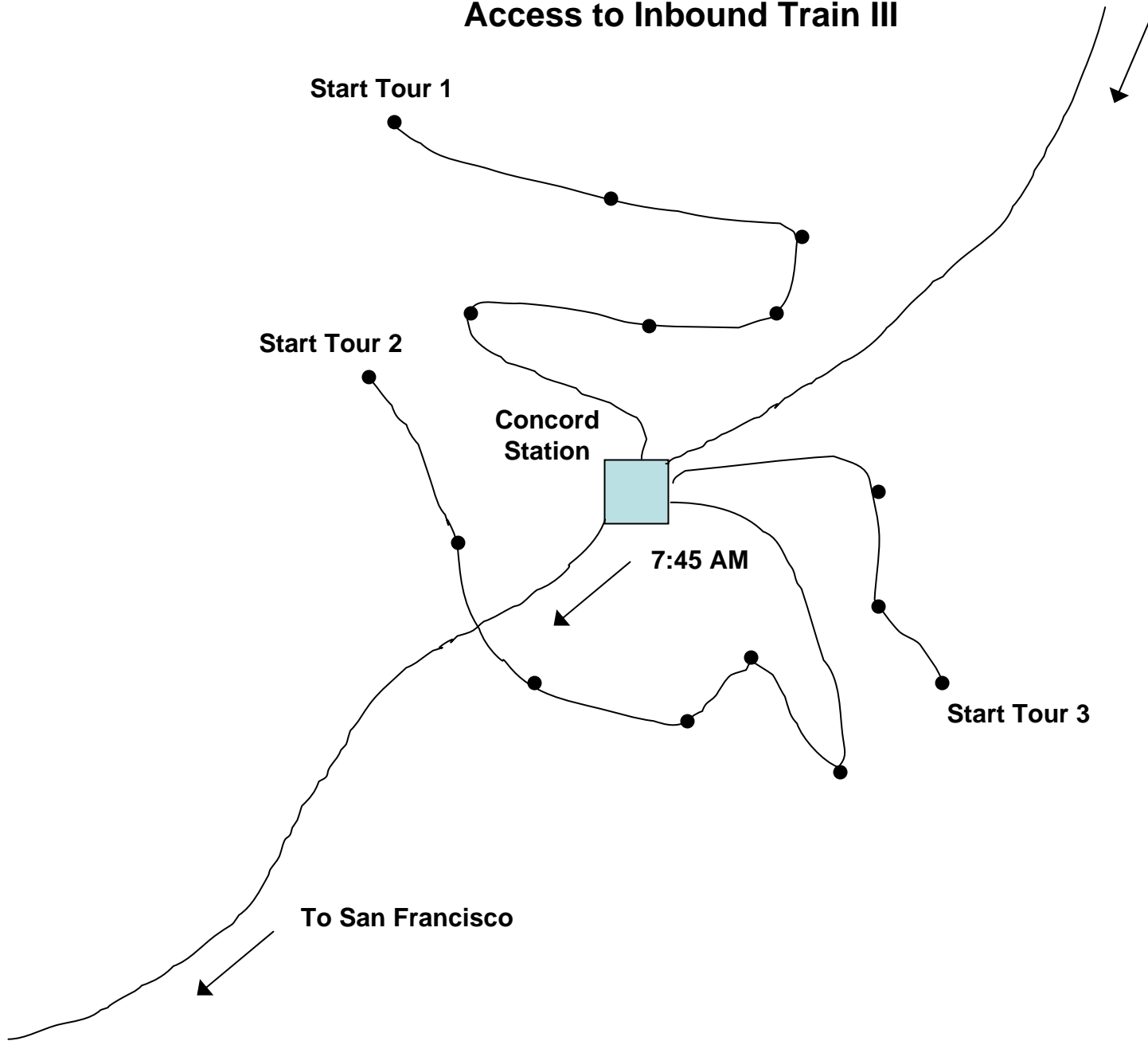
Start Tour 2

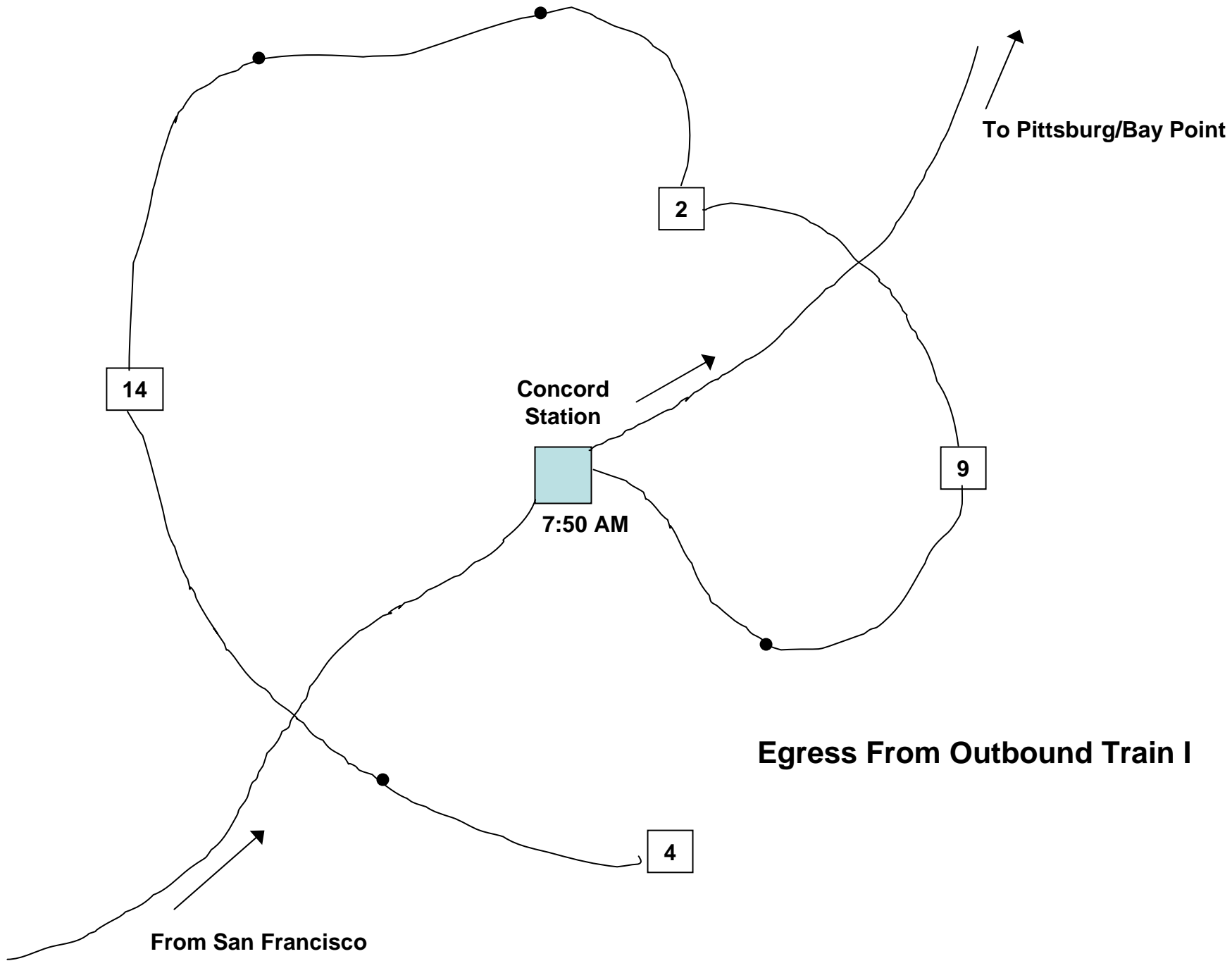
Concord
Station

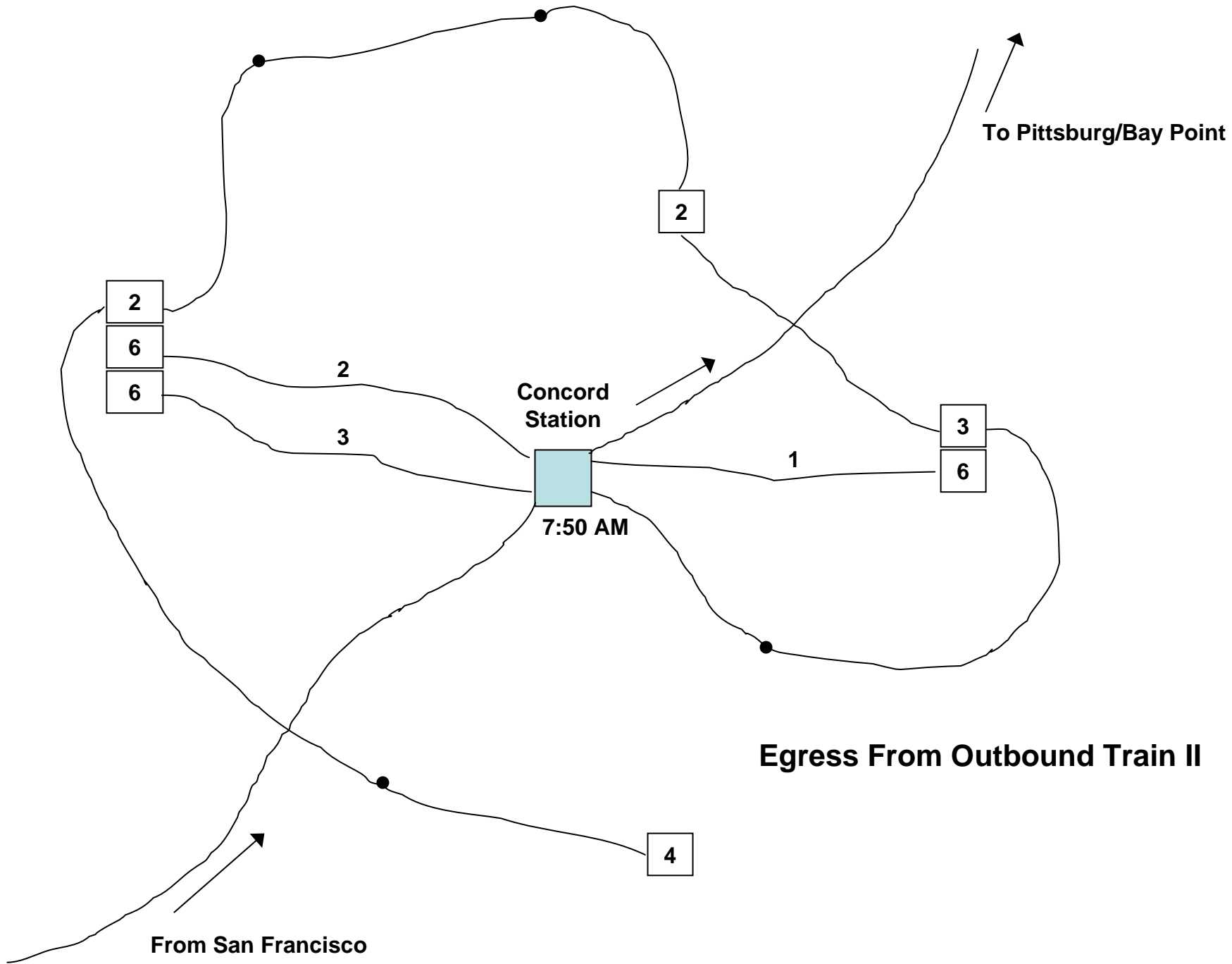
7:45 AM

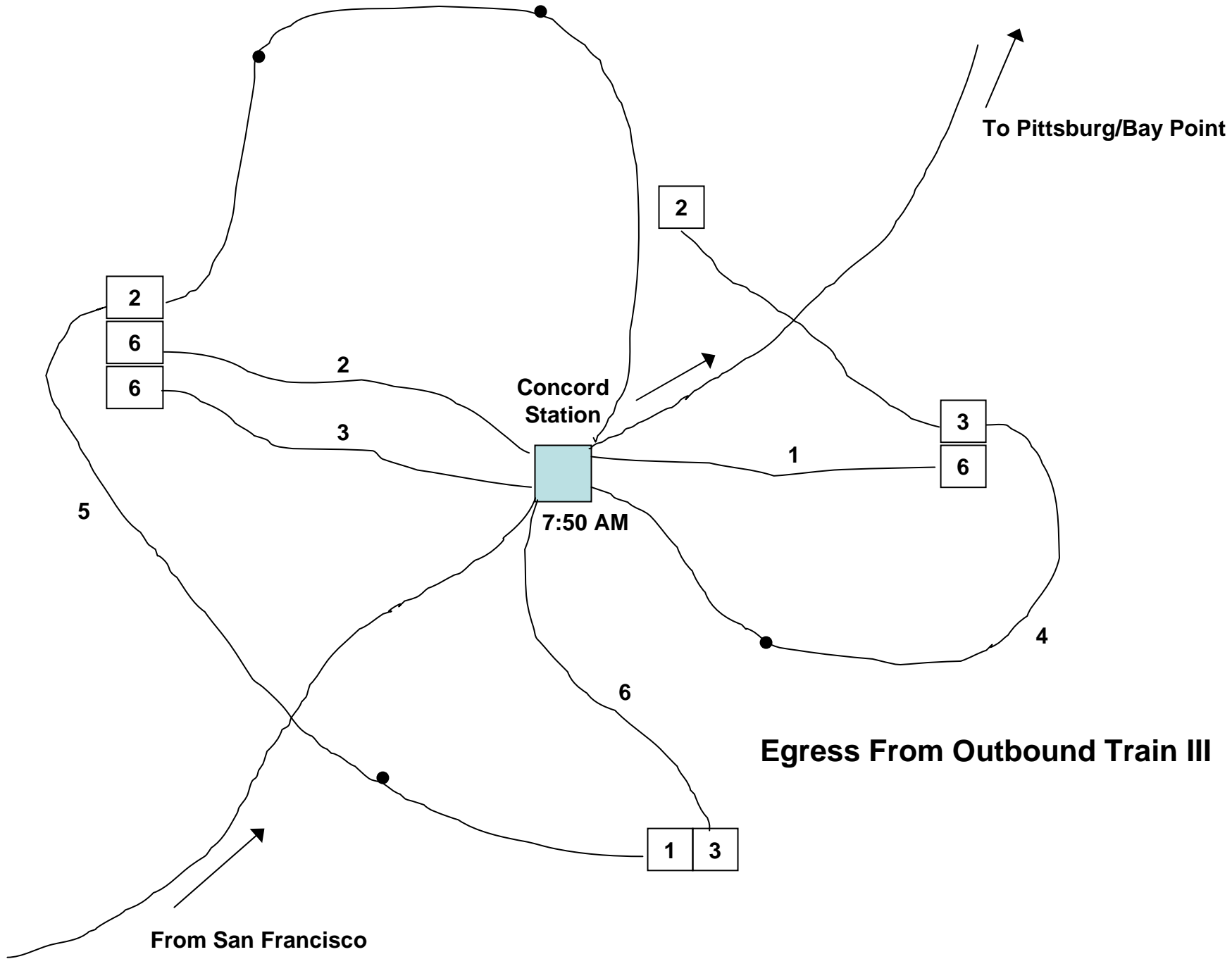
Start Tour 3

To San Francisco









Internet Reservations I

[Main Menu](#)

Address List

Number	Nickname	Street Address	City
1	Home	2345 Blake St	Berkeley
2	Work	10675 Stevenson Blvd	Fremont
3	Soda Hall	1850 Hearst Ave	Berkeley
4	Café Cocomo	650 Indiana Ave	San Francisco
5	Gym	2134 Broadway	Oakland

Internet Reservations II

[Main Menu](#)

Standing Orders

Day	Origin	Destination	Time	AM/PM	ETD/ETA
M	Home	Work	8:00	AM	ETA
T	Home	Work	9:00	AM	ETA
W	Home	Work	8:00	AM	ETA
Th	Home	Work	9:00	AM	ETA
F	Home	Work	8:00	AM	ETA

New Reservation

Reservation

Origin:

Destination:

Time: AM Departure
 PM Arrival

Routing and Scheduling

Routing and Scheduling area (empty)

User Display area (empty)

Vehicle Display area (empty)

User Display

Vehicle Display

New Reservation

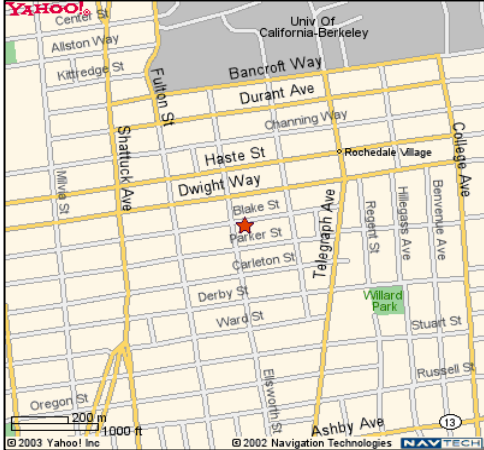
Reservation

Origin:	1	Home	2345 Blake St.	Berkeley
---------	---	------	----------------	----------

Destination:				
--------------	--	--	--	--

Time:		<input type="radio"/> AM	<input type="radio"/> Departure
		<input type="radio"/> PM	<input type="radio"/> Arrival

Routing and Scheduling



User Display

Vehicle Display

New Reservation

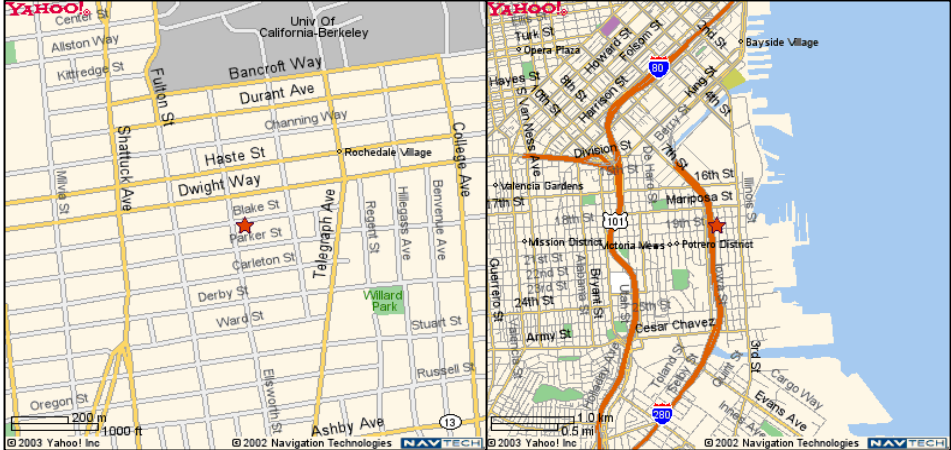
Reservation

Origin: 1 Home 2345 Blake St. Berkeley

Destination: 4 Café Cocomo 650 Indiana Ave San Francisco

Time: AM Departure
 PM Arrival

Routing and Scheduling



User Display

Vehicle Display

New Reservation

Reservation

Origin:	1	Home	2345 Blake St	Berkeley
----------------	---	------	---------------	----------

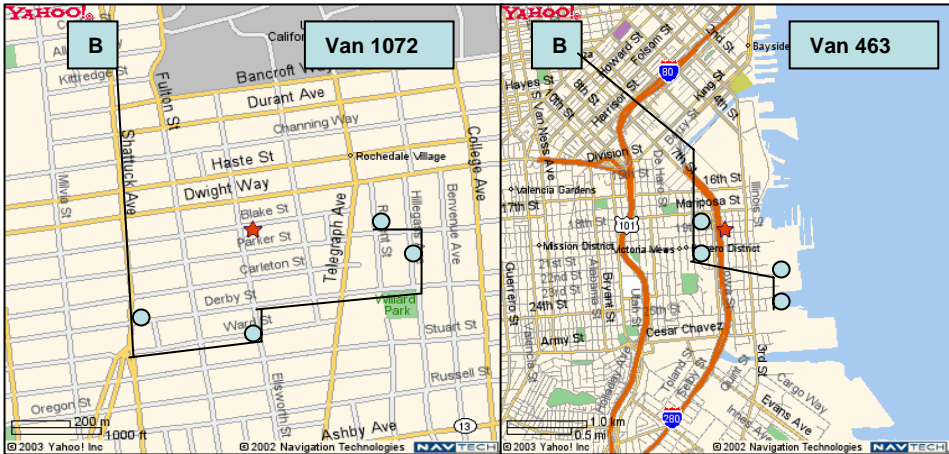
Destination:	4	Café Cocomo	650 Indiana St	San Francisco
---------------------	---	-------------	----------------	---------------

Time:	8:30	<input type="radio"/> AM	<input type="radio"/> Departure
		<input checked="" type="radio"/> PM	<input checked="" type="radio"/> Arrival

Van number 1072 will pick you up at 2345 Blake St., Berkeley, at 7:32 PM tonight. You will arrive at the Downtown Berkeley BART Station at 7:46. You will board the 7:50 Millbrae train, and get off at Civic Center at 8:10. Do you wish to confirm this trip?

User Display

Routing and Scheduling



Vehicle Display

New Reservation

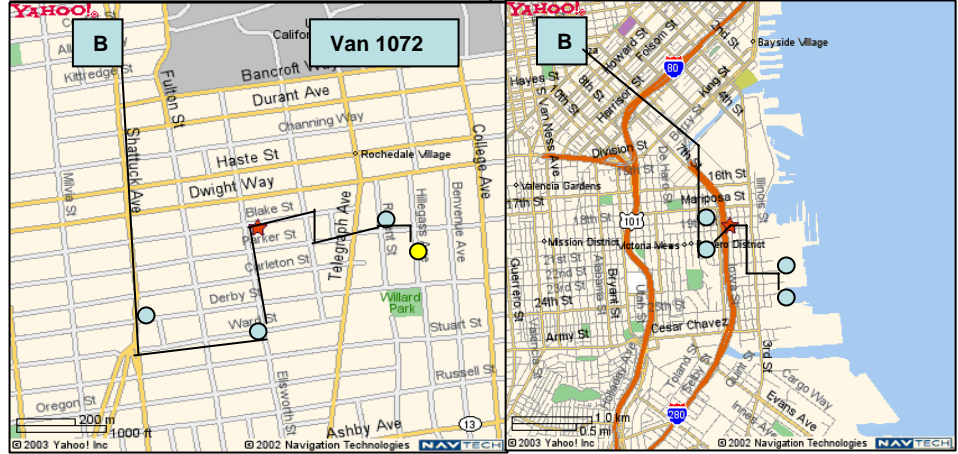
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Van number 1072 will pick you up at 2345 Blake St., Berkeley, at 7:32 PM tonight. You will arrive at the Downtown Berkeley BART Station at 7:46. You will board the 7:50 Millbrae train, and get off at Civic Center at 8:10.

Reservation Confirmed

Vehicle 1072

Stop 1 465 Hillgass Ave Berkeley 7:25

User Display

Vehicle Display

New Reservation

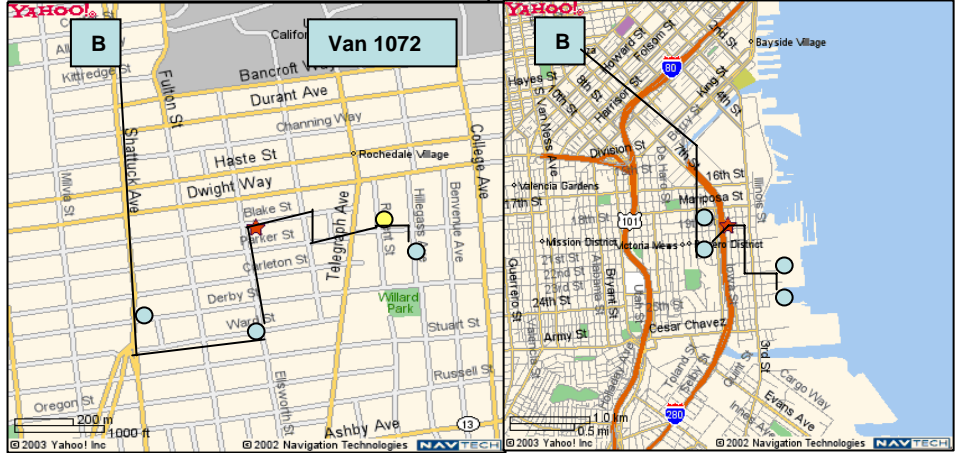
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Van number 1072 will pick you up at 2345 Blake St., Berkeley, at 7:32 PM tonight. You will arrive at the Downtown Berkeley BART Station at 7:46. You will board the 7:50 Millbrae train, and get off at Civic Center at 8:10.

Vehicle 1072

Stop 2 1622 Parker St Berkeley 7:27

User Display

Vehicle Display

New Reservation

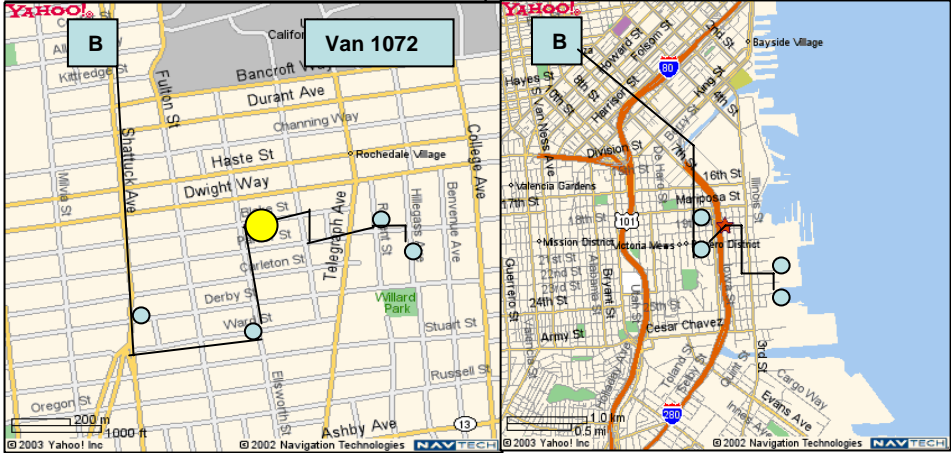
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Van number 1072 will pick you up at 2345 Blake St., Berkeley, at 7:32 PM tonight. You will arrive at the Downtown Berkeley BART Station at 7:46. You will board the 7:50 Millbrae train, and get off at Civic Center at 8:10.

Vehicle 1072

Stop 3 2345 Blake St Berkeley 7:32

User Display

Vehicle Display

New Reservation

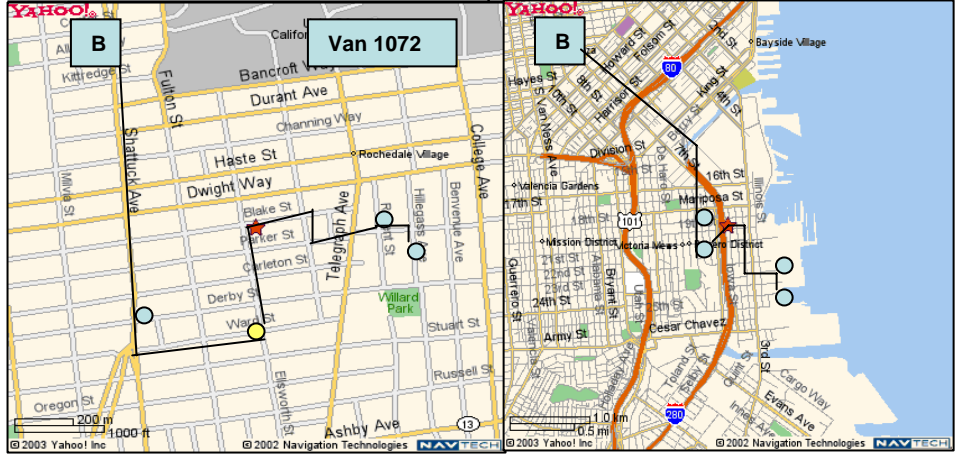
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Van number 1072 will pick you up at 2345 Blake St., Berkeley, at 7:32 PM tonight. You will arrive at the Downtown Berkeley BART Station at 7:46. You will board the 7:50 Millbrae train, and get off at Civic Center at 8:10.

Vehicle 1072

Stop 4 2215 Prince St Berkeley 7:35

User Display

Vehicle Display

New Reservation

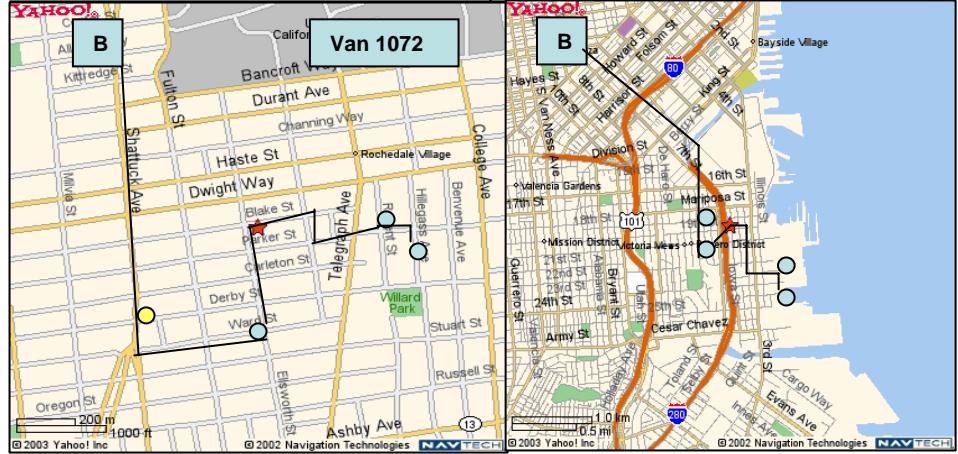
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Van number 1072 will pick you up at 2345 Blake St., Berkeley, at 7:32 PM tonight. You will arrive at the Downtown Berkeley BART Station at 7:46. You will board the 7:50 Millbrae train, and get off at Civic Center at 8:10.

Vehicle 1072

Stop 5 2318 Shattuck Ave Berkeley 7:40

User Display

Vehicle Display

New Reservation

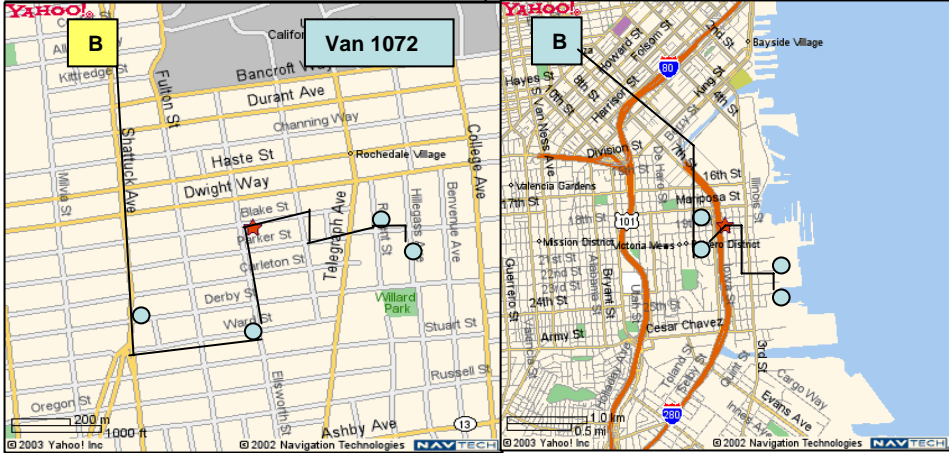
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Van number 1072 will pick you up at 2345 Blake St., Berkeley, at 7:32 PM tonight. You will arrive at the Downtown Berkeley BART Station at 7:46. You will board the 7:50 Millbrae train, and get off at Civic Center at 8:10.

Vehicle 1072

Stop 6 Berkeley BART Berkeley 7:46

User Display

Vehicle Display

New Reservation

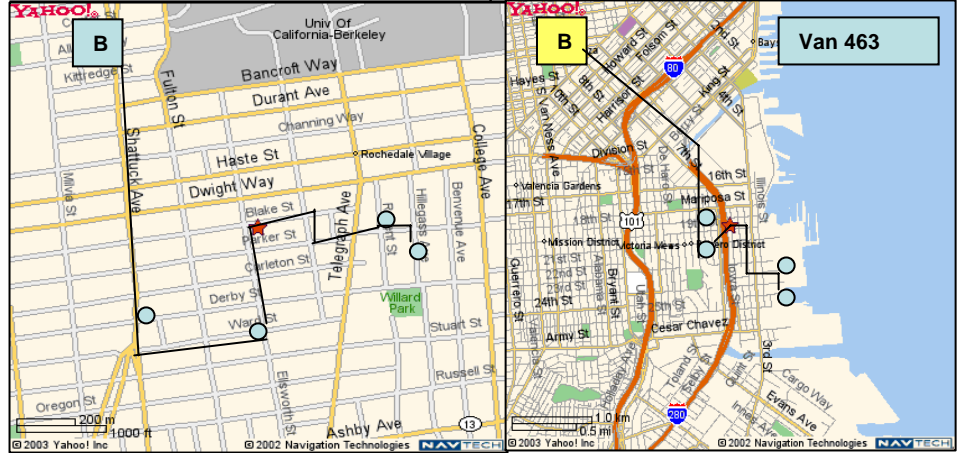
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Please board Van number 463 as you exit the Civic Center BART Station departing at 8:14 PM for your trip to Café Cocomo.

Vehicle 463

Stop 1 Civic Center BART San Francisco 8:14

User Display

Vehicle Display

New Reservation

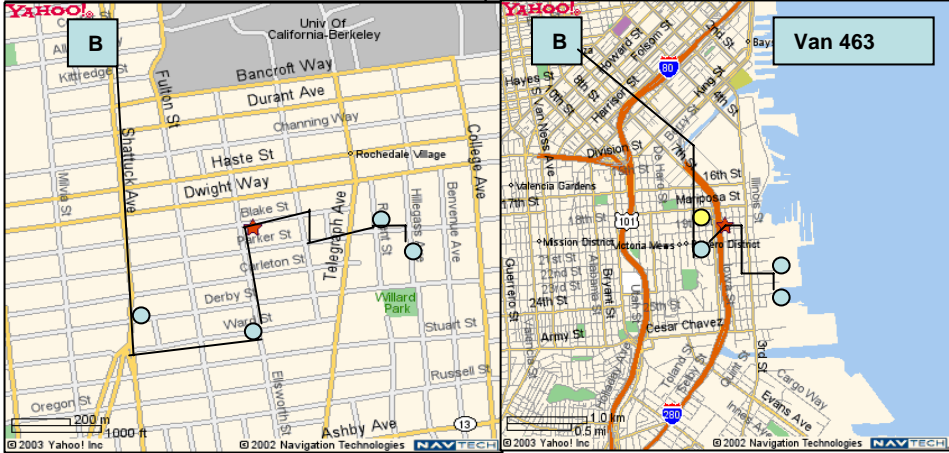
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Please board Van number 463 as you exit the Civic Center BART Station departing at 8:14 PM for your trip to Café Cocomo.

Vehicle 463

Stop 2 1541 Third Ave San Francisco 8:23

User Display

Vehicle Display

New Reservation

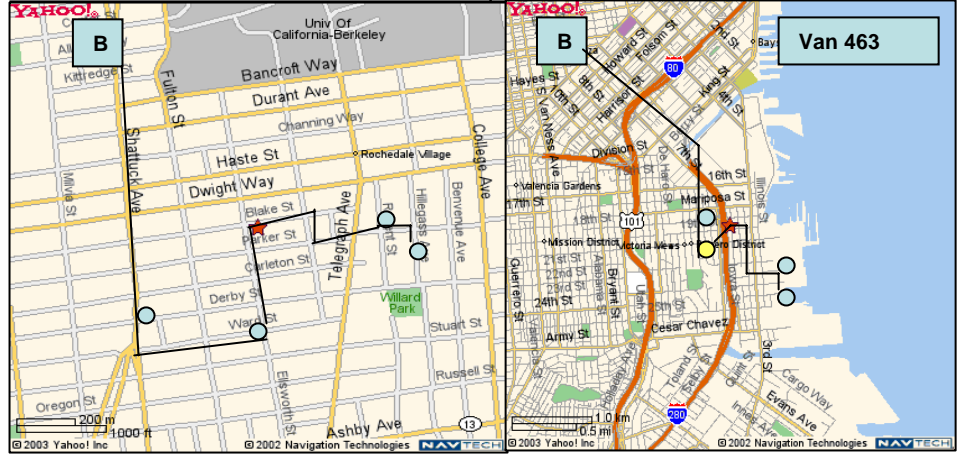
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Please board Van number 463 as you exit the Civic Center BART Station departing at 8:14 PM for your trip to Café Cocomo.

Vehicle 463

Stop 3 2106 Third Ave San Francisco 8:25

User Display

Vehicle Display

New Reservation

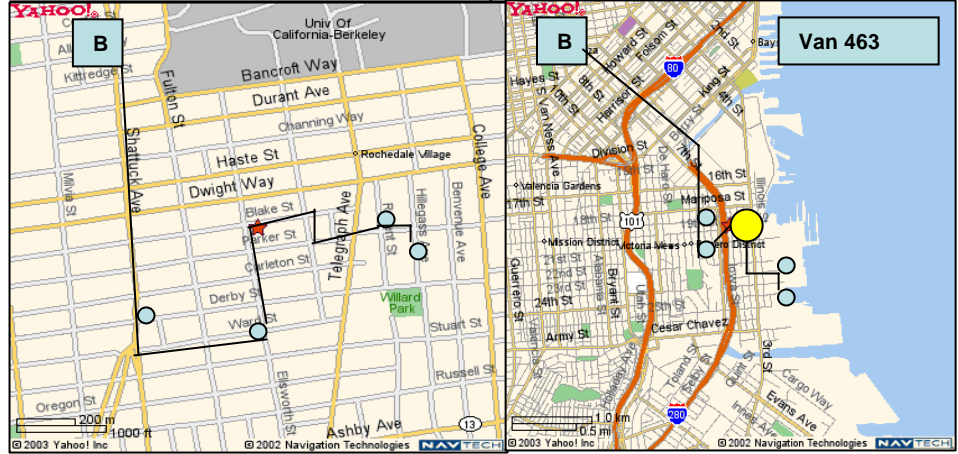
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Please board Van number 463 as you exit the Civic Center BART Station departing at 8:14 PM for your trip to Café Cocomo.

Vehicle 463

Stop 4 650 Indiana Ave San Francisco 8:30

User Display

Vehicle Display

New Reservation

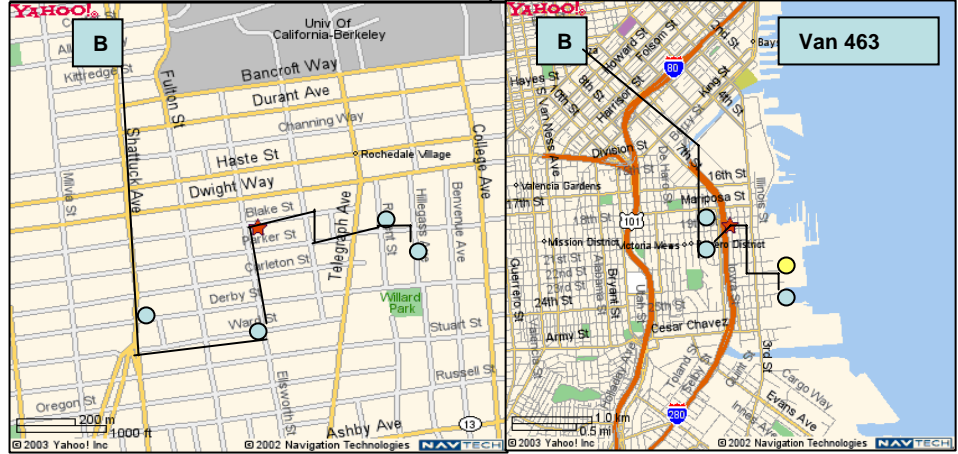
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Please board Van number 463 as you exit the Civic Center BART Station departing at 8:14 PM for your trip to Café Cocomo.

Vehicle 463

Stop 5 2146 22nd St San Francisco 8:34

User Display

Vehicle Display

New Reservation

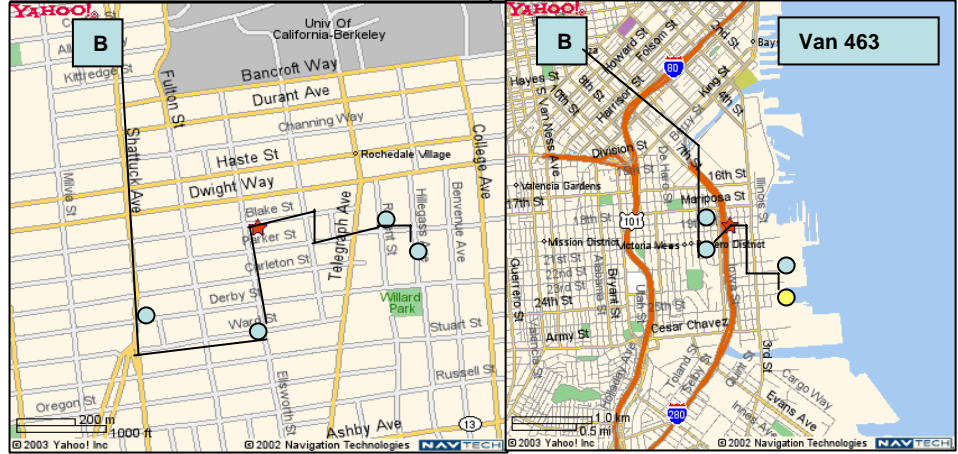
Reservation

Origin: 1 Home 2345 Blake St Berkeley

Destination: 4 Café Cocomo 650 Indiana St San Francisco

Time: 8:30 AM Departure
 PM Arrival

Routing and Scheduling



Please board Van number 463 as you exit the Civic Center BART Station departing at 8:14 PM for your trip to Café Cocomo.

Vehicle 463

Stop 6 1950 25th St San Francisco 8:36

User Display

Vehicle Display

VMT Reduction and Cost: Commute Trip Simulation Example

- 1) Select the 2,241 largest Bay Area commercial locations (square feet) *
- 2) Assume 125 sq. ft. per employee in cities, 375 sq. ft. in suburbs

The result is 1,121,423 employees.

- 3) The employee residence is selected at random from phone directory.
- 4) The assignment of employee to business is random.
- 5) Work ETA and duration are randomly selected from BATS distributions.
- 6) Each employee now has home/work locations and work ETA/ETD.

Structure of the Simulation

- 1) Assign each commute trip end to a BART station.
- 2) Assume regional service between 5 AM and 1 AM.
- 3) Construct tours for each combination of [Station, ETA, Board/Alight]
- 4) Make initial assignment of vehicles to tours.
- 5) Link vehicle tours together with “greedy” algorithm.
- 6) Add a vehicle whenever a tour can't be served by the existing fleet.

VMT and Cost I

1,121,423 employees * 2 = 2,242,846 commute trips.

Of these, 829,970 cannot be served (37.0%).

The remaining 1,412,876 can be served (63.0%).

Rule for switching from solo drive to transit:

- Door-to-Door Transit Time < Door-to-Door Car Time
- BART Fare < Car Cost @ 36.5 cents / mile

Rule must apply to **both** commute trips.

593,458 commute trips are switched (42.1%)

VMT and Cost II

	Transit	Solo Drive	Aggregate
Number of Commutes	593,548	819,328	1,412,876
Total VMT	1.7 M	11.4 M	15.7 M
VMT/Commute	2.9	13.9	11.1

Avoided VMT: 2.6 M

Net Reduction in VMT: 16.6%

Note: The VMT figures for Transit do not include travel on BART

VMT and Cost III

Average 3.4 passenger trips per tour.

Average 1.7 passenger trips on shuttle per commute trip.

593,438 commute trips → 291,368 tours.

Average 9.9 miles per tour.

Average 17.8 tours per vehicle/day = 175 miles per vehicle/day

= 16,398 vehicles

Average 14.8 service hours/vehicle/day = 243,037 hours/day

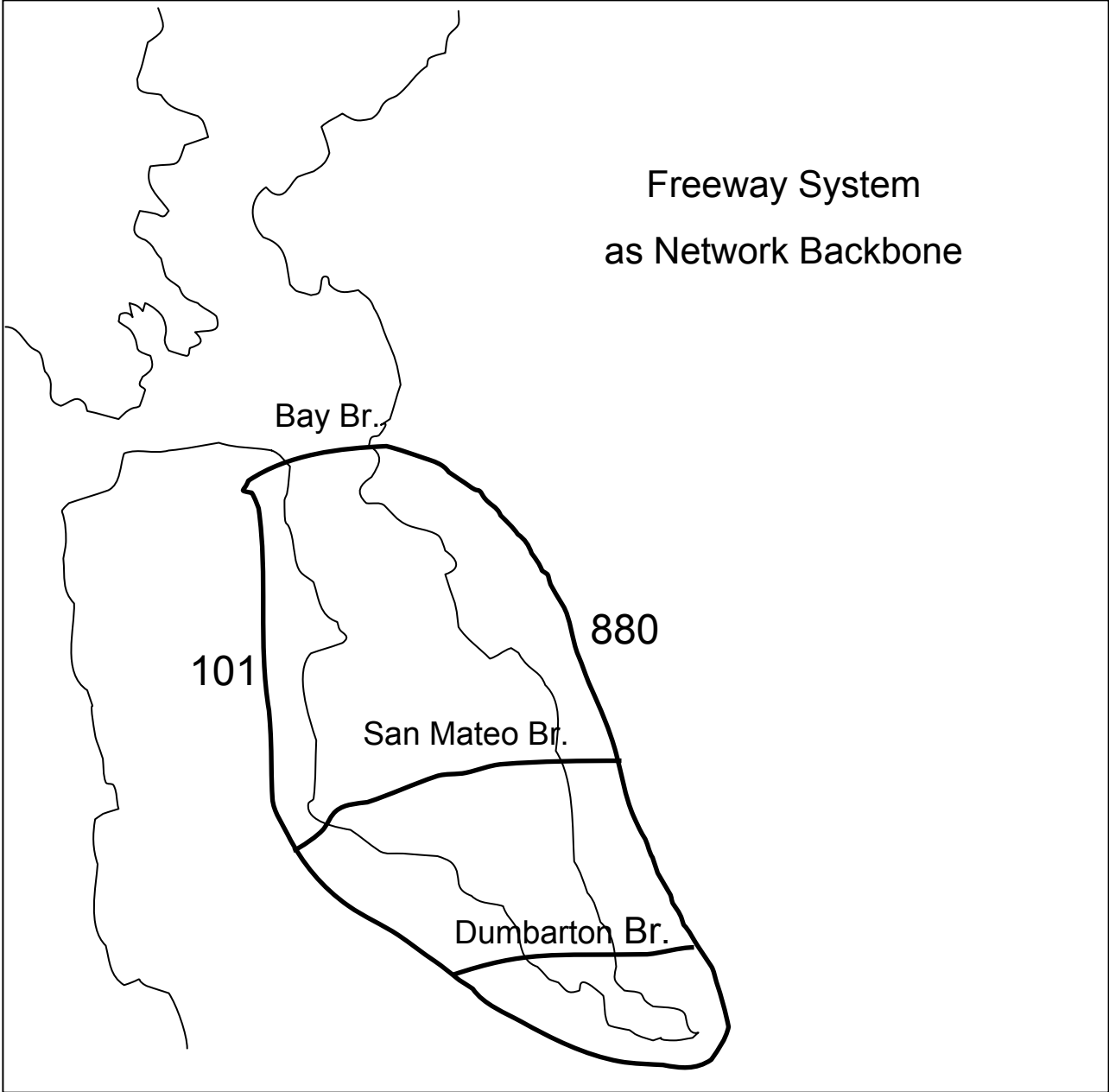
* \$45/hour = \$10.9 M / day

\$10.9 M / 593,458 commute trips = \$18.43 / commute trip

- \$2.75 average BART fare = **\$15.68 Net Deficit per Commute**

\$10.9 M / 2.6 M Avoided VMT = **\$4.19 per Avoided VMT**

Freeway System as Network Backbone



Advantages of Freeway vs. BART as Network Backbone

- 1) Flexible routing – no need to stop at every “station”.
- 2) Buses can pass each other.
- 3) Adding capacity is much cheaper and easier.
- 4) Uses the existing infrastructure for vehicles.

Freeway Simulation: Assumptions

- 1) Ten-minute headways on each of the 72 interchanges.
- 2) Bus travels 60 mph on dedicated lane.
- 3) Passenger bus fare = Average BART fare = \$2.75.
- 4) Construct tours for each combination of [Interchange, ETA, Board/Alight]

Summary Stats: BART and Freeway

	BART	Freeway
Avoided VMT	2.6 M	6.3 M
Net VMT Reduction	16.6 %	40.2 %
Net Deficit per Commute Trip	\$15.68	\$8.86
Cost per Avoided VMT	\$4.19	\$2.26

Note: Assumes that BART and buses contribute 0 to VMT

Are These Outcomes “Bad”, “Good”, or “Hard to Say”?

Bad

- 1) Difficult to “ramp up” system.
- 2) System reliability needs to be addressed.
- 3) Goes against the status quo of public transit.
- 4) Public subsidies for new forms of transit highly unlikely in near future.

Good

- 1) Algorithms are highly sub-optimal, especially the vehicle assignments.
- 2) Employees assigned to worksites at random.
- 3) Only a portion of the Bay Area train and freeway networks used.
- 4) Cost comparison: subsidy on BART Dublin/Pleasanton extension ~ \$25 per passenger trip; estimated to be even higher for San Jose extension.

Hard to Say

- 1) Extent to which people would use system is unknown.
- 2) Difficult to say how a given reduction in VMT translates into reductions in congestion, emissions, accidents, and their impacts on health and the economy.

Other Applications

- 1) Special Events (sports games, concerts)
- 2) Special Populations (low-income, ADA)

Average 14.8 service hours/vehicle/day = 243,037 hours/day

@ two overlapping 8-hour shifts = 15,190 shifts

- 3) Package Delivery

Future Work

- 1) Better and Faster Algorithms
- 2) Full Freeway Network Analysis
- 3) Integration with Local Trips

Key Research Considerations

A. Local vs. Global Optimization

B. Research Approach - generate and analyze VMT outcomes with varying:

- 1) Trip Population: SF, entire Bay Area, solo-drive commuters, low-income, etc.
- 2) Geographic Granularity: door-to-door, max walking distance of 4 blocks, etc.
- 3) Reservation Advance Time = ETD – request time
- 4) Constraints: new passenger, on-board passengers, service operation
- 5) Input Parameters: vehicle capacity mix, average board/alight times, etc.

ICT4M Vs. Alternatives

City Planning Approach: Transit-Oriented Development

Civil Engineering Approach: Optimize Signalization

Everyone Else's Approach: Alternate Fuels

	Alternate Fuels-Based Approach	ICT4M-Based Approach
Reduces Demand for Petroleum	Yes	Yes
Reduces Air Pollution	Yes	Yes
Reduces Congestion	No	Yes
Reduces Impact on Productivity	No	Yes
Reduces Incidence of Accidents	No	Yes
Reduces Parking Requirements	No	Yes
Reduces Road Maintenance Costs	No	Yes
Improves Emergency Response	No	Yes
Improves Long-Haul Access/Egress	No	Yes
Improves Events Management	No	Yes
Improves Airport Service	No	Yes
Reduces Need for New Infrastructure	No	Yes
Can Implement Quickly	No	Yes
Creates Jobs	?	Yes

Acute/Long-Term Disaster Scenarios and Responses

Some Scenarios:

- link is down (bridge, freeway segment)
- facility is out of operation (BART station, power station)
- area needs to be evacuated
- chronic petroleum shortages
- need dedicated lanes for emergency vehicle flow

Technology is all there:

- user interfaces
- vehicle interfaces
- trip assignment algorithms (local optimization)
- GPS/GIS (nice to have Google/Yahoo APIs)

Pilot Projects are highly feasible:

- BART access/egress
- “Olympics” scenario (many-to-few, few-to-many)
- simulation of area evacuation