RT Metro

From Sacramento's Community Dream to Operating Reality

JOHN W. SCHUMANN

Sacramento's RT Metro was built for the lowest capital cost per route mile to date of any new, federally funded rail system—$9.6 million. This paper describes planning and design approaches leading to this achievement. Innovative elements, how all the pieces fit together, and how the system is functioning are discussed. Observations are made as to which aspects of the Sacramento experience merit imitation, and which might better be avoided. RT Metro is an 18.3-mi light rail transit (LRT) system extending about 14.5 km (9 mi) from downtown in each of two directions, northeast and east. A fleet of 26 light rail vehicles serves the system. Because the project budget was limited, development followed four key design principles, which could be emulated beneficially by other projects: use available rights-of-way (ROW), limit the investment to facilities for a "starter" LRT line, employ proven off-the-shelf equipment, and build to an efficient, no frills operating plan.

SACRAMENTO, CALIFORNIA'S CAPITAL, IS growing rapidly. Metropolitan population is approaching 1 million. In 1975, citizen transit advocates first suggested light rail as a potential key element in a program to accommodate growth while maintaining a livable city. Over the ensuing decade, a convergence of community support, right-of-way availability, and Interstate transfer funding enabled a light rail transit (LRT) project to be moved from planning and design into construction. Limited service began in March 1987. The full system became operational in September 1987.

LTK Engineering Services, 33 N.W. First Avenue, 1 Norton House, Portland, Oreg. 97209.

Project planning required the cooperation of the Sacramento Regional Transit District, the City of Sacramento, Sacramento County, the Sacramento Area Council of Governments, and the State of California through the California Department of Transportation (Caltrans). Policy approvals had to be secured from the California Transportation Commission and UMTA. Safety issues were negotiated and resolved with the California Public Utilities Commission. From conception to commitment to build, the project benefited from the support of local elected officials who, together, constituted a "reform era" in local politics. The coalition of pro-LRT transit advocates and environmentalists produced a force to which the elected leadership listened. When they were joined by business leaders at the crucial go/no-go decision time, LRT approval was ensured.

This project's odyssey illustrates that even cumbersome decision-making mechanisms can be made to work when a community's dream is strong enough.

THE PROJECT

RT Metro is an 18.3-mi LRT line extending about 9 mi in each of two directions from the central business district (CBD): to northeast Sacramento at Watt Avenue and Interstate 80, and to the eastern suburbs at Folsom Boulevard and Butterfield Way. The essential elements of the system are set forth in Table 1. A necessary response to the local political situation was that the initial line had to serve both the Northeast and Folsom Boulevard corridors.

The basis for LRT system development was an efficient, no-frills operating plan, which fostered the specification of a minimal "starter line" that would (1) accommodate the modest initial ridership forecast, (2) fit the sum of construction funds available (Interstate transfer plus state and local match), and (3) be operable, together with its associated feeder bus network, within the limits of the Sacramento Regional Transit (RT) District's existing operating budget.

LRT planning extended from 1975 to 1982 [a summary of the project's development in this period may be found elsewhere (*1*)]. Technical development followed four key design principles, which were set forth formally in design criteria (*2*) prepared at the start of preliminary engineering (PE):

- Use available rights-of-way (ROW),
- Limit the investment to facilities needed for a "starter" line,
- Employ proven off-the-shelf equipment, and
- Build for an efficient, no frills operation.

TABLE 1 SACRAMENTO LRT PROJECT: SUMMARY DESCRIPTION

Length:	27 Stations:	Light Rail Vehicles:
Main Line..... 18.3 miles	1-Watt/I-80	Articulated, Double-End
Double Track......... 40%	2-Watt/I-80 West	80 Ft Long, 8.7 Ft Wide
	3-Roseville Road	64 Seats, 80+ Standees
	4-Marconi/Arcade	Air Conditioned
Patronage (04/88):	5-Swanston	
	6-Royal Oaks	Security:
Total Weekday..... 13,200	7-Arden/Del Paso	
Northeast Line.... 6,700	8-Globe Avenue	Telephones at Stations
East Line......... 6,500	9-Alkali Flat	Mobile Security Patrols
	10-12th & I	Police Officers on
Operations:	11-Cathedral Square	Trains
	12-St. Rose of Lima	
50 MPH Top Speed	13-Capitol Mall	Fare Collection:
20 MPH Avg Speed, w/stops	14-7th & O	
2-4 Car Trains Peak Hours	15-Archives Plaza	Proof of Payment (POP)
1-2 Car Trains Base Hours	16-13th St.	Self Service Vendomats
Fleet: 26 LRVs (3 spares)	17-16th St.	Separate Bill Changers
81 LRT Staff	18-23rd St.	
	19-29th St.	Signals:
Service Frequency, Peak	20-59th St.	
& Base, Entire Line:	21-65th St.	Line of Sight Control w/
	22-Power Inn	Signs, Traffic Lights,
Weekday Peak...... 15 Min	23-College Green	Block Occupancy Indctrs,
Weekday Base...... 15 Min	24-Watt/Manlove	Automatic Block Signals,
Weekday Evening... 30 Min	25-Starfire	Crossing Gates/Flashers
Sat/Sun/Hol....... 30 Min	26-Tiber	
	27-Butterfield	Communications:
Implementation Schedule:		
	Station Facilities:	2-Way Radios
Plans Begun......... 1975		PA Systems on LRVs
Full Funding........ 1983	Low Level Platforms	
System Opened....... 1987	~350 Ft x 10 Ft	Traction Power:
	Shelters, Benches,	
Yard & Shop:	Info Aids, Telephones	750 Volt DC Overhead
	Access Ramps or Lifts	Catenary & Trolley Wire
Location: Academy Way	8 Park & Ride Lots w/	14 Substations, Each
26 LRVs-Clean, Service,	4,056 Total Spaces	Rated at 1 Megawatt
Repair; Way Maintenance &	LRT/Bus Transfers @ 6	
Operations HQs	Outlying Stations	

Based on "As Built" data and Regional Transit (RT) ride checks.

Because the project budget was limited, designers were "specifically cautioned to avoid costly features that may be construed as 'gold plating'" (2). This term was never specifically defined, but was understood to mean that project design should follow the then-recent model of the San Diego Trolley.

USING AVAILABLE RIGHTS-OF-WAY

Sacramento was blessed with existing ROWs that were available, in reasonable locations for a functional LRT system, and could mesh with and enhance the existing transit network. The key possibilities were identified in 1975 by the citizens' group that first advocated LRT, and were confirmed after 8 years of planning:

- Northeast: land for proposed I-80 bypass freeway (4.5 mi),
- East: underused railroad branch line (7.8 mi),
- South: abandoned railroad branch line (7.1 mi).

The northeast and east ROWs form the basis of the new RT Metro system. The south ROW has been purchased and preserved for a future extension.

Each of these ROWs ends short of downtown Sacramento. Therefore, LRT reaches the CBD via a variety of private ROWs and city street alignments: reserved medians, curb lanes, transit/pedestrian malls, and mixed traffic lanes.

Underused or abandoned railroads connected to the inner ends of major ROW opportunities. In the northeast, Sacramento Northern's abandoned interurban branch line paralleled Arden Way. In the east, a Union Pacific (UP) (former Western Pacific) branch extended west from the Southern Pacific at 19th and R streets. Both were incorporated into the LRT alignment.

City streets were used for downtown access, forming the route between the former Sacramento Northern branch at Arden/Del Paso and the former UP branch at 12th between Q and R streets. From Arden/Del Paso, RT Metro trains run in mixed traffic on Del Paso Boulevard (0.5 mi), then in an exclusive curb lane along CA-160 and North 12th Street to G. Double track begins between G and H, with the exclusive curb lane used by outbound (northbound) trains, and a track in mixed traffic provided for inbound trains. The K Street pedestrian mall between 12th and Seventh in Sacramento's retail district was converted to a double-track LRT/pedestrian mall; and a new mall was created serving the state office buildings on O Street from Seventh to 12th.

K and O are connected by tracks in curb lanes with trains running in the same direction as traffic: south on Seventh and north on Eighth. LRT planning anticipated that these lanes would be reserved for LRT (*3*, p. 2-27); however, they have been installed without curbs and are operating as mixed traffic lanes, apparently without serious impact on LRT service. From O Street to the UP ROW, trains run on center-of-street tracks in traffic on 12th for 2.5 blocks.

As pieced together (Table 2), the available ROWs form a continuous line that includes all three LRT alignment classifications: exclusive, semiexclusive, and mixed traffic. Because suitable surface alignments were located, subways were avoided. This was essential, because subsurface construction was beyond the reach of the project budget.

TABLE 2 RT METRO ROW SEGMENTS

Segment	Description	Km(Mi)
I-80 Median	Constructed but never used portion of I-80 Bypass in wide I-80 median	2.7 (1.7)
I-80 Bypass	Cleared R/W for unbuilt freeway	4.6 (2.8)
Evergreen Connector	Private land, purchased for LRT	0.5 (0.3)
Arden Way	Ex-Sac. No. interurban R/W	1.0 (0.6)
Del Paso Blvd. (a)	Center of street, LRT in mixed traffic	1.0 (0.6)
Route 160	Reserved curb lane w/Jersey barrier	1.3 (0.8)
North 12th	Reserved curb lane (b)	2.2 (1.4)
K Street	Transit/Pedestrian Mall-5 blocks	0.6 (0.4)
7th/8th Streets (a)	One mixed traffic curb lane in each of two streets (c)	0.6 (0.4)
O Street	Transit/Pedestrian Mall-5 blocks	0.6 (0.4)
12th Street (a)	Center of street, LRT in mixed traffic	0.3 (0.2)
Whitney Ave.	Ex-WPRR R/W (adjacent to alley)	0.7 (0.5)
Bee Bridge	New aerial structure	0.6 (0.4)
SPRR-R Street (a)	Center of street, LRT in mixed traffic (c)	1.0 (0.6)
SPRR R/W	Exclusive LRT occupancy of RR R/W	3.8 (2.3)
SPRR R/W	LRT & SPRR share R/W but use separate tracks	7.9 (4.9)
	Total System	29.4 (18.3)

(a) Mixed traffic segments: 2.9 km(1.8 mi), 10% of total line.
(b) From G to K Street, LRT is double tracked, with the southbound track in mixed traffic. Northbound curb lane track reserved for LRT.
(c) Planning anticipated reserved LRT lanes; city traffic and RT implemented as mixed traffic.

INVESTMENT IN FACILITIES

A major focus of planning and preliminary design was development of limited scope, low-cost facilities to provide a no-frills system (again, following the example of San Diego) that would be buildable and operable within the limits of funds then anticipated.

The Sacramento project emphasizes reuse of existing structures but includes six new bridges. These are the major structures on the line:

Structure	*Status*
I-80 Median (3 overheads)	Existing
Grand Avenue Bridge	Existing
Arcade Creek Bridge	New
Marconi, El Camino, Arden (3 overheads)	New
North Sacramento Undercrossing (CA-160)	Existing
North Sacramento Viaduct and American River Bridge	Existing
12th Street Undercrossing (Southern Pacific)	Existing
Union Pacific Overcrossing	New
Business 80 (2 overheads)	Existing
Brighton Overcrossing (Southern Pacific)	New
Route 50 Overhead at Folsom & La Riviera	Existing

The use of single track on certain structures, necessary for political or economic reasons, causes numerous operating constraints, because cars obviously cannot be allowed to meet in single-track territory.

The segment including the American River crossing follows CA-160, a six-lane highway. Outbound lanes are on a newer three-lane bridge. The three inbound lanes use the older, original four-lane structures, with LRT in the extra lane. For traffic engineering reasons, it was necessary to limit LRT to one track, separated from traffic by a concrete New Jersey barrier.

Similarly, only one track was placed through the 12th Street undercrossing and along adjacent sections of North 12th Street because of city traffic officials' concerns about LRT intrusions on vehicular traffic using this main arterial street.

Both the Union Pacific and Brighton overcrossings were built with just one track, to conserve funds.

Operations and Maintenance Facility

The operations and maintenance facility includes the light rail vehicle (LRV) storage yard and a shop building containing LRV maintenance facilities; way maintenance component work areas for track, power, signal, and fare collection equipment; parts stores; and RT Metro facilities (administrative offices, Metro Control, and operators' lockers and day room). The site in the abandoned freeway ROW was ideally shaped (+350 ft wide and as long as was needed) and located (between a Southern Pacific main line and an industrial park).

The LRV storage yard was laid out for the initial 26-car fleet. Space for additional tracks was left to accommodate fleet growth up to 50 cars. Tracks were built double-ended to provide operating flexibility.

The shop building is typical of current design: tracks long enough for two cars, and access from both ends so cars in the shop are not trapped. A turning loop was built into the shop access trackage at the end of the shop opposite from the storage yard. There are three tracks, giving a total capacity of six cars in the main bay. The design includes a future fourth track to provide a heavy body repair position and a paint booth.

During design, staff wrestled with the problem of matching perceived needs with available budget. Several suggestions were made to reduce costs, among them replacing the shop access loop track with a simple track fan, making the yard stub-ended to eliminate some special trackwork, reducing the number of way maintenance component work areas, and using a steel building instead of concrete. None of these options was adopted. However, the body repair and paint booth bay was not considered essential for system start-up, and was dropped from the initial project when bids came in high. Capital funding now is being sought to add this feature in the near future.

Maintenance and supervisory equipment consists of shop machinery, small tools, and vehicles. Major pieces of shop machinery include an LRV exterior washer and a milling machine-type wheel truing machine. Support vehicles are discussed in a separate section below.

Passenger Stations and Pedestrian Malls

Passenger stations and downtown pedestrian malls were designed to fulfill community desires for pleasing aesthetics. As compared with a minimal "bare bones" approach (e.g., using off-the-shelf bus shelters at stations), some design elaboration occurred with regard to platforms, sidewalks, shelters, and parking lots. Many more parking spaces were designed and built than the demand estimate indicated were needed for initial operation.

Platform and Shelter Designs

Platforms are constructed to accommodate four-car trains and are built to a uniform width (10 ft) and surface quality for their entire length, about 350 ft. Since trains are only one or two cars long at most times, some savings could have been realized without seriously impairing aesthetics by building full-width concrete platforms for two car lengths, but narrower (6 ft) black-top platforms for the areas used by third and fourth cars operating only in weekday peak periods. This would have saved about 5,700 ft^2 of paving per station.

As has been the case for most new-start LRT systems, the Sacramento project is graced with unique, architect-designed shelters. Some savings were made by not building shelters at locations where waiting passengers were expected to be few in number, e.g., certain outbound suburban platforms. Further savings could have been achieved by installing off-the-shelf manufactured transit shelters. This was unacceptable to project architects and public officials who made up the policy board. Even in Sacramento, there were limits on how far the "no-frills" approach could be pushed.

Parking Lot Design and Sizing

Parking lot design began by determining the maximum number of spaces that could be constructed at each site. This totaled approximately 5,000 spaces (*3*, p. 2-32). Unfortunately, designers were reluctant to reduce the lot sizes after the demand forecasts indicated a need for about 2,800 spaces systemwide (*3*, p. 2-33). The number of spaces built eventually was cut back to 4,056; but designs for such items as drainage were based on building whole lots at once instead of modularly, so savings have been minimal.

Actual usage in late January 1988 was running about 1,600 parked automobiles per day, leaving the project vulnerable to criticism of public funds "wasted" on unneeded parking. It would have been far better to preserve parking lot ROW, and build spaces at, or even a bit under, the demand estimate, then let the market (i.e., actual usage) dictate where future expansion should occur.

Transit/Pedestrian Mall Designs

PE budgeting provided only for modest improvements on K Street and tracks embedded in blacktop on O Street. More elaborate mall designs were developed for both streets, however, in the hope that city and state funding might become available. Since 1984, such funds have been secured; and the more aesthetic designs have been put in place. Even so, the designs are economical compared with malls in other cities.

K Street is 80 ft wide from building to building. Basement vaults extend from the buildings under the sidewalks. LRT construction avoided the vaults by incorporating the existing 14-ft exposed aggregate concrete sidewalks into the new mall design, thus limiting construction to the 52-ft cartway. This accommodates two LRT tracks, one on each side of the street centerline, and an 11-ft strip on either side used for LRT platforms, plantings, and pedestrian amenities (benches, trash receptacles, public telephones, etc.).

On O Street, two blocks have been turned over to exclusive LRT/ pedestrian use. The remaining three blocks also provide a one-way travel lane and a pull-out lane for vehicular access to automobile passenger drop-off zones, building delivery entries, and parking facilities. The architectural elements (pavers, poles, benches, etc.) are the same as on K Street.

OFF-THE-SHELF EQUIPMENT

Wherever possible, proven designs were specified in procurement documents for LRVs, track materials, traction power equipment, signals, radios, fare vending machines, and maintenance equipment. This was necessary to meet the modest project budget, as well as to ensure high reliability and minimal phase-in and retrofit problems for RT, Sacramento's new-to-LRT system operator.

Light Rail Vehicles

Within the limitations of federal procurement regulations, Sacramento emphasized its desire to buy proven equipment. The rationale was that as a new-start project buying a small 26-LRV fleet, RT Metro would need every car (other than normal maintenance spares) available from Day 1. If LRT was to prove itself in this setting, there would be no room for a time-consuming program to debug and retrofit a new, unique-design car.

The LRVs purchased are yet another mutation of the Siemens-Duewag U2 car. As compared to modifications in the original Frankfurt design made successively for Edmonton, Calgary, and San Diego, the Sacramento version includes some relatively major changes, enough that the car is designated "U2-A" (advanced).

Changes include air conditioning (two roof-mounted units per LRV), a car body structure strengthened to support the air conditioning units, welded steel construction replacing the fiberglass end moldings, all steps built into the car body (as opposed to a retractable bottom step), and a modulating seven-step friction brake actuator replacing the former "on/off" arrangement.

Access for riders unable to use stairs is provided by placing fixed ramps and short car floor-level platforms at each station where the front door of the first car in each train stops. Trap doors, hinged and raised out of the way to allow steps to be used when doors are in trailing positions, are lowered to cover the front door step wells on both sides of the LRV in the lead position, thus providing a safe, flat space where wheelchairs can maneuver. Small, lever-controlled gangplanks are used to close the gap between the LRV and the platform. The matter of access is one area where an off-the-shelf solution was not available. Sacramento's response was to develop a simple system that avoids electrical, hydraulic, and mechanical gadgetry. It works.

The cars are "medium performance" LRVs, with maximum service speed of 80 km/h (50 mph) and initial acceleration of 1.1 m/s^2 (2.5 mi/h/s). Teething problems were relatively minor, and the cars have been performing reliably.

Lengthy negotiations were required to resolve issues related to federal "Buy American" regulations, to the point that despite delays on other contracts, the LRVs became the critical path for opening the Folsom portion of the system.

Track Materials

Standard North American track materials and construction methods were used to promote interest in bidding among domestic suppliers and to ensure that the track structure would be familiar to its maintainers, who were likely to have a U.S. railroad background.

Subgrade and ballast materials, depth, and cross-section are typical of North American practice, modified for local conditions and LRT loadings. American Railway Engineering Association (AREA) 115-lb/yd rail was specified, based on structural and electrical adequacy and availability. Rails were field-welded. Because wood ties were purchased when the lumber industry was depressed, concrete could not compete on price. Except for direct fixation on a few structures, track fasteners are standard cut spikes and tie plates, the latter purchased secondhand for economy.

Special trackwork also is to standard AREA designs. It was planned initially to limit frog angles to two, a small angle for yard and low-speed street trackage and a larger angle for use on private ROW. Also contemplated was location of double-to-single track transitions at stations, where slow-moving trains would require nothing bigger than a No. 10 turnout whose points could be spring-operated to avoid the capital and maintenance costs of a switch machine. Because fitting the track in the available ROW proved difficult in several instances, these goals were not achieved throughout the system, and turnout sizes range from No. 6 to No. 20.

Traction Electrification

The traction electrification system consists of three basic elements: substations converting high-voltage AC to traction-voltage dc current, a positive circuit (the overhead distribution system), and a negative return circuit (the tracks).

Electrical substations supplied by Controlled Power Corporation are rated at 1,000 kW and are virtually identical to units used in San Diego. These off-the-shelf units are factory-manufactured in halves and assembled on site, where they are mounted on poured slabs and ground mats custom-designed to local soil conditions.

Fittings for the catenary and direct suspension trolley-wire overhead systems are off-the-shelf designs from Ohio Brass, assembled to fit the requirements of the Sacramento alignment.

Signals

Two types of signaling are used. High-speed [57 to 80 km/h (36 to 50 mph)] sections of the line have railroad-type automatic block signals (ABS) using vital relays. In low-speed areas [56 km/h (35 mph) or less], trains are operated "on sight"; train operators obey street traffic signals at intersections; and nonvital block occupancy indicators (BOI) control access to single-track sections.

Two single-track sections of the Northeast line include both high- and low-speed segments. Unfortunately, system designers used both ABS and BOI in each segment, strictly following the design criteria. Now train operators face indicators for both types of signals at these block entry points. It would have been less confusing to use just one type of signaling—ABS—throughout such track sections.

Grade crossings on private ROW and along R Street from 23rd Street east are protected by railroad-type flashers and gates. Where LRT is in street ROW, intersection traffic lights include special indications for LRT movement, in most cases giving priority to LRT.

Two-Way Radio System and Train Control

A dispatcher at Metro Control (located at the maintenance facility) directs normal and abnormal train operations and coordinates maintenance crew occupancy of the ROW. Two-way radios in each LRV and support vehicle are the principal means of communication. The system operates as an expansion of RT's bus radio network, with one separate channel provided for LRT operations, maintenance, and security. A magnetized track schematic is provided at Metro Control but is used normally only during serious service disruptions; with just eight trains operating at one time, there is no need for a mimic board.

Ticket Vending Equipment

Self-service proof-of-payment (POP) fare collection is used on RT Metro to enable one-person operation of multicar trains, which was absolutely essential to the project's economic justification. Sacramento's approach follows what has become typical North American practice: ticket vendor/validators and changemakers on station platforms, no fare collection equipment on trains, "free" station platforms, "paid" train areas, and roving inspectors on trains to enforce the system. Fare evasion penalties, written into the criminal (not civil) code, range from $35 to $250.

POP works well. RT employs six inspectors to achieve an inspection rate of 25 percent. Fare evasion is low, according to SRTD officials, in the range of 1.5 percent, and consistent with the experience of other North American cities that have introduced POP.

Sacramento opted for vendor/validators and separate dollar bill changers to simplify the machinery. The Swiss supplier, Xamax, subcontracted with a U.S. firm for the bill changers to meet UMTA "Buy American" requirements. RT would like to have more than the single vendor/validator typically supplied at each station. A minimum of two vendor/validators per station would have been desirable had the project budget not been so tight.

Maintenance and Supervisory Equipment (Vehicles)

LRT operations and maintenance are supported by a service fleet of 11 automobiles and trucks. These range from sedans used by management and road supervisors, through pick-ups and vans for wayside cleaners and maintainers, to specialized trucks and other equipment, some with "hy-rail" road-rail capability. The more specialized vehicles are as follows:

- One Unimog (LRV mover, also carries rerailing equipment),
- One utility body line truck with lift (overhead maintenance), and
- Two electric utility carts (LRV cleaners).

Several of the sedans and pick-ups were purchased early in the project for use by construction management staff, then turned over to LRT operations. This saved the expense of renting vehicles for construction managers.

EFFICIENT OPERATING PLAN

The key to LRT capital and operating cost efficiency was found in the patronage forecast. Demand estimates indicated that peak passenger flows could be accommodated by lengthening one- or two-car off-peak trains to rush hour consists of up to four cars. Thus, peak operations continue at 15-min base service headways. As a result, only 40 percent of the Sacramento system has double track, and extra train operators are not required solely for peak traffic.

Peak hour, peak direction volumes at the peak load points were forecast to be about 1,600 on the Northeast branch and 800 on the East branch (*3*, p. 2-33). Based on loads of 144 (64 seats plus 80 standees) per 80-ft LRV and 15-min headways (four trains/hr), three-car peak direction trains would suffice on the Northeast line; and the peak hour policy consist of two-car trains would be more than adequate in the peak direction on the East line and in the off-peak direction on both branches.

With eight trains required to meet the round trip operating cycle time of 120 min, there would be a peak requirement of (4 trains × 3 cars) + (4 trains × 2 cars) = 20 cars in use, leaving a shop and spares margin of 6 cars (30 percent), which is more than adequate. To equalize peak hour loadings at about 100 to 110 per LRV on both branches, preliminary engineering assumed that a fourth car would be run on up to three of the four Northeast trains. This would require up to 23 cars, leaving as few as three spares, or 13 percent. Because "proven" cars were to be acquired, it was thought that this would be adequate, even though it was on the tight side of current rail transit practice.

Adequacy of 26-LRV Fleet

In actuality, RT feels pressed for equipment. Peak hour loadings are running as high as 120 standees per train (40 per LRV on a three-car train). Although this is less than the forecast, local bus riders have been used to sitting, so there are complaints about having to stand on the trains. In addition, Sacramento commuters are still learning how to adjust their commuting times to less crowded trains, and RT has not spread feeder buses among trains sufficiently.

Further, the split of demand between the two branches is almost even (51 percent Northeast, 49 percent East), whereas the Final Environmental Impact Statement (FEIS) forecast was heavily skewed (64 percent Northeast, 36 percent East). As a result, RT is running a.m. peak service as follows as of January 1988: (1 train × 4 cars) + (5 trains × 3 cars) + (2 trains × 2 cars) = 23 cars of 25 currently available (1 car undergoing wreck repairs). Having only two spares (9 percent) is really tight. Even with the wrecked car repaired, three spares (13 percent) is well under the 20 percent ratio more typical of rail transit.

It seems inevitable that system builders will continue to be frugal—even stingy—when buying initial fleets, effectively placing the requirement on their operating successors to be very sharp. But with every car such a big-ticket item, there is little option to do otherwise.

Adequacy of Single Track

A mostly (60 percent) single-track main line with six double-track segments was adopted based on PE train performance simulations and negotiations with city traffic authorities. Project staff at the time recognized that "tight" meet situations with some potential for delays existed at two double-to-single track transitions: 12th and G in downtown Sacramento and Arden/Del Paso in North Sacramento. LRT operating reliability would have been better had double track been extended north on 12th Street at least four more blocks to C Street, and around the corner from Del Paso Boulevard through the Arden/Del Paso station. Traffic engineers' concerns about arterial street operations scuttled both of these extra lengths of double track. The LRT operating plan had slack time added at these locations to compensate for the lack of a second main track.

As construction progressed, RT reconsideration of the LRT operating plan raised fears that 15-min headways might not be achievable, and that a 20-min interval service might be necessary until more double track could be installed. These fears proved to be overstated; and RT is operating 15-min LRT service, albeit with minor delays (typically 1 to 2 min, but occasionally up to 4 min) at the two points noted above.

When delays occur, recovery is more difficult than on a double-tracked line. A benefit of single track, however, is that it enforces the timetable. Trains simply cannot run ahead of schedule.

Single track limits the system to minimum headways of 15 min. This is adequate for initial demand, but restrains feasible expansion of peak capacity to four 4-car trains/hr. At 144 passengers per LRV, this is a total of 2,300 riders, the equivalent of over 30 similarly loaded buses (at 70 passengers per bus) or nearly 2,000 automobiles (at 1.2 persons per automobile)—well over a lane of freeway traffic.

Given Sacramento's limited funds, the choices were no system, a weak double-track system in the Northeast only, or a single-track system in two corridors. Sacramento selected the last, matching the investment to short-term peak demand to get as much system as possible for the money available.

Few single-track sections will have to be permanent. Only the American River crossing and the Arden/Del Paso intersection were not designed for future double-tracking. If the remainder of the system eventually is doubled, these segments will limit minimum headways to 5 to 7.5 min, twice or three times the existing service, and as much capacity as is ever likely to be needed.

PROJECT COSTS: ESTIMATED AND ACTUAL

As noted earlier, a major focus during PE was fitting the project scope to the available funds. Unfortunately, this goal was not achieved. When finally completed, the project capital investment exceeded the PE estimate by 34 percent, as shown in Table 3.

Except for the LRV procurement, which benefited from sharp car builder competition and a favorable exchange rate, increases were experienced in every major cost category. Fully 86 percent of the extra costs ($38.74 million of $44.97 million) were in two areas: ROW construction and management and engineering.

In the systems area, the procurement and furnish/install contract bids came in at or below budget. Increases were due to (1) significantly underestimating the traction power system installation cost ($3.96 million versus $840,000) and (2) supplemental contracts added late in the project to purchase additional signal equipment ($1.62 million), ticket vendors ($260,000), and copper wire ($40,000).

PE-level ROW construction estimates were tight and excluded items not directly part of the LRT system, but that were added later at the behest of agency staffs and citizen groups as the project progressed through final design, e.g., street repavings around suburban stations, reconstruction of a sewer under Seventh Street that project senior staff expected designers to avoid, K and O Street mall amenity improvements, etc. Regarding the improvements to mall aesthetics, it should be noted that some of these extra costs were covered by additional funds provided by the agencies benefiting: the local redevelopment agency (K Street) and the State of California (O Street).

Similarly, the stations budget had elements added during final design to satisfy various agencies and community groups. About 5 percent of the difference is the added-on art program (including art works and artistic tree grates). Parking lot design issues discussed above also increased station costs.

Like the stations, the shop suffered from architect's hubris. Designers were instructed to develop a modular facility to or from which functional areas could be added or deleted consistent with system maintenance needs and the budget. This was done to some extent; but when it came time to "value engineer" the building to the available budget, design staff resisted. The only substantive cut made was deferral of the fourth track (body repair spot and paint booth). Fortunately, procurements of shop equipment and maintenance vehicles came in below estimates to partially offset the building overrun.

In the ROW acquisition category, PE estimates tended to be less than the ultimate purchase prices. In addition, several more small parcels not

TABLE 3 INITIAL ESTIMATED AND ACTUAL SYSTEM COSTS

Cost Category	PE Estimate ($ mil)	As Built ($ mil)	Difference ($ mil)	% Diff
Light Rail Vehicles (26)	26.37	24.57	- 1.80	-7%
Power, Signals, Communication, Fare Collection	17.19	21.32	+ 4.13	+24%
Subtotal - Systems	43.56	45.89	+ 2.33	+5%
R/W Construction	34.42	54.15	+19.73	+57%
Stations and Parking	10.70	17.65	+ 6.95	+65%
Maintenance Facility & Equip	4.79	5.36	+ 0.57	+12%
Subtotal - Facilities	49.91	77.16	27.25	+55%
Right-of-Way Acquisition	12.36	16.92	+ 4.56	+37%
Management & Engineering	14.95	33.96	+19.01	+127%
Contingencies & Financing	10.25	2.07	- 8.18	-80%
Subtotal - Other Costs	37.56	52.95	+15.39	+41%
Total Project	131.03	176.00	+44.97	+34%

Sources:

PE Estimate: ______. Project Report. Sacramento Transit Development Agency, 1983, Table 3.

As Built: ______. Light Rail Monthly Progress Report. Sacramento Regional Transit District, November 1987, p. 12.

identified during PE were purchased at locations such as substation sites and sharp corners downtown (notably at 12th and the UP ROW).

Almost as large as the increase in ROW construction was the growth of management and engineering expenses. The primary cause appears to have been lengthening of the project schedule. Based on the timing of the physically similar LRT project in San Diego, Sacramento expected to open its system in late 1985 but experienced a delay of 15 months for the Northeast Line and 21 months for the Folsom Line. Major reasons for this included (1) an 11-month design concept resolution phase added to answer UMTA questions about patronage, costs, and traffic impacts in more detail than provided in the alternatives analysis; (2) the Sacramento Transit Development Agency (STDA) board's allowance of a bid protest that led to a second round of technical proposals and bids for the LRV procurement; (3) designer delays in completing civil plans, specifications, and estimates for construction packages; (4) negotiations between UMTA and the car builder (with RT in the middle) to settle disagreements over "Buy American" compliance; and (5) slower than forecast availability of Interstate transfer funds. Numerous other incidents had minor impacts that were mostly masked by the overriding concern with the timing of car deliveries due to the "Buy American" issue (*4*).

In trying to emulate San Diego's fast-tracked pace, Sacramento did not build into its schedule the time allowances required to appropriate and draw down federal funds, to confirm compliance with federal planning requirements and procurement regulations, or to accommodate the design of civil elements by a public agency with very limited prior LRT engineering experience. The failure of the political leadership drafting the original joint powers agreement to provide a strong local staff structure exacerbated the problem by severely limiting the STDA executive director's authority to run the project.

CONCLUDING REMARKS

Like any project, the Sacramento LRT system represents a mix of opportunities grasped and problems overcome with varying degrees of success.

Most notably, the LRT's construction was a victory for local citizen advocates determined to change the course of transportation system development in their community. Further, Sacramento achieved the lowest initial cost per mile of line of any federally funded rail system, yet has built a project adequate for present needs and capable of incremental expansion as demand requires and funds allow. Finding the funds for expansion, however, will be difficult under present federal, state, and local conditions.

It will be interesting to watch how local public agencies and developers react to the system—whether they take advantage of it or ignore it. On the positive side, for example, the California Franchise Tax Board (over 3,500 employees at a new location chosen because it is adjacent to the Butterfield Way transit center) encourages staff to commute by LRT or bus, and requires them to use LRT for business trips during the day to and from the State Capitol and other downtown destinations.

On the negative side, RT continues to limp along with a woefully tight operating budget: \$36.9 million in fiscal 1987–1988 for a service area of 929,000, compared with \$80.7 million for 1.1 million people in Portland, Oregon, another new LRT city. Sacramento's transit expenditures of \$39.72 per capita were little more than half Portland's rate of \$73.36. LRT is helping. Thanks to RT Metro's high ratio of passengers to operators, it is already RT's most productive service: 117 LRT rides per service hour compared with 60 for the best bus route and 27 for the overall bus system as of April 1988, according to SRTD. Further, the simple LRT hardware selected should help keep maintenance costs in check.

It can only be hoped that as Sacramento grows—and it is growing, rapidly—the electorate will see fit to provide the source of local operating and capital funds that RT desperately needs.

This background must be considered when evaluating the development of LRT and its initial performance in Sacramento.

Single Track—An Appropriate Solution

The system works as built, with 40 percent of the line double-tracked. Thanks to the diligence of the operating staff, 15-min headway service is being maintained reliably. It has developed that had some short additional lengths of double track on 12th Street and at Arden/Del Paso been built as noted above, a virtually trouble-free system could be running in Sacramento today. Instead, RT must wait to add these additional short lengths of second track until some future time when traffic authorities will agree and funding becomes available.

Sacramento's experience should encourage others to consider single-track operation where relatively long LRT headways will suffice to accommodate initial forecast demand, and where cost savings will help build political support to move ahead. However, adequate lengths of double track must be provided at all locations indicated by the system operating plan, and this must not be an area of compromise. As has been done in Sacramento, single-track section designs should enable eventual addition of the second track.

Ridership: Forecast and Actual

The FEIS was published in 1983, and included forecasts of demand made with the Urban Transportation Planning System (UTPS) battery of models, validated for metropolitan Sacramento. Initial LRT ridership was forecast at 20,500 per weekday. Actual patronage as of April 1988 is averaging 13,200, well below the FEIS estimate. Nonetheless, RT Metro carried 24 percent of all RT boardings on only 7 percent of the service hours.

Table 4, which makes several comparisons of the FEIS forecast versus actual ridership as of April 1988, may be summarized as follows (figures in Actual column obtained from SRTD, January 13 and April 29, 1988):

- Total weekday LRT boardings: actual is 64 percent of forecast, but
- Total RT system use is only 73 percent of forecast.

TABLE 4 FORECAST AND ACTUAL RT METRO RIDERSHIP

Item	FEIS	Actual	% FEIS
Total Weekday RT Unlinked Boardings (Bus & LRT)(a)	76,400	55,700	73%
Total Weekday LRT (Two-Way):			
Northeast	13,200	6,700	51%
Folsom	7,300	6,500	89
Total Weekday	20,500	13,200	64
% Northeast/Folsom	64/36	51/49	
Peak Hour/Direction (PHPD):			
Northeast	1,715	1,220	71%
Folsom	1,140	1,040	91
Combined	2,855	2,260	79
PHPD as % of Weekday:			
Northeast	13%	18%	
Folsom	16%	16%	
Both Lines	14%	17%	

(a) Forecast: FEIS, Ex. 2-20 fol p. 2-29, and p. 2-32.

The shortfall results from several differences between model input assumptions and present real-world conditions:

- Shorter hours of LRT operation due to RT budget constraints;
- Less feeder bus service, 29 percent fewer routes feeding the Northeast LRT, and 14 percent fewer feeding Folsom trains (*3, 5*), due to RT budget constraints;
- Cheaper downtown parking due to apparent city reluctance to raise rates as rapidly as anticipated and state construction of more new downtown parking spaces even as LRT was under construction; and
- Lower gasoline prices due to international market factors.

The split between lines is close to even (Northeast—51 percent:Folsom—49 percent), compared with the demand model's projection (64 percent:36 percent). On an all-day basis, Folsom line use is much closer to forecast (89 percent) than with the Northeast (51 percent). Finally, actual ridership to date is more skewed toward the peak hour and direction (18 percent) compared to the projection (13 percent).

LRT ridership seems likely to remain below FEIS estimates until local officials address the issues of improving LRT and feeder bus service and adjusting downtown parking rates and availability. Sacramento is one of the fastest growing areas in the United States, and no more freeways or other major road improvements to downtown are planned. LRT patronage may be expected to grow as ever-increasing traffic congestion on the area's existing freeways and streets makes LRT more and more attractive.

Summary: Sacramento Demonstrates LRT's Flexibility

Sacramento built for the future by taking advantage of one-time opportunities available in the early 1980s:

- Deletion of an unwanted freeway to create an Interstate transfer funding entitlement,
- State and local administrations sufficiently interested in rail transit to provide matching funds, and
- A variety of existing ROWs and structures that LRT could use, not all of which would have remained available had construction been delayed.

These opportunities, coupled with design criteria stressing proven technology, allowed Sacramento to build a system that works, at a price the community was willing to pay. On balance, Sacramento is pleased with the system. In fact, studies of extensions to the initial lines and new lines in other corridors were begun even before the first trains started running.

The principal lesson from the Sacramento system and other similar projects is that rail transit need not be limited only to the largest U.S. metropolitan areas. By using modern, yet technically simple and proven LRT, and by avoiding gold-plating, systems can be built to serve the arterial express routes in medium-to-large cities where the capacity of full rapid transit is not needed, but where LRT investment and operating costs will be affordable, and where LRT will increase transit productivity.

Short of massive, long-term oil shortages, North America's reluctance to fund opulent rapid transit systems is likely to continue. Only the largest metropolitan areas have any hope of finding the capital for these massive projects costing \$30 million to \$60 million/km (\$50 million to \$100 million/mi) or more. Local leaders seeking the benefits of guideway transit will best serve their constituents by emulating the practical and affordable solutions embodied in the new surface LRT systems in Calgary, Portland, San Diego, and, now, Sacramento.

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