Light Rail—A Mile High: The Denver Experience

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Denver, Colorado, one of the fastest growing metropolitan regions in the United States, recognizes the significance of light rail transit (LRT) in addressing the ever-present problems of pollution and automobile congestion. In October 1994, Denver's dream of once again operating electric rail vehicles became a reality. The simple system was 100 percent locally funded from a use tax established in 1989 and was designed from lessons learned from other North American systems. The central corridor, as it is called, provides the spine of the proposed rapid transit system in the Denver metropolitan region. The total budget for the 5.3-mi alignment was $113.7 million. Off-the-shelf technology was implemented whenever possible as the central corridor project was the starter line for the region and it was important for providing the citizens of the region an opportunity to become familiar with the efficiencies inherent in LRT operations. A small design and construction staff team was organized to manage consultants in the design and construction of the project. In this process, the Regional Transportation District (RTD) evaluated every element of the light rail system to ensure that future construction would benefit by the project. In general, RTD attempted to balance the existing project demands with future expansion. Less than 3 years following preliminary engineering, Denver once again is operating electric railway revenue service within its city limits. Metropolitan Denver officials continue to support this mode of transportation and anticipate that future funding will be made available to enhance and complete the proposed regional rapid transit plan, which will include at least four more corridors. The planning has taken decades to accomplish, but light rail in Denver is healthy and rolling along.

Denver's dream of once again operating electric rail vehicles, after their 40-year absence, became a reality on October 7, 1994. Following nearly 20 years of planning, a 5.3-mi light rail starter line was inaugurated with a free fare weekend, carrying more than 150,000 citizens and officials of the metropolitan area. The system was locally funded with simplicity in mind and the idea of designing expansion around lessons learned from other North American systems.

After its first year of operation, the system's peak-hour ridership is at capacity, and six additional vehicles are to be delivered in January 1996. In addition, preliminary engineering for an 8.7-mi extension is complete, and three new corridors are in the major investment study (MIS) phase.

Denver, one of the fastest growing metropolitan regions in the United States, has recognized the significance of light rail transit (LRT) in providing an alternative to the automobile and in addressing the need for minimizing pollution and congestion in its burgeoning downtown area. Metropolitan Denver officials continue to support this mode of transportation and anticipate

that future funding will be made available to enhance and complete the proposed regional rapid transit plan.

Project History

The central corridor provides the spine or center segment of the proposed rapid transit system in the Denver metropolitan region (Figure 1). With the construction and implementation of the first-phase central corridor, the Regional Transportation District (RTD) will be able to lower the costs of building the remaining corridors substantially, since the downtown segment, as with many other systems, is the most expensive and restrictive to construct. This corridor provides a collection and distribution alignment for connecting all proposed rapid transit system extensions.

Although planning for the metropolitan region's rapid transit system began in the early 1970s, it was not until 1987 that RTD was directed under Colorado Legislature House Bill 1249 to develop a plan for financing and implementing rapid transit within the seven proposed corridors and to submit that plan to the Colorado General Assembly. As a direct result of House Bill 1249, in 1987 the RTD Board of Directors also adopted the "Fastrack Program" and identified the preferred alignment, technology, and financing on each of seven corridors.

In 1989 a Colorado state use tax ruling on appeal allowed RTD to collect a use tax on goods and services

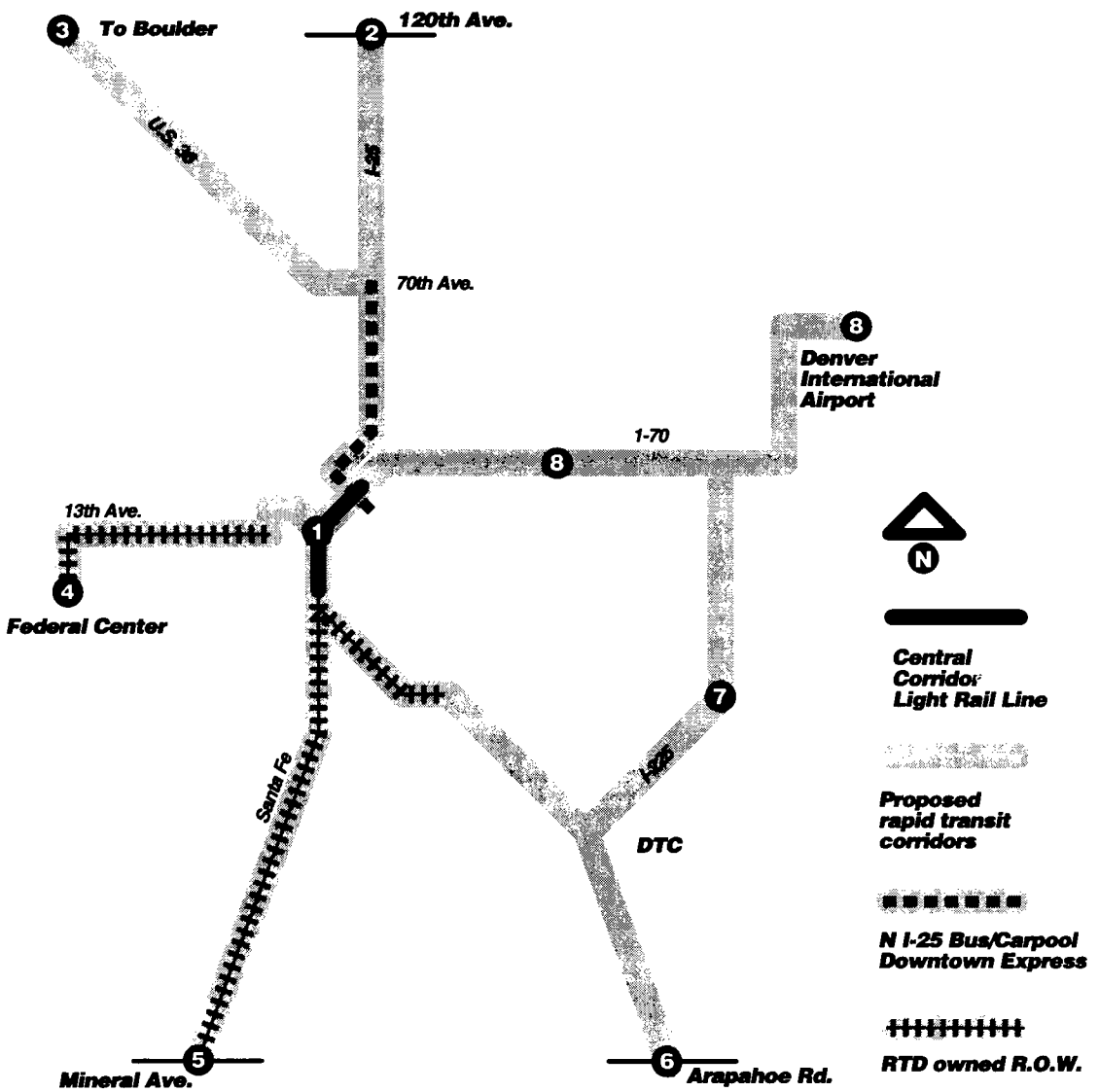

FIGURE 1 Proposed rapid transit corridors.

purchased outside the district for use within, thus providing the 100 percent local funding source for the central corridor. The corridor was selected by the RTD Board of Directors for a rapid transit demonstration line that would connect the Auraria Higher Education Center (a three-college campus with approximately 32,000 commuting students), the central business district (CBD), and Stapleton International Airport and would be funded entirely with local funds or the income generated from the use tax, which was a tax of 0.6 percent on metropolitan region retail sales.

In 1990 light rail technology was selected by a community advisory committee and adopted by the RTD Board of Directors to be used in the Northeast Corridor. Originally, the alignment was to run from Auraria to the old Stapleton Airport. However, because of outcry from residents along Martin Luther King Boulevard near the airport who associated LRT with mile-long freight trains, the line was shortened from Auraria to Downing Street.

In 1991 the conceptual engineering was completed and the starter line designated as the central corridor. Studies began to produce a detailed operating scenario, ridership forecasts and costs, as well as other technical memoranda in order to document the feasibility of the project. Late in 1991, preliminary engineering was initiated and 11 light rail vehicles (LRVs) were ordered.

In 1992 preliminary engineering was completed and approved by the RTD Board of Directors and the Denver Regional Council of Governments (DRCOG). Construction of the LRV maintenance facility and storage yard was started, and vehicle manufacturing began. Later that year, the RTD Board of Directors voted to approve an extension to the project, doubling the original revenue alignment from 2.7 to 5.3 mi along a previously purchased railroad right of way where speeds of 55 mph could be reached and demonstrate more efficiencies of the light rail technology. Since more than 530 bus trips into the CBD would be discontinued and their passengers transferred to light rail, the extension was funded by bonds and financed as a direct result of operational savings. The total budget for the 5.3-mi alignment in the central corridor between Broadway and I-25 on the south and 30th and Downing streets in northeast Denver was $113.7 million, which again was all locally funded.

In late summer 1993 the operations facility was completed, including a 1-mi stretch of double track with catenary for testing of the vehicles. The first LRV arrived in November 1993, and the training of personnel along with the LRV acceptance testing and commissioning process began. RTD also purchased a 9-mi unused rail corridor to the southwest, bringing the total rail corridor right of way owned by RTD to approximately 24 mi within six of the seven proposed rapid transit corridors.

In June 1994 civil construction as well as system elements were completed and integration testing was started. (Integration testing is the process of ensuring compatibility between the operating vehicle and system elements such as track, catenary, signals, and facilities.) Testing was completed approximately 2 months later and prerevenue operation began. On October 7, 1994, free service was initiated for citizens of the metropolitan region for 3 days; estimated ridership was between 150,000 and 200,000. On October 10, 1994, less than 3 years after preliminary engineering, Denver once again was operating electric railway revenue service within its city limits.

Physical Description and Operating Challenges

RTD's light rail starter line is a conventional system running from a southern Denver terminus through the heart of the city and north to another terminus. The line is 5.3 mi long and consists primarily of double track. The southern half of the alignment is located in a former Denver and Rio Grande Railroad corridor with open ballast track, where the LRVs reach speeds of 55 mph. The remaining track alignment is in Denver city streets with maximum operating speed of 30 mph.

Within the heart of the city, the alignment completes a loop that connects major east-west streets and Denver's famous 16th Street Mall for transit and pedestrians as well as the Civic Center and Market Street bus transfer stations. The downtown LRV operation is within a curb-separated, restricted lane in a contraflow direction to automobile traffic.

Traction power at a nominal 750 V direct current (DC) is transmitted to vehicles through simple trolley wire in the downtown section, and compound catenary is used in the high-speed sections of the alignment. Power is supplied by six mainline 1-MW substations and one 1-MW substation dedicated to the operations facility for shop and storage track power. These unmanned substations use state-of-the-art PLC transformer/rectifier units to convert 13,200 V alternating current (AC) power (supplied to RTD by the Public Service Company of Colorado) to the 750 V DC required for operation.

Most of the 5.3-mi alignment is double-tracked, providing for one-way travel on each track under normal operating conditions (Figure 2). The two major exceptions are as follows:

1. In order to provide on-street parking for the Five Points business district, six blocks of single track were constructed along Welton Street in that area.
2. The circulator loop in the downtown area consists of single track along California Street northbound and Stout Street southbound between 14th and 19th streets.

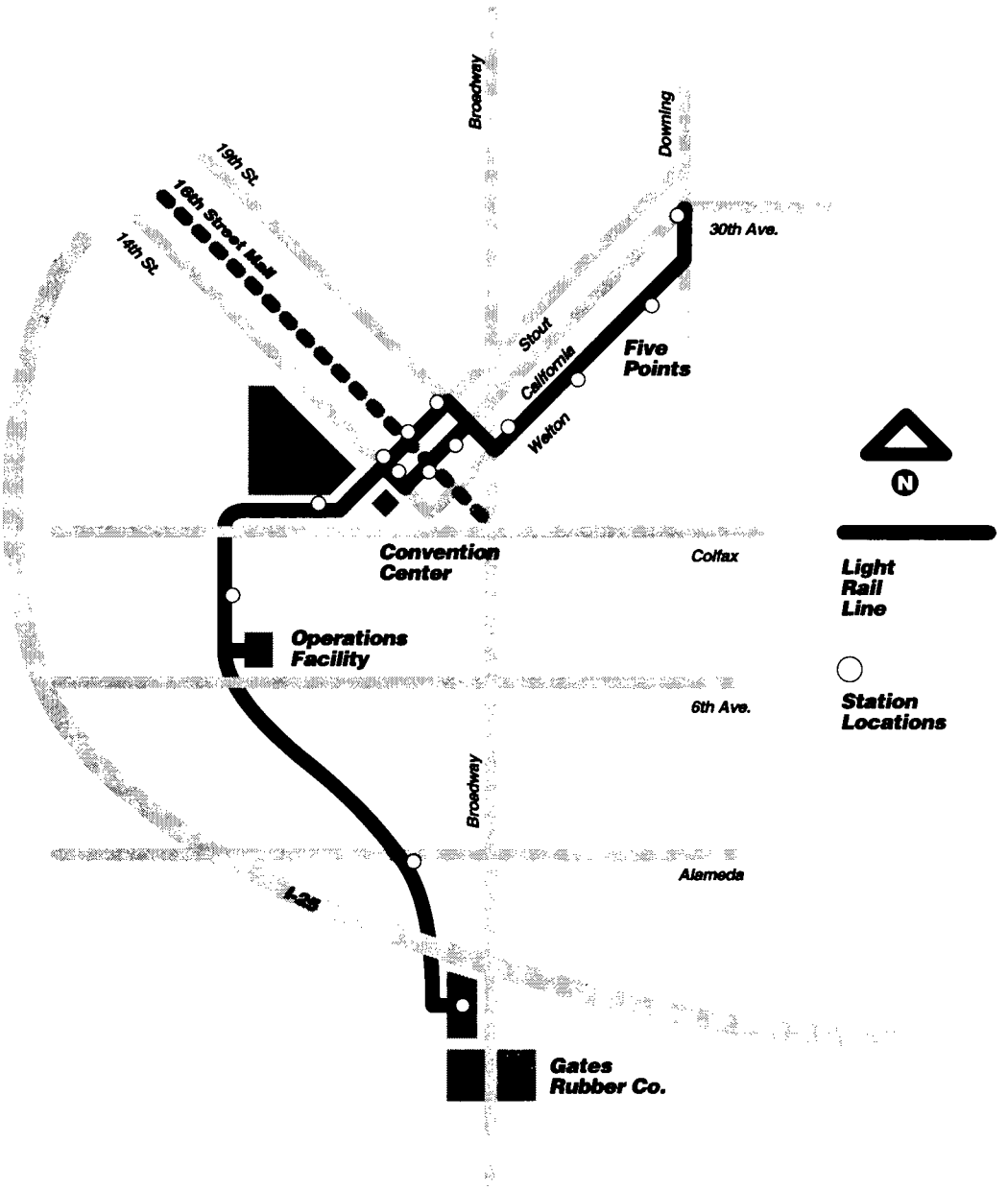

FIGURE 2 Central corridor light rail line.

Track gauge is standard railroad of 4 ft 8½ in. All rail is continuous welded 115 lb and heat-treated in curves. All rails, with the exception of yard storage tracks and switches, are secured on concrete ties with rail clips.

Crossovers between north- and southbound tracks are provided at intervals to permit operation in both directions on a single track during maintenance repairs or service disruptions. Most mainline switches are powered and controlled by the operator via a train to wayside communication system on board the vehicle. All switches are also heated electrically because of Denver's winter climatic conditions.

Rail operation is controlled by automatic block signals in the high-speed sections from Colfax Avenue to the southern terminus. In these areas, trains are protected by the operator's visual observation of wayside signals. Trains are also governed by traffic-type signals in the single-track section through the Five Points business district. All downtown streets are controlled by

special transit signals that permit the LRV to proceed when automobile traffic is stopped.

Grade crossing protection in high-speed areas is controlled by typical railroad grade crossings consisting of gates, bells, and flashing lights. In addition, distinct trolley crossing (international trolley symbol) signs with flashing yellow caution beacons are located across from each railroad flasher to supplement the warning (Figure 3).

There are 14 passenger station areas with 24 platforms: 17 single-side platforms and 7 center-island platforms. All platforms are accessible to persons with disabilities via a ramp and minihigh block loading area. With the exception of the center-island type, all stations are initially constructed for two-car trains. The center-island platforms, however, are constructed to the maximum train consist length of three vehicles. The three-vehicle platform length is the result of the length of the shortest city block along the alignment within Denver.

All passenger stations are of similar design, generally consisting of concrete pads or pavers, a vaulted arch-shaped canopy, ticket machines and validators, information displays and signage, benches, and trash receptacles. Three of the station sites have bus transfer facilities, kiss-and-ride areas, bicycle lockers, and parking spaces for nearly 1,000 automobiles. Platform security is provided by a combination of RTD supervisory personnel, Denver police, and contracted security services.

An initial fleet of 11 LRVs (Siemens Duewag Corporation Model SD 100) has been in operation since the October 19, 1994, revenue start date. However, because of extremely heavy peak passenger loads, six more vehicles have been ordered; expected delivery dates are January to March 1996. These vehicles are six-axle, single-articulated, double-ended, and bidirectional. They are approximately 80 ft long, 8 ft 9 in. wide, and 13 ft high and operate on a standard railroad gauge of 4 ft 8½ in. They are powered from an overhead wire by 750 V DC and capable of speeds up to 55 mph. Each vehicle will seat 64 passengers and will accommodate up to an additional 61 standing passengers by the RTD's passenger loading standards. Additional standing passengers may be accommodated at a crush load capacity. All vehicles are accessible to persons with disabilities via an on-board ramp located at

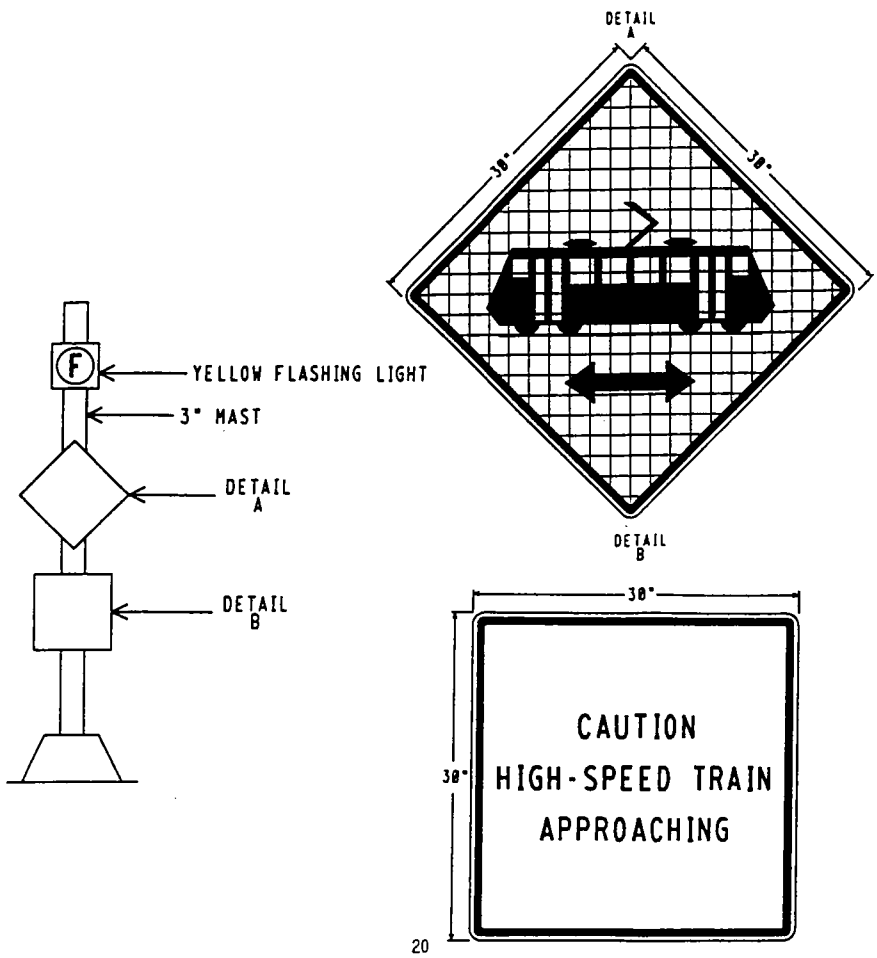

FIGURE 3 International trolley symbol and flashing caution beacon.

the front doors. The vehicles are well lit and equipped with surveillance cameras, passenger emergency intercoms, and adequate heating and air conditioning requirements to meet the demands of the Denver environment.

The light rail operations facility is approximately 45,000 ft^2 and is located on a 5-acre site. The site includes a storage yard for approximately 19 vehicles, maintenance of way (MOW) storage, a vehicle maintenance area of 10 bays that includes exterior wash, body repair, paint room, blow down, inspection pits, mezzanine level rooftop inspection areas, wheel truing machine pit, in-floor jacking system, and a flat truck. In addition, some unit repair and nonrevenue vehicle maintenance as well as inventory storage will be accomplished at RTD's bus facilities. Central control is located on an upper floor of the facility along with all light rail administrative and training offices. The central control is the operational authority for all yard and mainline LRV movements, including the coordination of MOW or contractor activities. Central control personnel (controllers) direct, control, and monitor revenue service operations using radio, a global positioning satellite automatic vehicle location system, telephones, and public address communications systems.

The original fleet of 11 vehicles was designed to accommodate a peak schedule requirement of 10 cars, with 10-min headways throughout the entire alignment, overlaid with short-turn trips between the southern terminus and 19th Street in the CBD in order to create a 5-min peak headway on the south segment (Table 1). However, during integrated testing in August 1994, operating tests indicated that the planned headways were not realistic because many factors had changed during the final design and construction:

- Traffic signal timing was not as efficient as anticipated.
- Trains moved more slowly in the CBD and along Welton Street than planned because of real as well as perceived safety precautions.
- Two additional stations had been introduced along Welton Street.

Ridership forecasts were also increasing. The original forecast was 13,000 weekday riders by 1994; however, by opening day the forecast had changed to 14,000. The transferring passengers from buses would eliminate nearly 530 bus trips from the downtown areas, a commitment given to the city of Denver and its residents as part of the advantages of light rail. The LRV order was already in the delivery stage by that time, and little could be done to alleviate the expected overcrowding immediately after the revenue start date.

As a way to accommodate the greatest numbers of riders and to alleviate the areas where anticipated slower travel times would occur, the line opened with a 5-min peak headway on the south segment from 19th Street to I-25 and Broadway and a 15-min peak headway on the north segment from 19th to 30th and Downing streets. LRVs were deployed in the cycles given in Table 2.

Actual ridership immediately after the start of revenue service was nearly 16,000 each weekday. This increase was generated by transfers to and from buses by customers who had been projected to prefer local bus routes into the CBD and a larger-than-anticipated number of automobile drivers parking near and around the terminus stations. The latter group was particularly significant because it was not predictable by specific train times as were the bus transfers. This unpredictability created overloading of many of the peak trains and, combined with the factors previously cited, created additional schedule problems and resulted in public criticism. Most of the criticism came from long-time suburban express and regional bus riders, who had been accustomed to traveling into the city with no transfer penalty and very comfortable seating arrangements. Other complaints came from local bus riders on the north segment who had experienced 15-min peak service and who saw the difference between the two peaks as unfair and in direct opposition to RTD's "promised"

TABLE 1 Original Vehicle Deployment Plan, Peak Periods

Cycle	Minutes	Trains	Cars/Train	Total LRVs	Hourly Capacity at Peak Load Point		
					Seated	Standee	Total
Whole line	40	4	1	4	384	366	750
19th St.–I-25 & Broadway	30	3	2	6	768	732	1,500
Spares	—	—	—	1	—	—	—
Total		7		11	1,152	1,098	2,250

SOURCE: R. W. Rynerson, Regional Transportation District.

TABLE 2 Opening Vehicle Deployment Plan, Peak Periods

Cycle	Minutes	Trains	Cars/Train	Total LRVs	Hourly Capacity at Peak Load Point		
					Seated	Standee	Total
Whole line	60	4	1	4	256	244	500
19th St.–I-25 & Broadway	30	2	2	4	512	488	1,000
19th St.–I-25 & Broadway	30	2	1	2	256	244	500
Spares	—	—	—	1	—	—	—
Total		8		11	1,024	976	2,000

SOURCE: R. W. Rynerson, Regional Transportation District.

10-min planned headway. The process that led to this situation could be explained to the individual, but technical details were not so easy to communicate to the community.

To alleviate some of the complaints and overcrowded conditions on the trains, less than 2 weeks after revenue operations started, three heavily traveled suburban bus routes were extended to the Civic Center Station in downtown Denver. This was expected to satisfy most complaints and relieve the overcrowding. However, after this rerouting, approximately 30 percent of the riders continued to rely on the trains, decreasing the effectiveness of the rerouting plan.

The combination of bus rerouting and the decreasing numbers of curiosity riders resulted in some ridership drop in late October and early November. After Thanksgiving week, however, ridership again increased with shoppers and participants in holiday events. Again, public criticism increased and RTD responded by rerouting another significant number of bus trips into the downtown Civic Center Station.

After the first few months of operation and the changes in bus transfers at the terminus facilities were reviewed, in January 1995 the peak headways were modified to make additional improvements. Trains on the south segment from 19th Street to I-25 and Broadway now operate every 6 min, and trains through the north segment from 19th to 30th and Downing streets operate every 12 min. With these changes, service reliability and customer satisfaction improved dramatically (Table 3).

Once the six new LRVs are introduced in early 1996, bus routes will be removed from downtown Denver once again. The proposed schedule assigns two-car trains to all trips turning at 19th Street, where loads are greatest and—more important from the customers' perspective—the following advantages will be recognized:

1. Capacity in the peak of the peak period will exceed all observed situations other than those created by special events so that passengers will not be left on the platform.
2. Capacity in the fringe of the peak period will allow for the majority of passengers to be seated.
3. Service will be more reliable, even when buses are delayed and connections made at times when double-car trains are not scheduled.

TABLE 3 January 1995 Vehicle Deployment Plan, Peak Periods

Cycle	Minutes	Trains	Cars/Train	Total LRVs	Hourly Capacity at Peak Load Point		
					Seated	Standee	Total
Whole line	60	5	1	5	320	305	625
19th St.–I-25 & Broadway	36	2	2	4	428	412	840
19th St.–I-25 & Broadway	36	1	1	1	107	103	210
Spares	—	—	—	1	—	—	—
Total		8		11	855	820	1,675

4. The spare ratio will be improved: two vehicles will be available for emergency situations when vehicles must be taken out of service.

Lessons Learned

During the 1980s light rail projects were at a distinct disadvantage since most surface trolley systems were discontinued in the 1950s. The technology had changed, and experienced rail transit personnel were retired and lost to the industry, so a new generation of transit professionals had to be developed in order to accommodate the resurgence of rail projects. After nearly two decades of development, Denver was able to take advantage of new technology and these new-generation transit professionals.

As part of the planning phase, it was decided that off-the-shelf technology would be implemented whenever possible. Furthermore, the design criteria would require the system to be simple and yet expandable. The central corridor project was the starter line for the region, and it was important for providing citizens an opportunity to become familiar with the efficiencies inherent in LRT operations.

A relatively small design and construction staff team was organized to manage consultants in the design and construction of the project. The team was composed of transportation planners, engineers, and project managers with previous experience in light rail design, civil construction, community relations, and light rail operations personnel. In the design and construction process, RTD evaluated every element of the light rail system to ensure that future construction would benefit by the project. The elements specifically addressed were the installation and maintenance for drainage, duct banks, utilities, street pavement treatments, station design and consistency, adjacent facilities, electrification, signalization, and track appurtenances.

Duct banks were designed and built with capacity for a future supervisory communication and data acquisition (SCADA) system to ensure improvements in systems operation, communications, and security as the transit corridors developed. As a means of alleviating additional disruption, adjacent streets in the CBD were paved with concrete so that future paving construction and modifications would be limited. A removable flangeway boot was used instead of flangeway filler to ensure ease of maintenance as well as electrical isolation and possible stray current mitigation. The expansibility of each station was accomplished by making sure that future electrical pull boxes and ticket vending machine locations were constructed so station modifications could be simplified at a later date. All center-island platforms were constructed at minimal costs to meet the future three-car consist so as not to seriously affect operations when platform modifications were eventually required. Substations were designed to allow an easy upgrade from the initial 1-MW output to 1.5-MW as the system expands. All substations and signal relay cases were designed with the ability to be upgraded for SCADA controls. All special track work was of typical American Railway Engineering Association design and standards to allow for efficient modifications and repairs. Concrete ties were used throughout the alignment, except for switches and yard tracks, as a way to reduce maintenance costs. The operations facility was designed and constructed to allow expansion to larger vehicle fleets in the future. The facility was to be utilized as both a running repair and heavy maintenance facility until the fleet size required additional storage spaces, and then it would be a heavy maintenance facility. Additional expansion would require a future running repair facility.

In general, RTD attempted to balance the existing project demands with future expansion and do so within a budget supported entirely by local funds. Lessons learned from other projects prompted many of these considerations. It is the charge of public officials to continue to seek ways to ensure efficiency as well as effectiveness.

Corridor Expansion Since Light Rail Implementation

The southwest corridor (Figure 1), Denver's next transit priority, was selected through the alternative analysis process to be a new light rail corridor and was approved by both the RTD Board of Directors and the DRCOG as the highest-priority transportation project for the region. In the southwest corridor, preliminary engineering and the environmental impact statement process have been completed and the final design is ready to begin. This grade-separated and double-tracked 8.7-mi extension that parallels Santa Fe Drive, a major arterial in the southwest metropolitan area, will have five additional stations. Three of the stations will have large park-and-ride facilities, adding an additional 2,000 spaces, and all five will serve as bus transfer facilities. The estimated ridership in addition to the existing central corridor will be approximately 10,000 passengers per weekday, making the total weekday passenger ridership along the combined 14-mi alignment approximately 25,000 riders a day. The 10-min peak and 15-min base headway in the new extension will require an additional 14 vehicles, increasing the fleet size to 31 vehicles.

Also beginning in the early part of this year, RTD, in conjunction with the Colorado Department of Transportation (CDOT) and DRCOG, initiated three MISs.

The three corridors to be studied include the southeast Corridor (I-25 south to the Denver Tech Center), the west corridor (downtown Denver to Golden), and the east corridor (downtown Denver to the new Denver International Airport).

The primary purpose of an MIS is to provide a decision-making process determining future transit corridor priorities for the metropolitan region. The MIS must contain enough information to measure and evaluate a range of corridor alternatives. Included within the MIS process is a careful and thorough evaluation of a full range of alternatives and an open public process that includes community input for determining the preferred alternative.

The three agencies involved in the studies (RTD, CDOT, and DRCOG) have established a cooperative and collaborative process. Each agency will be responsible for directing the analysis efforts in one of the corridors. RTD will manage the work efforts in the west corridor, CDOT will be responsible for the southeast corridor, and DRCOG will oversee the east corridor. It is the intent of the three agencies to bring each corridor forward in the MIS process to an equivalent point—that being the definition of a preferred alternative that then can be advanced to preliminary design and the preparation of an environmental impact statement. Policy and decision makers at each of the three agencies then will be able to evaluate the technical merits of each corridor and decide which of the three should be advanced to the next stage of development. It is also anticipated that the process will identify which investment may be eligible and thus supported for federal funding in the future. It is expected that the process will be completed for all three corridors about the middle of 1996.

Although the planning has taken decades to accomplish, this brief description of the recent results shows that because of a mile-high attitude, LRT in Denver, Colorado, is healthy and rolling along.